INTERNATIONAL SURVEY OF BEST PRACTICES IN CONNECTED AND AUTOMATED VEHICLE TECHNOLOGIES

2014 UPDATE

September 26, 2014

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International Survey of Best Practices in Connected and Automated Vehicle Technology: 2014 Update
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Abstract:
Early research and deployment in connected and automated vehicle (CAV) systems can provide a variety of benefits. Such efforts are taking place throughout the world (especially in the United States, Europe, and Asia). This study highlights major CAV deployment efforts throughout the world and evaluates important factors for successful deployment. Using information gathered from interviews and electronic searches, 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 how CAV technology is being developed, tested, and deployed around the world, the authors identify best practices that will allow transportation agencies to strengthen their own CAV programs.

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EXECUTIVE SUMMARY

The Michigan Department of Transportation (MDOT) is a national 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 examining how CAV technology is 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 requested that the Center for Automotive Research (CAR) 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 originally compiled in 2010 and has been updated 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, update of the database continues. At the time of preparation of this report (September 2014), the database contained 90 entries for Asia, 172 for Europe, 176 for North America, and 10 for Oceania.

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 projects and other efforts that were already underway in earlier versions of the report, as well as 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.

CONCLUSIONS AND RECOMMENDATIONS

Despite the regional differences in CAV programs, many overarching themes have emerged that are useful to consider with respect to technology deployment. CAR research and analysis has identified funding strategies that have been used to support CAV programs, important factors that can affect the success of deployment, and an overall trend in convergence of connected and automated vehicle technologies. These points are summarized below. A full description of each point can be found in the Conclusions and Recommendations section of this report.

COMMON 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 FOR SUCCESSFUL PROGRAMS

- Forming coalitions
- Creating industry competition
- Developing programmatic themes and bold goals
- Generating expertise
- Regulating technology to make a strong business case
- Standardizing global/regional architectures

CONSIDERATIONS FOR CAV RESEARCH, DEVELOPMENT, AND DEPLOYMENT

- Increasing convergence of connected and automated vehicles
- Decreasing dependence on public infrastructure
- Emerging regional competition for automated vehicle technology supremacy

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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, however, 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 PREVIOUS 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 U.S. activity outside Michigan is concentrated. These efforts resulted in contacts with numerous organizations.[1] In 2011, 2012, and 2013, CAR conducted updates to the previous study.[2] In these updates, CAR researchers documented additional programs in the United States and developed broader documentation of international best practices.

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(s) of technology used, nature of the work, applications, and descriptions of work.

[1] Wallace and Sathe Brugeman 2008.
[2] Wallace et al. 2011; Wallace et al. 2012; Wallace et al. 2013.

1.2 2014 UPDATE

This report is an update and expansion of all 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 the inclusion of information on projects conducted in the state of Michigan. Previous versions of this report did not discuss Michigan-based CAV activities. This may have given readers the mistaken impression that Michigan is not doing much work in the realm of CAVs.

The accompanying database has been updated since it was originally created, both to account for its expanded scope and to ensure it remains current. Over the past year, some previously covered projects have been completed, put on hold, or discontinued while new ones have been created or expanded.

At the time of this report's publication, the database has 448 entries. Of these, there were 90 for Asia, 172 for Europe, 176 for North America, and 10 for Oceania. 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.

WHAT'S NEW?

This study includes all of the coverage provided by the previous report. It also contains several new projects not covered in the previous version as well as updates to several projects covered previously.

1.3 NEW PROJECTS

In North America, there are several major new projects. Michigan-based organizations are investing in testing centers. University of Michigan began construction on its Mobility Transformation Facility and Walbridge may soon begin constructing its own connected vehicle research center, which will be open to private companies and other interested stakeholders. Google has entered the second phase of its own automated vehicle project and will soon begin testing a fleet of 100 vehicles designed and manufactured with automation in mind. At the national level, the U.S. Department of

Transportation (USDOT) has decided to move forward with connected vehicle regulations and will be expanding its *Safety Pilot* to include additional sites across the country. In Michigan, MDOT began offering *Truck Parking Information and Management System* (TPIMS) services to commercial drivers along I-94. Other newly added North American projects include Selmon Expressway Automated Vehicle Testing in Florida, Accelerate Texas Center in Texas, and the Ontario Automated Driving Pilot in Canada.

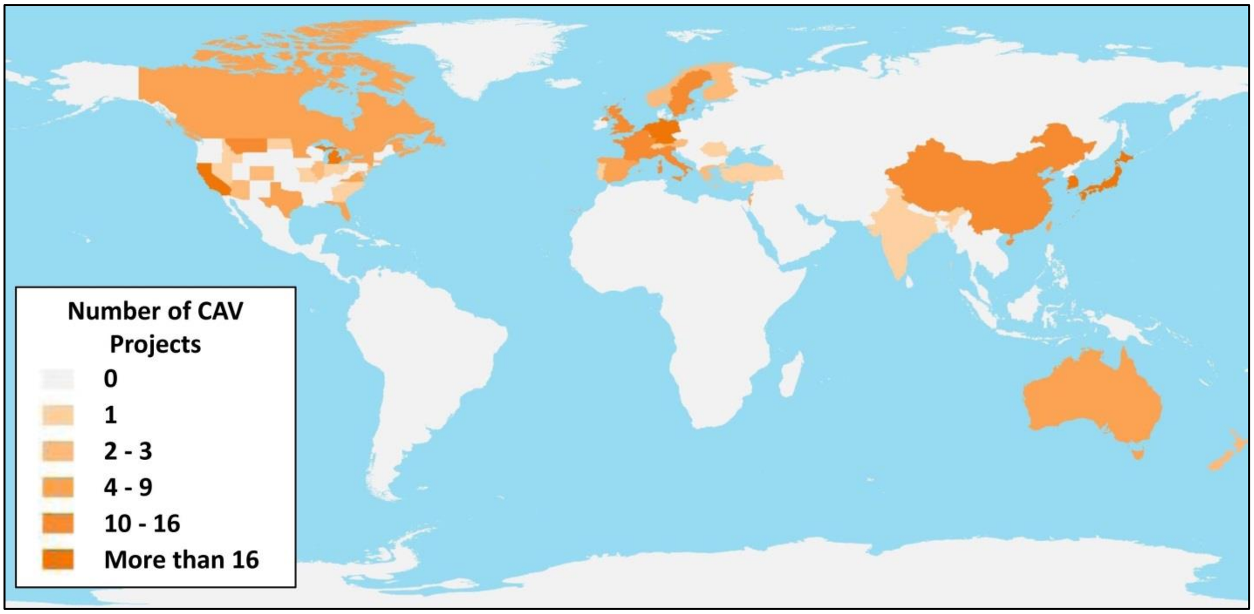

FIGURE 1: WORLD MAP SHOWING PROJECTS BY COUNTRY (STATE FOR U.S.-BASED PROJECTS)[3]

In Asia and Oceania, new CAV projects were added related to Nissan's testing of automated vehicles on public roads in Japan. The Singapore-MIT Alliance for Research and Technology (SMART) is creating and testing an automated vehicle in Singapore. An automated "new energy" vehicles partnership between the Hefei Institute and the Guangzhou Automobile Group was formed, and a similar automated electric vehicle partnership between BYD and a top technology institute in Singapore. In Singapore there are plans to deploy a fleet of automated vehicles in the One-North area beginning in January 2015. In 2014 Australia began its five-year Cooperative Intelligent Transport Initiative (CITI). The University of New South Wales and GoGet, an Australian car sharing service announced an automated vehicle testing

[3] CAR 2014.

partnership. New Zealand has released its Intelligent Transport System Technology Action Plan.

In Europe, several new projects have launched. These include: the creation of the Cooperative ITS Corridor test bed between Netherlands, Germany, and Austria; the *Drive Me* project in Sweden, focused on testing a fleet of 100 automated vehicles; and *Co-Gistics*, a pilot program to explore cooperative logistics services in seven European cities. Other newly added European projects include the *City Alternative Transportation System* (CATS), *Plateforme Avancée de Mobilité Urbaine* (PAMU), *Automated Driving Applications & Technologies for Intelligent Vehicles* (AdaptIVe), Milton Keynes area automated vehicle deployment testing, and *Future Truck 2025* projects.

1.4 UPDATED PROJECTS

Several projects have been updated for this version. The major North American project, the USDOT *Safety Pilot* testing in Ann Arbor, Michigan and its six-month extension is not complete. The University of Michigan plans further expansion of the study to 9,000 vehicles by 2016. Similarly, in Europe, the *DRIVing implementation and Evaluation of C2X communication technology* (DRIVE C2X) project (and the seven associated projects throughout Europe) concluded, though the participating countries are still involved in related work. The *CityMobil* project concluded, but its follow-on project *CityMobil2* began shortly after and will involve demonstration projects in several cities across Europe. In the summer of 2014, Chevrolet EN-V 2.0 models were delivered to the Tianjin Eco-City in China for testing to begin.

Several projects were completed in 2013 and 2014. Recently completed projects in North America include the *Clarus Initiative* and *IntelliDriveSM for Safety, Mobility, and User Fee Project: Driver Performance and Distraction Evaluation* (ISMUF). In Asia, Japan completed testing for the truck platooning portion of its *Energy ITS Project*. In Europe, projects that have ended since the beginning of 2013 include *Communications for eSafety 2* (COMeSafety2), *Instant Mobility - Future Internet for Smart, Efficient & Green Mobility*, phase 1 of *Harmonized eCall European Pilot* (HeEro), *Co-Operative Systems for Sustainable Mobility and Energy Efficiency* (COSMO), *Co-Cities, Dynamic Information and Applications for assured Mobility with Adaptive Networks and Telematics infrastructure* (DIAMANT), *Cooperative Sensor Systems and Cooperative Perception Systems for Preventive Road Safety* (Ko-FAS), *Cooperative Mobility Systems and Services for Energy*

Efficiency (eCoMove), *Connected Cruise Control* (CCC), *Sensor City* pilot test, *Testfeld Telematik*, *Support Action for a Transport ICT European* large scale action (SATIE), and *79 GHz*.

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. The recent focus of USDOT connected vehicle research has been related to a National Highway Traffic Safety Administration (NHTSA) regulatory decision on connected vehicle technology. The decision to regulate connected vehicle technology in new passenger vehicles was announced in February 2014. A similar decision for heavy-duty commercial vehicles is planned by the end of 2014. 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.

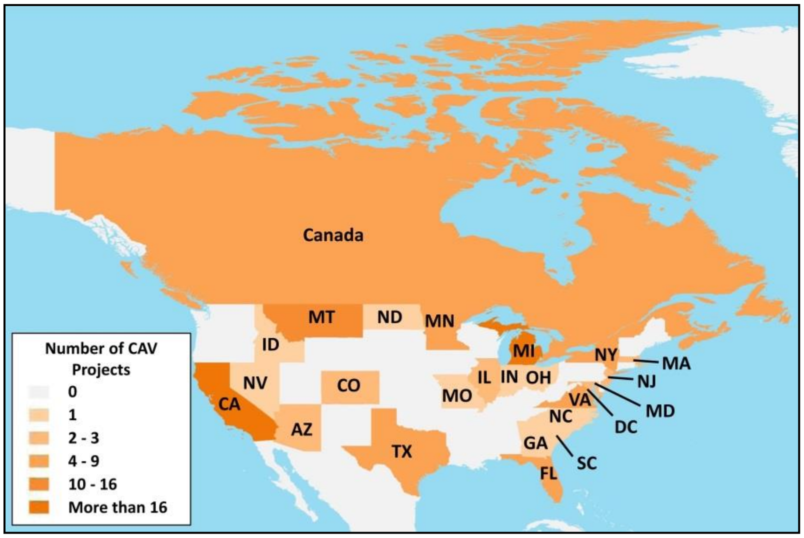

FIGURE 2: CONNECTED VEHICLE PROJECTS IN NORTH AMERICA[4]

[4] CAR 2014.

2.1 U.S. NATIONAL-LEVEL PROJECTS

CONNECTED VEHICLE SAFETY PILOT DRIVER CLINICS

Most demonstrations of connected vehicle and ITS applications have focused on proving and presenting technical capabilities to those in the transportation community. Until recently, most connected vehicle testing has been done using trained drivers and experimenters. There has been little testing that has used inexperienced drivers who were not familiar with connected vehicles before test drives. These tests have been limited to closed test populations and self-selected groups.[5]

From August 2011 through January 2012, the Crash Avoidance Metrics Partnership (CAMP) held driver acceptance clinics with naïve drivers that were unfamiliar with connected vehicle technologies. The clinics were held in six different locations across the country:

- Michigan International Speedway: Brooklyn, MI (August 2011)
- Brainerd International Raceway: Brainerd, MN (September 2011)
- Walt Disney World Speedway: Orlando, FL (October 2011)
- VTTI Smart Road: Blacksburg, VA (November 2011)
- Texas Motor Speedway: Fort Worth, TX (December 2011)
- Alameda Naval Air Station: Alameda, CA (January 2012)

Each clinic involved four days of testing, 112 drivers, and 24 vehicles equipped with connected vehicle technology. Each driver was accompanied by a tester who monitored the driver throughout the clinic. Care was taken to get a diverse range of driver characteristics such that drivers were evenly divided between genders and spread evenly across different age categories.[6] In addition, the clinics targeted different regional populations such as environmentally conscious drivers in California and pickup and sports utility vehicle drivers in Texas.[7] A total of 688 drivers participated in the clinics and shared opinions on the usefulness and effectiveness the technology.[8]

During testing, the vehicles would broadcast information (including brake status, Global Positioning System (GPS) location, rate of acceleration, speed,

[5] Hill and Garrett 2011.
[6] Ahmed-Zaid 2012.
[7] Kuchinskas 2012.
[8] Toyota 2012.

and steering-wheel angle) ten times each second.[9] Each of the eight participating automakers had different systems to provide safety information to drivers; these systems used sounds, lights, displays, and seat vibrations to alert drivers of various threats. Drivers tested several scenarios that involved applications of connected vehicle technology including emergency electronic brake lights, forward collision warning, blind spot warning/lane change warning, do not pass warning, intersection movement assist, and left turn assist.[10] After driving through several scenarios, drivers would pull over and be interviewed to find out which features seemed useful.[11]

After the driver clinic trials, each location hosted a small focus group involving 16 of the drivers that participated in the clinic. The two main points made by the participants were:[12]

- When it comes to accident prevention, there is nothing better than defensive driving. Overreliance on technology is bad.
- All vehicles on the road must be equipped with connected vehicle technology for the system to work. Retrofits for older vehicles will be important.

SAFETY PILOT MODEL DEPLOYMENT

After the completion of the driver acceptance clinics, the project began its second phase, an originally yearlong (later extended to 18 months) model deployment field test in the northwestern part of Ann Arbor, Michigan. The University of Michigan Transportation Research Institute (UMTRI) conducted the $22 million test,[13] which officially began on August 21, 2012.[14] The Ann Arbor tests involved 2,836 vehicles equipped with vehicle-to-vehicle (V2V) communications devices using 5.9 Gigahertz (GHz) Dedicated Short Range Communications (DSRC). DSRC gives the ability to transmit data at a rate of ten times per second.[15] The vehicles, which included cars, trucks, commercial

[9] Kuchinskas 2012.
[10] Ahmed-Zaid 2012.
[11] Kuchinskas 2012.
[12] Ahmed-Zaid 2012.
[13] Walsh 2014.
[14] Fancher 2012
[15] Fancher 2012.

vehicles, and transit vehicles, transmit information, such as location, direction, speed, and other vehicle data, during testing.[16]

The 16 CAMP vehicles with integrated systems used in the driver acceptance testing were reused for the *Safety Pilot* deployment. Another 48 light-duty vehicles with integrated systems were provided as were three Freightliner heavy-duty trucks, making a total of 67 vehicles with integrated systems for the deployment. Ford, General Motors, Honda, Hyundai-Kia, Mercedes-Benz, Nissan, Toyota, and Volkswagen provided vehicles with integrated systems.[17]

An additional 300 light-duty vehicles, 16 heavy-duty trucks, and 3 transit vehicles were outfitted with retrofit and aftermarket devices, which send and receive data and are able to issue warnings to drivers.[18] All vehicles with integrated systems and 100 of the vehicles with aftermarket devices were also outfitted with data acquisition systems (DAS), which collect data on driver performance and response to warnings.[19] The remaining 2,450 vehicles (2,200 light-duty vehicles, 50 heavy-duty trucks, 100 transit vehicles, and 100 medium-duty vehicles) were outfitted with a vehicle awareness device (VAD), which only sends data to other vehicles and is not be able to generate warnings.

The layout of the infrastructure for the deployment can be seen in Figure 3. The roadside infrastructure for the deployment covers 73 lane-miles of roadway with equipment installed at 25 sites and additional equipment installed at an intersection for radar-based pedestrian detection.[20] In the map, traffic light symbols designate areas where roadside equipment (RSE) is co-located with traffic signals; orange symbols indicate signal phase and timing (SPAT) enabled traffic signals and blue symbols indicate roadside equipment without SPAT capabilities. Orange dot symbols indicate equipment co-located with a freeway ITS installation and the blue dot symbol indicates a prototype solar/cellular equipment installation.

[16] Ahmed-Zaid 2012.
[17] Ahmed-Zaid 2012.
[18] Bezzina 2012.
[19] Fancher 2012.
[20] Bezzina 2012; Bezzina 2013.

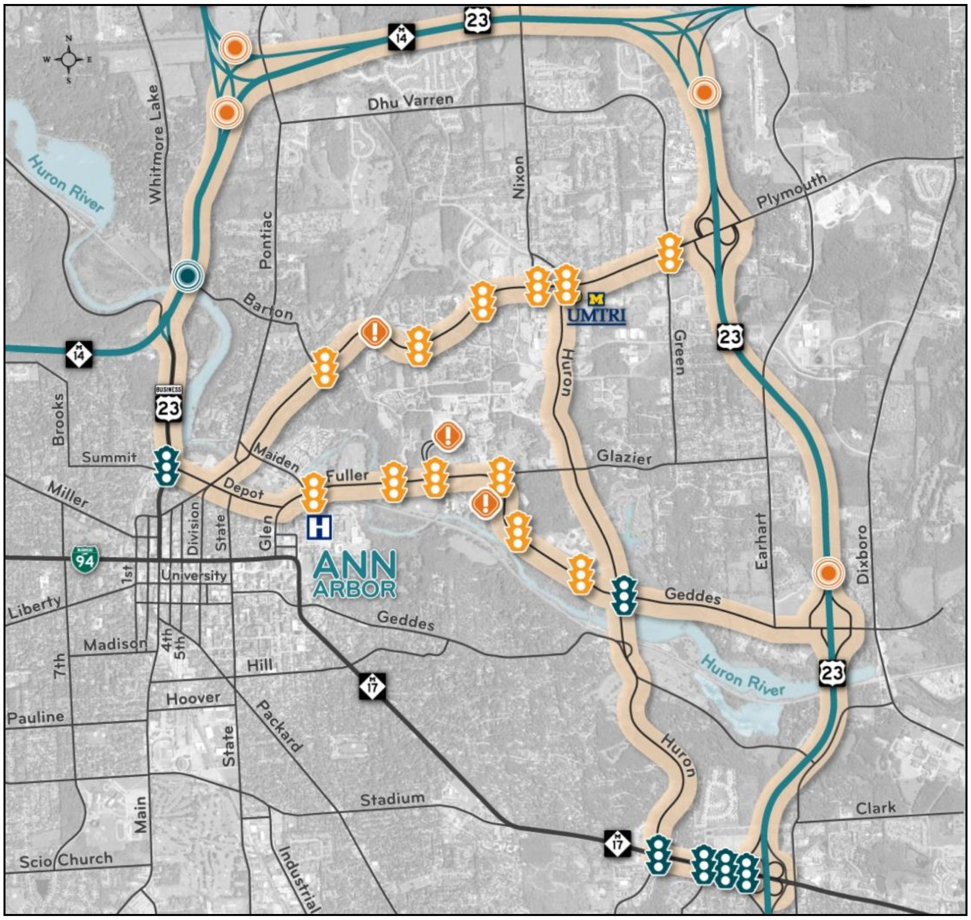

FIGURE 3: LAYOUT OF ANN ARBOR SAFETY MODEL DEPLOYMENT ROADSIDE INFRASTRUCTURE[21]

As of August 2012, UMTRI already had 3,500 local volunteers, hundreds more than needed for the testing.[22] The first 500 vehicles were put on the road in early August 2012 and within a few months after the project began, the entire fleet was in operation.[23] This deployment was significant because it involved the long-term observation of so many vehicles in real-world driving conditions. Most of the previous connected vehicle studies had collected data over shorter periods, involved fewer vehicles, and used staged scenarios rather than observing normal driving conditions.[24] The data provided by the deployment tests was used to analyze the system’s effectiveness at reducing crashes and inform regulatory agency decisions concerning connected vehicle

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[21] Bezzina 2012.
[22] Priddle 2012.
[23] Priddle 2012.
[24] Fancher 2012.

technology.[25] By the end of the project, UMTRI collected approximately 200 terabytes (TB) of data.[26] This data was delivered to an independent evaluator to support USDOT efforts.

The project was originally scheduled to last for one year, but it received a six-month extension for additional tests of communications technology on motorcycles and vehicle-to-infrastructure (V2I) applications.[27] The extension did not affect the timetable for the agency's notice of regulatory intent (NRI). In February 2014 NHTSA announced its decision to move forward with connected vehicle regulations.

SAFETY 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 *Safety Pilot* deployments. The pilots will facilitate initial connected vehicle deployments in real-world settings. Throughout the summer and fall, USDOT plans to engage in regional pre-deployment workshops and webinars, and in early 2015, the agency will solicit applications for the first wave of pilot deployments. These will be awarded in fall 2015. Solicitation for a second wave of applications will occur in early 2017 and awards will be made in fall 2017. All pilot deployments will be completed by September 2020. USDOT literature suggests that communities interested in hosting one of the pilots learn more about the program, form partnerships, identify needs, and assess connected vehicle technologies and applications.[28]

PREPASS FOR COMMERCIAL VEHICLES

PrePass is a system that can automatically identify, cross-reference, and clear commercial vehicles, allowing them to bypass weigh stations. Participating commercial vehicles can be prescreened at designated weigh station facilities and are equipped with transponders that enable V2I communications. These prescreened vehicles can then bypass other weigh stations while traveling along highways, eliminating the need to pull over for additional inspections and saving time, fuel, and labor costs. The program also benefits states and

[25] Fancher 2012.
[26] Bezzina 2013.
[27] Shepardson 2013a
[28] Hartman 2014.

other drivers by reducing congestion and enabling inspection staff to focus their efforts on carriers that demand the most attention.[29]

EARLY U.S. AUTOMATED VEHICLE ACTIVITIES

From the mid-1990s to the early-2000s, the United States established itself as a leader in automated vehicle systems through its Cooperative Vehicle-Highway Automation Systems (CVHAS) initiative. CVHAS was a federal pooled-fund program whose main purpose was to partner with public and private sector organizations to research, develop, evaluate and deploy connected and automated solutions to improve mobility, safety, environmental performance, and fuel economy in the transportation sector.

More recent automated vehicle initiatives have been driven primarily by the military and the automotive industry, though the U.S. Department of Transportation continues to support automated vehicle research through the Federal Highway Administration (FHWA) Exploratory Advanced Research (EAR) program.

PRIVATE COMPANY AUTOMATED VEHICLE EFFORTS

Many companies within the United States, including traditional automakers such as General Motors, 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 announced its self-driving car project in 2010, and since then, the company has logged several hundred thousand miles of autonomous driving experience among its test vehicles. Until recently, all of Google's self-driving test vehicles have been commercially available vehicles, such as Toyota Prius or Lexus RX450h 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 vehicles specifically designed to operate

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[29] PrePass 2012.

safely and transport occupants from one location to another without requiring human intervention. Not only will these new prototypes not require a human driver, they will not have a steering wheel, nor will they include accelerator or brake pedals. These early prototypes will have a top speed of 25 miles-per-hour (mph). This limitation will restrict their use to urban and suburban settings, not highways. This summer, Google's safety drivers will begin testing these vehicles, and, depending on the test results, Google may begin a pilot program in California.[30]

NHTSA Notice of Regulatory Intent

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. This decision took into account data from both the *Safety Pilot Driver Clinics* and *Safety Pilot Model Deployment* projects conducted by USDOT. NHTSA noted the Driver Clinics suggested high favorability ratings and levels of customer acceptance for the technology. NHTSA also reported that it is finalizing its analysis of the *Safety Pilot Model Deployment* data, which will be included in a research report the agency plans to release in the near future. Once the report is published and public comment period is over, NHTSA will begin drafting its regulatory proposal for V2V technology in new light-duty vehicles.[31]

Automated Vehicle Legislation

In the United States, regulation related to automated vehicle testing has been largely left up to the states. Currently Nevada (2011), Florida (2012), California (2012), the District of Columbia (2013), and Michigan (2013) have passed laws addressing the use of fully automated vehicles on public roads. Several other states throughout the country had considered similar legislation (see Figure 4). In May 2013, the National Highway Traffic Safety Administration released guidelines for states issuing licenses for testing fully automated vehicles on public roads.[32]

Michigan law had already allowed companies to operate prototype automated vehicles on public roads if they had manufacturer license plates. In December 2013, Michigan Governor Rick Snyder signed two bills that allow testing of

[30] Urmson 2014.
[31] NHTSA 2014.
[32] NHTSA 2013a.

automated motor vehicles on Michigan roads. The first bill (Senate Bill 169) covered testing and modifying vehicles. It allowed entities other than automakers and Tier-1 suppliers to qualify for "manufacturer" license plates. The second bill (Senate Bill 663) addressed liability protection for automakers and technology firms. The new legislation clarified rules and broadened eligibility for automated vehicle testing in Michigan.

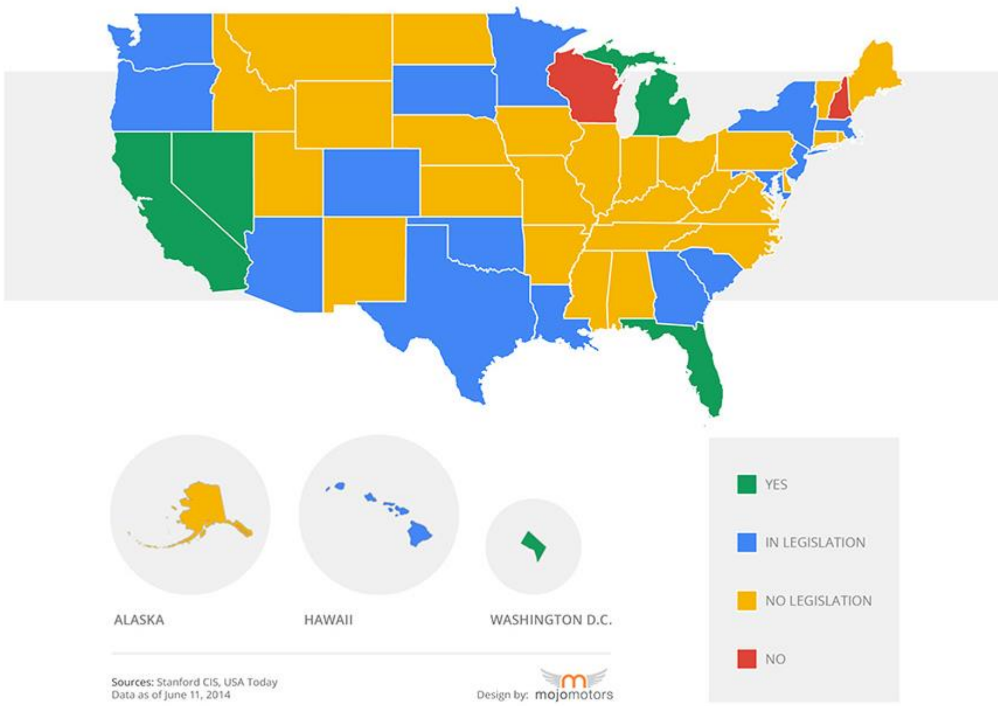

FIGURE 4: LEGAL STATUS OF AUTOMATED VEHICLE TESTING BY STATE[33]

In May, the California Department of Motor Vehicles officially approved rules to allow automated vehicle testing on public roads. The rules, which will take effect in September 2014, cover requirements a manufacturer must meet related to vehicle testing, insurance, registration, and reporting. Rules governing use of automated vehicles by the general public are currently being developed and are set to be adopted in 2015.[34]

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[33] Mojo Motors 2014. Data is believed to be current as of June 2014.
[34] DMV 2014.

U.S. MILITARY AUTOMATED VEHICLE EFFORTS

Throughout the mid-2000s, the Defense Advanced Research Projects Agency (DARPA) held a series of "Grand Challenge" events to encourage development of automated vehicles. The DARPA Grand Challenge was the first long-distance automated vehicle competition in the world. The first Grand Challenge was held in March 2004. No competing vehicle was able to complete the challenge's 150-mile long route. The event was followed by a second challenge in October 2005. Five vehicles successfully completed the 2005 Grand Challenge route. In November 2007, DARPA held its third event, the Urban Challenge, which required all vehicles to obey traffic regulations and negotiate with other traffic. The event took place at the former George Air Force Base in California.[35] The challenges helped develop expertise in automated vehicle systems and helped advance automated vehicle efforts in the United States and abroad. Google went on to hire some of the researchers who participated in the DARPA challenges for its own automated vehicle initiative.

Various truck automation projects are also underway in the United States. For instance, the U.S. Army's *Autonomus Mobility Applique System* (AMAS) project uses low-cost sensors and control systems on military vehicles to enable driver assistance features or automated operation. AMAS technology has been used in the *Convoy Active Safety Technology* (CAST) program to produce automated vehicles that are able to travel in a platoon lead by a manned vehicle. Automated truck projects also are being carried out by the University of California Berkeley-PATH and the Federal Highway Administration.[36]

2.2 MICHIGAN

MICHIGAN DEPARTMENT OF TRANSPORTATION ACTIVITIES

Vehicle-Based Information and Data Acquisition System (VIDAS) is an MDOT project intended to use visual observations to determine the accuracy and reliability of mobile test data relating to road conditions. MDOT utilizes instrumented fleet vehicles for business operations traveling on roadway infrastructure on a daily basis. The instrumented vehicles collect real-time

[35] DARPA 2013.
[36] Poorsartep 2013.

data for aggregation into an associated database, allowing data users to visualize and interact with the data. This allows MDOT to evaluate the performance and accuracy of roadway data for use in pavement condition and management, as well as roadway surface conditions (cracking, heaving, etc.). As a final step in the project, MDOT will compare visual observations to determine the accuracy of *Road Weather Information System* (RWIS) data. This data provides a longer-term opportunity to evaluate current conditions of travelled roadways and to manage the roadway infrastructure effectively from a pavement performance and system preservation perspective.

MDOT's RWIS is an ITS subsystem expressly used to collect, analyze, and report current roadway surface conditions (e.g., salinity, surface temperature, rate of cooling, etc.) and specific atmospheric conditions (e.g., ambient air temperature, precipitation, humidity, wind speed/direction, visibility, etc.). Through use of RWIS data, operations staff can more effectively plan salting operations. This allows for reductions in staff time, idling emissions, fuel consumption and potential reductions in fleet maintenance.

Teletrac Data Server is a separate ITS subsystem utilized for fleet management and performance tracking. The system supports analysis of routes, miles travelled, maintenance performed/maintenance cycles, regulatory compliance, and GPS tracking/routing. This system is a vendor solution and has a degree of overlay with OEM Fleet data server. Currently, this system has a limited deployment of less than 50 vehicles in total.

The Data Use Analysis and Processing (DUAP) program was initiated in 2006 by the MDOT to complement research initiatives from USDOT, the Vehicle Infrastructure Integration Consortium (VII-C), and others to design and deploy the connected vehicle infrastructure, vehicle equipment, and initial applications. The intent of the program is to support performance management by enhancing agency-wide usage of connected vehicle and mobile data and increasing data sharing, availability, and awareness across the agency.

DUAP 1 was the first iteration of the DUAP program. The project presented the concept of collecting mobile data in near-time and making it available to all business units across MDOT regardless of its associated business process. DUAP 1 also established the need for MDOT to create a platform that would better define and clearly identify the types of data required for their applications.[37]

The recently completed DUAP 2 Concept of Operations describes the advanced applications of connected vehicle data, concepts for the proposed systems, and operation scenarios.[38] The proposed DUAP 2 system will serve as the back office system that houses the processes making the DUAP system possible. The system will be designed to serve a multitude of purposes, as well as be scalable and modular. The physical DUAP 2 system will consist of:

- Data collection system
- Data management system
- Data distribution system

The DUAP 2 system is intended to draw data from existing MDOT data sources and other relevant data sources (e.g., *Safety Pilot* program data, Chrysler test fleet data and Android accelerometry data) to be integrated with connected vehicle data. The integrated system output will feed existing MDOT applications as an enriched data stream or be used in new applications.

Operational scenarios within the proposed DUAP 2 system primarily consist of ways the systems will interact with each other and the external environment. For the data input environment, data collectors read and process data from each source in its native format using existing communications infrastructure. An archival process also stores collected data in its native format in a file that is tagged with the source and collection time for future retrieval and verification needs. Once the data is processed and stored in the back office system, it becomes available for access by the data output environment. Data applications previously discussed will allow users to interface with the system.[39]

WALBRIDGE CONNECTED VEHICLE RESEARCH CENTER

Planning is underway to convert the former General Motors Willow Run Powertrain Plant in Ypsilanti Township, Michigan into a connected vehicle research center. In September 2013, Walbridge Group Inc. entered into a redevelopment agreement with RACER trust, the organization responsible for

[37] Mixon/Hill 2012.
[38] Mixon/Hill 2013.
[39] Mixon/Hill 2013.

cleaning up and selling old General Motors properties that were divested in the company's 2009 bankruptcy.[40] Under the agreement, Walbridge will own and operate the connected vehicle research center, which will be open to automakers, suppliers, research organizations, and other interested groups. Under the current plan, the existing buildings on the 332-acre site will be demolished, and Walbridge will construct new buildings, test tracks, and roadside infrastructure at the site. Demolition has begun, and redevelopment appears to be contingent on a combination of government and industry support.[41]

UNIVERSITY OF MICHIGAN MOBILITY TRANSFORMATION FACILITY AND CENTER

In 2014, the University of Michigan in Ann Arbor announced that it would be opening a 32-acre testing center for automated vehicles called the Mobility Transformation Facility (MTF). The MTF will have a four-lane highway and simulated city center. It will contain merge lanes, intersections, stoplights, road signs, roundabouts, road signs, mechanical pedestrians, a rail crossing, and other features (as illustrated in Figure 5). The University broke ground on the site of the MTF in May 2014, construction continued through the summer, and a ribbon cutting ceremony is scheduled for September 2014. When completed, the facility will be operated by a public/private partnership called the Mobility Transformation Center (MTC).[42] Several companies are already members of the MTC, including automakers Ford, General Motors, and Toyota and suppliers Bosch, Xerox, and Econolite Group, Inc.[43]

[40] Walsh 2013.
[41] Walsh 2014.
[42] Moore 2014.
[43] Jones 2014.

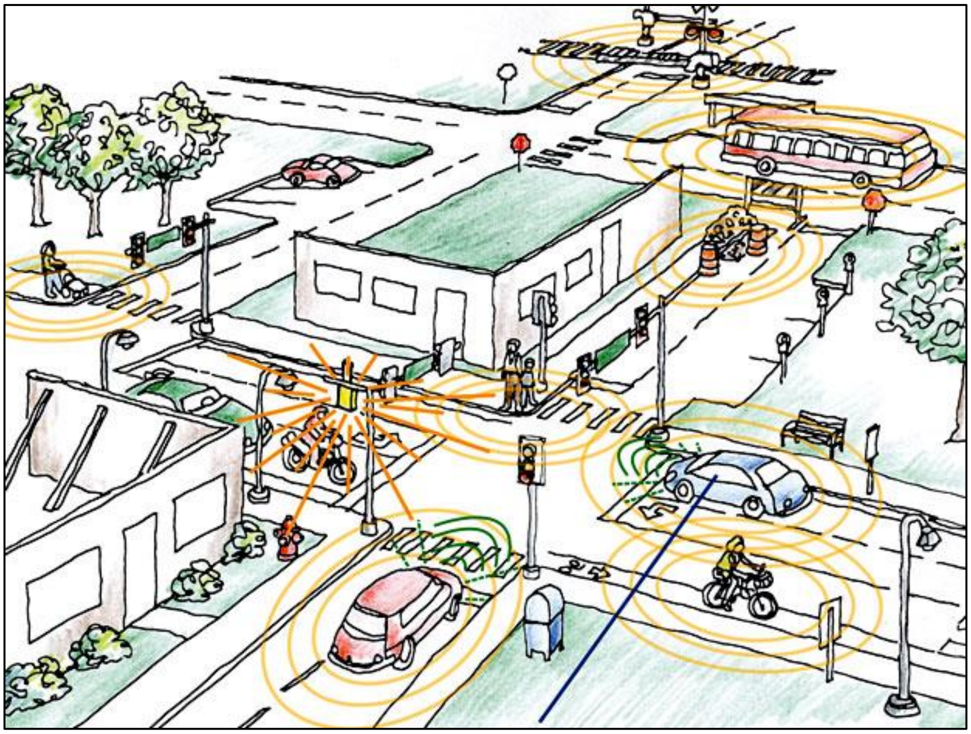

FIGURE 5: CONCEPTUAL DRAWING OF THE MOBILITY TRANSFORMATION FACILITY[44]

I-94 TRUCK PARKING INFORMATION AND MANAGEMENT SYSTEM (TPIMS)

The $4.48 million I-94 *Truck Parking Information and Management System* (TPIMS) is a system that provides truck drivers real-time data on the availability of spaces at private and public truck parking facilities (e.g., private truck stops, public rest areas, and welcome centers). The system is intended to allow truck drivers to better plan their rest stops and reduce the number of trucks dangerously parked along the shoulder of the freeway.[45]

The system uses detection technology to gage the availability of truck parking spaces and disseminate it to drivers through:

- Dynamic roadside signs
- Websites (MiDrive and Truck Smart Parking Services)
- A smart phone application
- On-board 5.9 GHz DSRC equipment

[44] Jones 2014.
[45] Castle 2014.

The system has been deployed in Michigan along I-94 between I-69 and the Indiana border. There are currently five DSRC roadside units for the system which are located at critical decision points on the freeway. On-board DSRC units have been installed in a number of pilot trucks. In the future, the system may be expanded to include sections of I-94 east of I-69 as well as other freight corridors.[46]

Project partnerships for TPIMS include FHWA, MDOT, private truck stop owners, private trucking and freight companies, system suppliers, and engineering firms. HNTB and ParkingCarma worked together to develop the smartphone application and the connected vehicle application was developed by Kapsch. UMTRI is conducting an independent evaluation of the system, which is expected to be completed in early 2015.[47]

ANN ARBOR SAFETY PILOT MODEL DEPLOYMENT EXPANSION

The Ann Arbor deployment 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*.[48]

MICHIGAN BASED TEST BEDS

In 2009, CAR conducted an inventory of connected vehicle test beds in the state of Michigan.[49] The inventory involved visiting the site of each installed roadside unit and creating an asset inventory database. In total, CAR researchers documented infrastructure at eight different test beds. Among these eight locations, CAR documented 97 deployed roadside units. The test beds documented in the study included:

- Chrysler Tech Center (Auburn Hills)
- Telegraph and 12 Mile (Southfield)
- Telegraph and 15 Mile
- Farmington Hills (and parts of Novi)
- Rock Financial Showcase (Novi)
- USDOT Development and Test Environment (Novi and vicinity)

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[46] Castle 2014.
[47] Smart Park for Trucks 2014
[48] MTC 2014.
[49] Wallace and Brugeman 2009.

- CVPC Intersection (Southfield)
- CVPC Rest Area (Chelsea)

Some of the test beds documented in the 2009 report are still in use while others are inactive. The largest test bed, USDOT *Development and Test Environment*, established in 2007 for proof of concept testing, was updated in 2010 to support more general testing and use. The USDOT test bed still has approximately 50 roadside sites supporting signal phase and timing, commercial vehicle, signage, and probe data applications.[50]

More recently, the Detroit Test Bed has been created for the 2014 ITS World Congress. The test bed consists of 17 roadside units, installed between the Cobo Center and Beaubien Street. The Detroit Test Bed is unique, because no other urban test bed environment exists in the United States. Test beds in Orlando, Palo Alto, Novi, and Ann Arbor are all in more suburban, open areas. The Detroit Test Bed provides features, such as an "urban canyon" and the tunnel under the Millinder Center, both of which will challenge existing technologies. The outcomes of such testing have unique value to future connected vehicle applications.

2.3 CALIFORNIA

The State of California is the locus of numerous connected vehicle activities, and the California efforts are rooted in a close working relationship between the California Department of Transportation (Caltrans) and the California Partners for Advanced Transit and Highways (PATH), part of the University of California - Berkeley's Institute of Transportation Studies. With aide from several private-sector entities, including a handful of automotive research facilities located in Silicon Valley, these two organizations are leading the way on a variety of efforts. This section elaborates on the roles being played by various organizations involved with connected and automated vehicles in California. Much of the information contained in this California section is based on in-person discussions with Greg Larsen (Caltrans), Jim Misener (Qualcomm, formerly Booz Allen Hamilton and PATH), Chuhee Lee (VW NA), and Alex Busch (BMW).

A significant portion of the connected vehicle work done in California is part of the efforts of Caltrans and PATH. Caltrans manages California's freeways,

[50] Krueger and Fehr 2013.

provides inter-city rail services, and permits airports and heliports. Its mission is to improve mobility across California, and its goals include improving safety, mobility, delivery, stewardship, and service.[51] As the state department of transportation, Caltrans is the lead state agency responsible for connected vehicle efforts in California.

PATH is a multi-disciplinary program that includes employees and students from universities throughout California working on projects in conjunction with industry, government agencies, and non-profit institutions. Within the areas of safety, traffic operations and modal applications, the program emphasizes long-term, high-impact solutions. It receives funding from Caltrans, the U.S. Department of Transportation, state and local governments, and private sources.[52]

Caltrans and PATH have a tight working relationship and are engaged in many joint efforts to expedite deployment of connected vehicle assets in the state. These have included establishing a wireless test area in Richmond, California, that supports V2I communications and application development and testing. Originally, the intelligent intersection used Wi-Fi for in-vehicle warnings and to facilitate communication between vehicles and between vehicles and the intersection. Later an IEEE 1609 capable Multiband Configurable Networking Unit (MCNU) was installed. Figure 6 contains an overview of the field station. Caltrans also has test sites in San Jose and Palo Alto.

In 2004, Caltrans and PATH worked with other universities and agencies to design a DSRC development in the San Francisco Bay Area. Partners included the Metropolitan Transportation Commission, Telvent Farradyne, Daimler Chrysler, Volkswagen of America, and Navteq. Currently, funding resources for further work with connected vehicle in California have been halted. While options to obtain federal funding are being considered, additional stakeholder support will be needed to resume connected vehicle work in California.[53]

Caltrans and PATH have been working on several other fronts. For instance, they were both part of an Urban Partnership proposal that was submitted to the federal government. The funding of this proposal provided Caltrans and PATH with additional resources to expedite their connected vehicle

[51] CA.GOV 2010.
[52] ITS Berkeley 2010.
[53] PB 2010.

deployment and conduct research associated with it. For the project, Caltrans and PATH partnered with the Metropolitan Transportation Commission (MTC) to implement and expand programs in the San Francisco Bay Area to relieve congestion. Among these programs was a pilot to demonstrate the capabilities and feasibility of connected vehicle technology.[54] The total amount of federal funding for the program was $158.7 million.[55]

Another joint Caltrans and PATH project was a field test with Nokia featuring 100 vehicles that served as cellular-based traffic probes. Their field test took place February 8, 2008 and is described in more detail in the *Safe and Efficient Travel through Innovation and Partnerships in the 21st Century* (SAFE TRIP-21) section of this report. Local automotive facilities, such as the Volkswagen North America research lab, also participated in this test.

PATH has conducted work at its Richmond Field Station to investigate the potential benefits of broadcasting SPAT data. The work used the *Intelligent Intersection* facility,[56] which is highlighted in Figure 6. In October of 2009, Caltrans, along with partners BMW and Siemens, demonstrated connected vehicle technology that used DSRC and SPAT information to detect vehicles and save fuel.[57] The demonstration took place during the American Association of State Highway and Transportation Officials (AASHTO) meeting in Palm Desert, California, and showed fuel savings of up to 15 percent.[58] Furthermore, in 2009, USDOT awarded $8.5 million to Caltrans to expand its *Integrated Corridor Management (ICM) Pioneer Site Demonstration and Evaluation Project* along the San Diego I-15 corridor. The project furthered development of several mobility applications, including provision of multi-modal travel times and real-time incident information.[59]

[54] Mixon/Hill 2009a.
[55] MTC 2007.
[56] Dickey et al. 2010.
[57] Larsen 2010.
[58] Siemens 2010.
[59] PATH 2010.

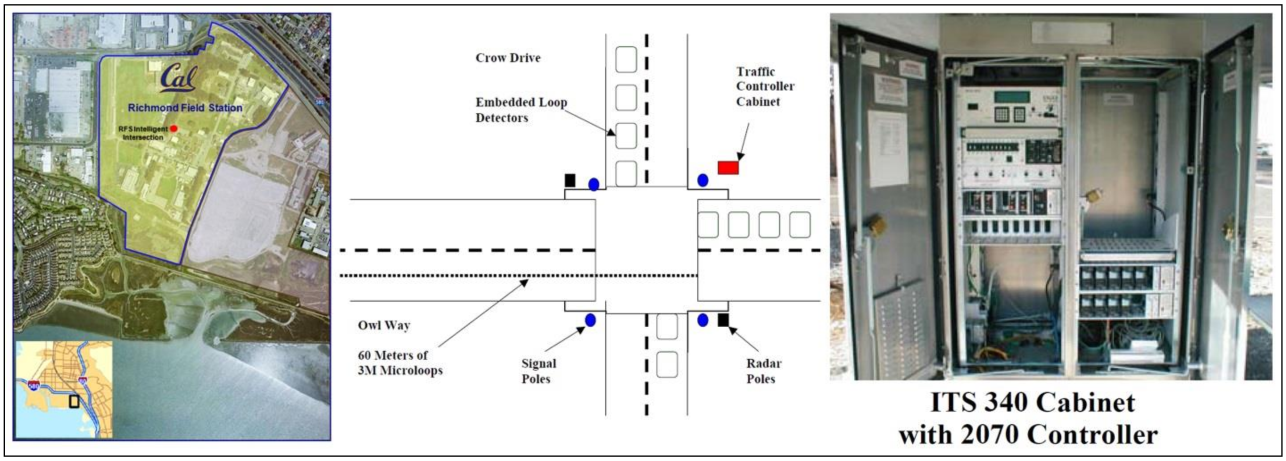

FIGURE 6: RICHMOND FIELD STATION INTELLIGENT INTERSECTION LOCATION, LAYOUT, AND TRAFFIC CONTROLLER[60]

USDOT also awarded $1.57 million to Caltrans in partnership with the Western Transportation Institute for the *Coordinated Speed Management in Work Zones* project. This project was designed to provide highway patrol officers with information on excessive vehicle speed and a picture of the license plate. Using the system developed by the project, nearby workers can be provided with vibrating pagers to alert them when a vehicle is speeding.[61] The project began in 2010 and was completed in October 2013.[62]

Looking forward, Caltrans envisions eventual deployment of connected vehicle infrastructure at every signalized intersection and every ten miles on state highways. Caltrans believes this will be privately funded, with incentives provided to attract private investment. It also recognizes that it will face some challenges in some of the extreme topographical and climatic regions of California (e.g., high mountains, extreme winter snow, deserts), especially where these exist in remote areas that lack good communication backhaul options.

Caltrans and PATH are also active at the national level, participating in ITS America, Transportation Research Board (TRB) committees, VII-C Steering Committee, and other organizations that affect the national connected vehicle effort. Eventually, Caltrans and PATH activities became recognized as part of the connected vehicle proof-of-concept tests being undertaken by the VII-C.

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[60] PATH 2014.
[61] PATH 2010.
[62] TRID 2013a.

PATH's approach for expediting connected vehicle deployment has been published, at least in part.[63]

SAFE AND EFFICIENT TRAVEL THROUGH INNOVATION AND PARTNERSHIPS IN THE 21ST CENTURY (SAFE TRIP-21)

In the first half of 2008, Caltrans applied for and was awarded a USDOT grant under the auspices of SAFE TRIP-21, a connected vehicle program managed by the Volpe Center. This program was intended to build upon lessons from previous ITS proof-of-concept tests to improve safety, mobility, energy independence, and environmental stewardship. It involved testing and integrating applications into field test environments, and it also was used to develop and provide demonstrations for the 2008 ITS World Congress testing environments in New York. California was initially awarded $2.9 million from USDOT for a field test site, with the possibility of receiving additional funding if available. The total cost of the field test, which was planned in 2008 and implemented in 2009, was $12.4 million.[64]

In 2009, the SafeTrip-21 Initiative was awarded a research grant for an additional $943,000 from USDOT. The partners receiving the grant included Caltrans and PATH, as well as Navteq and ParkingCarma. Using this grant, the partners developed and tested a traveler information tool. The tool combines information on real-time traffic, train and bus, and parking space availability information to enable travelers to plan more efficient trips. The tool makes use of data collected along the US-101 corridor between San Francisco and San Jose.[65]

MOBILE MILLENNIUM

Through its contacts at Navteq and the Connected Vehicle Trade Association (CVTA), CAR understands that the Caltrans project most likely builds upon previous work that Nokia and Caltrans conducted together. Specifically, in February of 2008, they performed a test for which they gave 100 university students a Nokia phone equipped with GPS and traffic-monitoring software developed by the team. The students drove a 10-mile stretch of freeway, while the phones sent data on speed and location back to Nokia's research

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[63] Dong et al. 2006.
[64] Sengupta 2010.
[65] PATH 2010.

facilities.[66] The original test, known as *Mobile Century* was followed up by *Mobile Millennium*, an 18-month project that was announced in November 2008. The public participation period lasted from November 2008 through November 2009. Mobile Millennium had more than 2,000 registered users and collected/reported data all day for one year. It protected privacy by generating traffic data at pre-set locations rather than using identifying information or tracking mobile devices.[67] The project was notable for its use of cellular phones and large number of participants.

HYUNDAI EMPTY CAR CONVOY TESTING

In June 2014, Hyundai released a video of the *Empty Car Convoy* test, which involved several Hyundai Genesis models being driven in a convoy at the Hyundai-KIA Motors California Proving Grounds near California City, California. The test shown in the video used the vehicle's advanced smart cruise control, automatic emergency braking, and lane keep assist systems to demonstrate a convoy of empty vehicles following a lead vehicle. When a vehicle in front of the convoy suddenly brakes all vehicles in the convoy are able to automatically apply the brakes and avoid collision.[68]

PRIVATE SECTOR CONNECTED VEHICLE ACTIVITIES

In addition to public-sector and university activities, California is also involved with private-sector connected vehicle activities. The state is home to several automotive electronics research units belonging to the major automotive manufacturers. This includes facilities operated by BMW, Daimler, and Volkswagen North America. While much smaller than, for example, the Chrysler Tech Center, these facilities are heavily focused on vehicle electronics and applications being developed by these automakers for the U.S. market. BMW, for example, is very interested in using wireless pipelines to connect BMW drivers for safety, mobility, and commercial applications.

CALIFORNIA AUTOMATED VEHICLE ACTIVITIES

The University of California PATH program has been involved in many automated vehicle projects. In August 1997, PATH demonstrated an eight-

[66] Mobile Millenium 2011.
[67] SAIC 2011.
[68] Hyundai 2014.

vehicle platoon. The vehicles were separated by a distance of 6.5 meters while driving at highway speeds.[69] Current automated vehicle projects PATH is working on include cooperative adaptive cruise control (CACC), automated truck platooning, and vehicle-assist and automation applications for full-size public transit buses.[70] Google has also been involved with automated vehicle testing in California since 2010. Google's new prototype automated vehicles, announced in 2014, may be used in a California pilot program in the near future.[71]

2.4 ARIZONA

ARIZONA E-VII PROGRAM

Arizona has researched connected vehicle applications and strategies to support incident management and enhanced traffic control. This research was conducted under the *Arizona Emergency VII (*E-VII) program, which consisted of two projects under Arizona DOT: SPR-653, *Arizona VII Initiative: Proof of Concept/Operational Testing* and SPR-678, *Dynamic Routing for Incident Management*. Prototype applications for the program included traffic signal preemption and priority, ramp meter preemption, and mobile incident warning. The project started in early 2008 and a site demonstration occurred in late 2008.[72] All testing and evaluation was completed by 2011.[73] Figure 7 shows photographs of the ramp meter priority (left) and signal preemption (right) field demonstrations.

The project was divided into two phases. Phase 1 developed and tested potential incident management applications. Phase II involved the testing of applications in a pilot deployment, evaluating functionality of hardware and software, human factors, and viability applications for incident management. The University of Arizona (UA) and Arizona State University (ASU) were involved, with UA developing technology and software as well as field demonstration scenarios, and ASU evaluating the program's outcomes. UA was responsible for writing the research report with support from ASU.[74]

69 PATH 1997.
70 Meade 2012.
71 Urmson 2014.
72 Gettman 2009.
73 ADOT 2011.
74 Arizona DOT 2008.

FIGURE 7: RAMP METER PRIORITY AND SIGNAL PREEMPTION FIELD DEMONSTRATIONS[75]

MARICOPA COUNTY ACTIVITIES

The *Next Generation of Smart Traffic Signals* project is an EAR program project started by the FHWA in 2007 and has been conducted by Arizona State University in Phoenix. The traffic signal system being researched in this project is called *Real-Time Hierarchical Optimized Distributed Effective System Next Generation* (RHODES^{NG}). Though smart traffic signals have been used by some countries for decades, they are relatively rare in the U.S. due to their associated high infrastructure costs. These systems, however, have considerable value in that they are able to reduce travel time, delays, and stops as compared to the more common fixed-length, time-of-day traffic signals. The system is designed to continuously adapt operations based on changing conditions using data from vehicles, infrastructure sensors, and transmitters. It uses self-adaptive algorithms that integrate the position, speed, and queue data, accurately perform high-speed computations, make predictions, and continuously adjust critical parameters.

Continued development of the RHODES^{NG} system was focused on integrating connected vehicle technology components. Because these technologies are in a constant state of change and development as innovations are introduced and tested, incorporating them into the RHODES^{NG} system is a major challenge. With better information from a vehicle itself, including location, destination, speed, and acceleration, smart signal control systems could more effectively allocate signal phasing times to handle changing traffic demands. A field test

[75] Gettman 2009.

of RHODES[NG] with connected vehicle capabilities took place at the Maricopa Proving Grounds.[76]

Maricopa County's state-of-the-art field lab is known as the *SMARTDrive Multi-modal Intelligent Traffic Signal System* prototype. It consists of six traffic lights along a 2.3 mile stretch of Daisy Mountain Drive in Anthem, Arizona. The earliest application tested was an emergency vehicle prioritization system. The test bed has been equipped with DSRC devices, integrated Wi-Fi and Bluetooth connections, closed-circuit television (CCTV) cameras, traffic detection software, data collection software, fiber optic systems, and communication connections to the Maricopa County Department of Transportation Traffic Management Center.[77]

The Maricopa County test bed was selected, along with a Caltrans test site, to serve as a national test sites for the USDOT and Cooperative Transportation Systems Pooled Fund Study-funded *Multi-Modal Intelligent Traffic Signal System* project. The Daisy Mountain Fire District and Valley Metro buses agreed to participate in live SMARTDrive field testing in order to simulate real traffic conditions.[78] The project was completed in September 2009.[79]

2.5 COLORADO

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH (NCAR) ACTIVITIES

The National Center for Atmospheric Research (NCAR) in Boulder, Colorado has been conducting research on how connected vehicles can be used to document real-time weather conditions.[80] The goal of this research and development effort is to gain a better understanding of how to effectively utilize weather-related data retrieved from connected vehicles. The projects at NCAR are applied research and involve acquiring, analyzing, and processing data from vehicles and using it to improve knowledge of current road conditions as well as forecasts of future road conditions. With improved knowledge of road conditions, warnings can be issued to drivers about hazardous conditions.

[76] FHWA 2012.
[77] Maricopa County 2012.
[78] Maricopa County 2012.
[79] TRID 2013b.
[80] NCAR 2011.

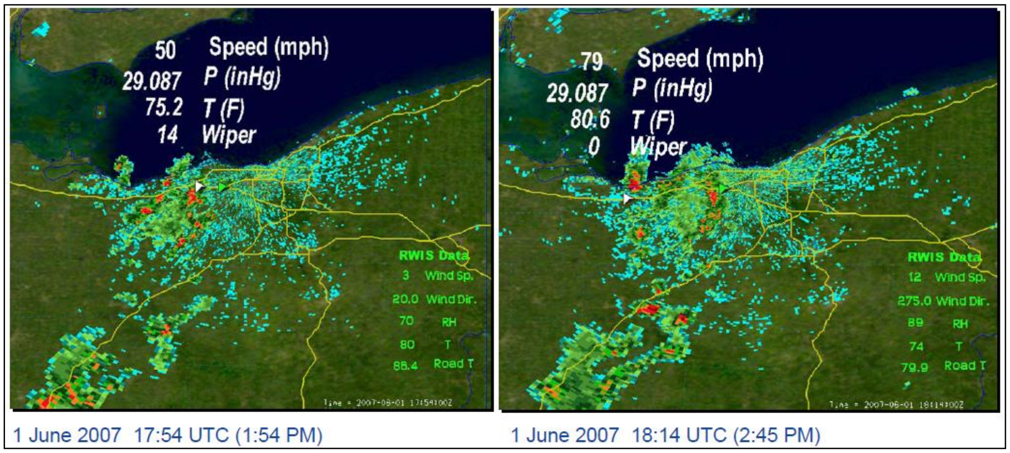

FIGURE 8: WEATHER DATA TRANSLATOR EXAMPLE CASE[81]

A major connected vehicle project at NCAR is the *Weather Data Translator* (WDT). The WDT was a demonstration system that could receive and analyze probe data from vehicles driving through connected vehicle test beds.[82] The information created by the WDT was used by the *Clarus Initiative* (an integrated surface transportation weather observing, forecasting, and data management system) or other applications.[83] An example case of the WDT is shown in Figure 8. The *Clarus Initiative* ended in June 2013.[84]

DENVER TEST BED

Another example of connected vehicle work in Colorado is the *Denver Test Bed*, also known as the *Denver E-470 Test*. The purpose of this test was to demonstrate multi-lane free flow (MLFF) and open road tolling (ORT) high performance tolling and enforcement. The system being used is based on Kapsch TrafficCom's 5.9 GHz DSRC technology. It was installed on three southbound lanes next to an existing toll collection system on the E-470 highway.[85] The installation includes 5.9 GHz DSRC roadside infrastructure and in-vehicle units as well as lane cameras with illumination units, overview cameras with external infrared (IR)-flashes and the laser units. Applications tested included toll tags and detectors, vehicle detection and classification, and automatic license plate recognition solutions. The testing was completed using

[81] Petty and Chapman 2008.
[82] Petty and Chapman 2008.
[83] FHWA 2011.
[84] USDOT 2014.
[85] Kapsch 2008.

a fleet of 27 vehicles and lasted for a few weeks.[86] An independent research and development laboratory evaluated the system and concluded that 100 percent of the over 10,500 samples that were identified using a GPS data logger were also identified using the DSRC toll tags.[87]

2.6 FLORIDA

SELMON EXPRESSWAY AUTOMATED VEHICLE TESTING

In January 2014, the Tampa Hillsborough Expressway Authority announced the Selmon Expressway had been approved by the Research and Innovative Technology Administration (RITA) and USDOT as an automated vehicle test bed.[88] This designation has also been awarded to the Orlando test bed location in Florida, along with other test bed locations nationwide, including test beds in:

- Manhattan, New York
- Maricopa County, Arizona
- Mclean, Virginia
- Novi, Michigan
- Oak Ridge, Tennessee
- Palo Alto, California

By the summer of 2014, tests were already occurring on Selmon Expressway. In July, Audi used the test bed to test and demonstrate its autopilot applications. The Audi A7 demonstration vehicles used for testing have between 17 and 20 radar, sonar, and LiDAR sensors, as well as video cameras. The Audi system demonstrated on the Selmon Expressway should be commercially available in five years and likely will cost slightly more than current Audi sensor packages that cost around $10,000.

Audi engineers selected the Selmon Expressway because of its test bed certification. They wanted to test the technology in realistic traffic conditions and examine the effects of a high temperature environment on the system. The testing was followed by a more formal demonstration event that was attended by Florida Governor Rick Scott and State Senator Jeff Brandes.[89]

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[86] Mixon/Hill 2009b.
[87] Kapsch 2008.
[88] Frey 2014.
[89] Altman 2014.

FLORIDA'S TURNPIKE ENTERPRISE (FTE) ACTIVITIES

Florida's Turnpike Enterprise (FTE) presents an instructive model for one approach for operating public assets as a business. Florida's Turnpike is responsible for all operations on every Florida Department of Transportation (FDOT) owned and operated toll road and bridge. FTE is a part of FDOT, but it operates with a uniquely-defined charter. Created in 2002, the enterprise aims to use private-sector business methods to operate in the public good. In transitioning to this new charter, FTE engaged in intense training sessions to help employees understand and accept the new mentality of operation. FTE's business model, which places more emphasis on paying customers, is feasible given that turnpikes actually have paying customers in the form of motorists paying to use the toll facilities. Florida's Turnpike Enterprise operations are 100 percent self-financed from toll revenues.

Florida's Turnpike installed a fiber optic backbone on its 600 miles of roadway. Additionally, FTE has installed cameras placed every mile and vehicle sensors every half mile. The video cameras help with accident detection, as well as with data augmentation through FTE's routine visual scans. The sensors use radio-frequency identification (RFID) technology and detect vehicle motion and traffic density using radar. These data are then sent to Traffic Management Centers (TMCs), which use the data both for congestion mitigation and safety applications.[90]

Florida's Turnpike has several interesting initiatives aimed at reducing drive times, traffic congestion, and improving safety. The initiatives include Highway Advisory Radio (HAR), Citizen Band (CB) transmission systems, tolling maintenance, the SunPass prepaid tolls program, and the Rapid Incident Scene Clearance (RISC) program.

Sensor data contribute to the HAR program. The data are sent to TMCs which then transmit the data to informational signs along the road. These signs contain radio frequency information for the driver to tune into and change driving patterns as appropriate. This quickly allows the driver to receive the most updated traffic information.[91]

The CB program is intended to assist truck and commercial drivers who frequently rely on CB radios. In practice, this program operates quite similarly

[90] Suarez 2008.
[91] Suarez 2008.

to how the HAR program operates: sensors send data to TMCs, and the TMCs then transmit information over CB radio frequency. The CB program also includes information about weather-related incidents, and FTE uses video cameras for fog and smoke (from wild fires) detection.[92]

To ensure that toll station malfunctions do not cause major delays for drivers, Florida's Turnpike uses a grid system that tracks all the toll stations on a map. Additionally, the grid is able to track toll maintenance vehicles so that the TMC knows where each maintenance person is at any given time. When a toll station is not working properly, the grid indicates the problem, as well as shows where the nearest maintenance person is to fix the problem. This allows for speedy correction of toll collection problems.[93]

The SunPass program participants pre-pay their toll fees and receive a discount for doing so. When they sign up for this service, they attach a transponder to the windshield of their vehicle. This transponder sends radio signals to sensors mounted on the SunPass toll lanes, which then automatically deduct the proper toll amount from the prepaid account.[94]

The RISC program is designed to enable emergency responders to arrive at a scene quickly and begin to clear away any crashes and associated debris. This helps to ensure that the road is once again fully operational as soon as possible.[95]

ITS World Congress Roadside Unit Deployment

Florida is becoming a leader in ITS technologies and as a result, the state hosted both the Transpo2010 Conference[96] and the combined 2011 World Congress in Intelligent Transport Systems and Annual Meeting of ITS America.[97] Transpo2010 was held in Ponte Vedra Beach, Florida and previewed many of the emerging technologies that would later be showcased at the ITS World Congress which was held in Orlando. Roadside infrastructure was deployed for the demonstrations that took place at the ITS World Congress in the fall. Five units were installed along John Young Parkway, 11 units were installed along I-4, and 11 units were installed along

[92] Suarez 2008.
[93] Suarez 2008.
[94] SunPass 2011.
[95] Suarez 2008.
[96] Mobile Synergetics 2010.
[97] Florida DOT 2010.

International Drive/Universal Boulevard. The installations can be seen in Figure 9.

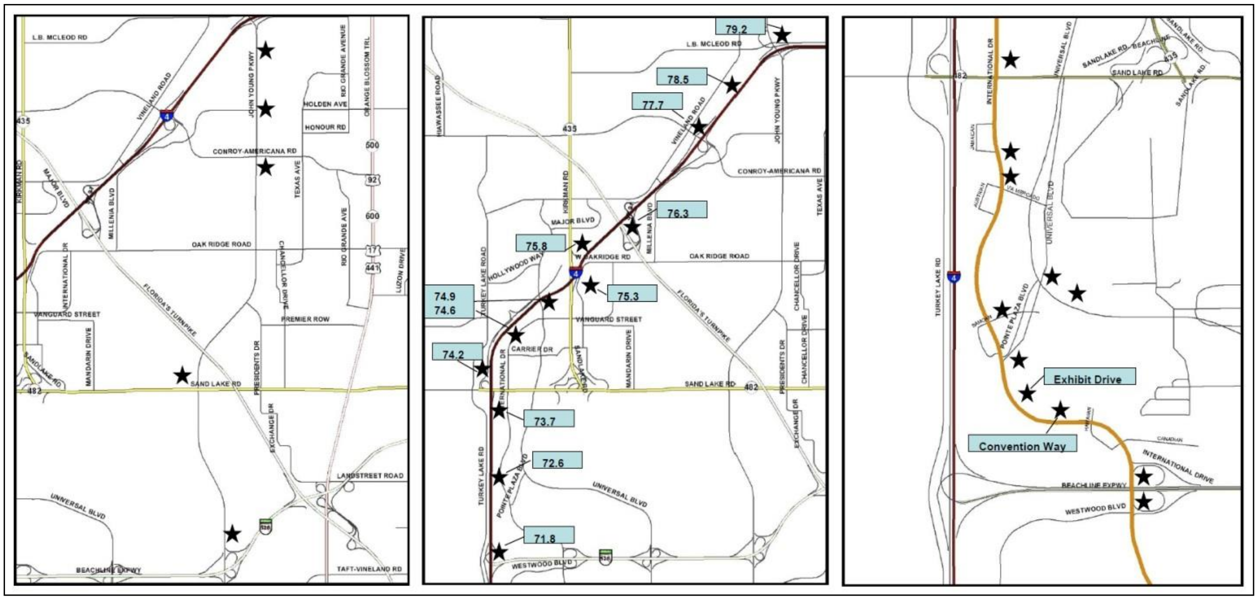

FIGURE 9: ROADSIDE UNIT SITES FOR 18TH ITS WORLD CONGRESS DEMONSTRATIONS[98]

2.7 MINNESOTA

MINNESOTA DEPARTMENT OF TRANSPORTATION (MNDOT) ACTIVITIES

The Minnesota Department of Transportation (MnDOT) has made significant headway in developing and deploying ITS systems. MnDOT's Office of Traffic, Safety and Operations manages most of the Department's ITS activities. This office is located within the central MnDOT office, but works with satellite offices in the eight regional MnDOT districts, as necessary. It also works with the University of Minnesota's ITS Institute, which has numerous programs dedicated to ITS research.

The office used to rely heavily on earmarks, matched with state funds, to finance its ITS program and achieve its goals, but it has received no new earmarks since 2004. Currently, the office is using state and federal construction funds to accomplish its mission, and it has obtained federal support for specific programs, as described in detail below.[99]

[98] Gilhooley 2011.
[99] Starr 2008.

MNPASS PROGRAM

MnDOT developed an innovative program for using market mechanisms to allow access to faster travel lanes, without turning entire roadways into toll roads. This program, called *MnPass*, is designed to charge a fee for faster travel (less congested lanes), without the need to designate the entire road as a toll road. In the Twin Cities metro area, *MnPass* is implemented on 18 miles of high occupancy vehicle (HOV) lanes intended to reduce congestion by encouraging carpooling. Single-occupancy vehicles may also use some of these lanes, called high occupancy toll (HOT) lanes, provided that they pay a toll to do so. Drivers wishing to use the program obtain and place a transponder in their vehicle. As a vehicle enters the HOT lane, an electronic sign indicates the price to drive in that lane at that point in time, and the appropriate fee is deducted from the driver's pre-paid account. The charges vary depending on how relatively busy or free the HOV lane is, and this represents an interesting attempt to harness the power of marginal cost pricing into the freeway management system.[100]

INTELLIDRIVESM FOR SAFETY, MOBILITY, AND USER FEES (ISMUF)

MnDOT's *IntelliDrive*[SM] *for Safety, Mobility, and User Fee Project: Driver Performance and Distraction Evaluation* (ISMUF) project began after the Minnesota legislature authorized $5 million for the project in 2007. Phase I of the project produced a preliminary concept of operations, a set of stakeholder requirements, and a scope of work for Phase II. Phase II began in 2010, and involved a technology demonstration in a real-world setting.[101] The project was completed and a final report was submitted in February 2013. The project used DSRC enabled aftermarket on-board equipment and roadside equipment. Specifically, the applications that were explored in the project included mileage based user fees, in-vehicle signing, curve and intersection collision warnings, and enhanced traveler information using probe vehicles. This project's goal was to evaluate the effectiveness of in-vehicle signing safety and mileage based user fee applications of VII.[102]

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[100] MnDOT 2011a.
[101] Battelle 2013.
[102] MnDOT 2012.

FEDERAL FUNDING FOR PROJECTS

Federal Projects are also an important part of connected vehicle programs in Minnesota. MnDOT has received directed federal funding for several initiatives that contribute to its overall efforts in ITS and connected vehicle-related areas. Indeed, the state has been quite successful (at least up until 2004) in securing such funding beyond its normal annual allocation for USDOT, and these funds have helped extend the state's ITS capabilities. Since 2004, the state has had success with some competitive programs, including the Urban Partnerships program. Federal funding, obtained through earmarks or other means, have led to ITS and connected vehicle projects.

COOPERATIVE INTERSECTION COLLISION AVOIDANCE SYSTEM (CICAS)

MnDOT, working in collaboration with the University of Minnesota's ITS Institute, obtained funding from USDOT RITA under the *Cooperative Intersection Collision Avoidance System* (CICAS) program. Michigan has also been home to CICAS activities, notably those performed by CAMP, a consortium of automotive companies. This program focused on installing signage at rural intersections to alert drivers as to whether or not the gaps in traffic are large enough to enable vehicles to safely cross the intersection.[103] This project built on a previous program called *Intersection Decision Support* that was completed by the ITS Institute.

The *CICAS Stop Sign Assist* (CICAS-SSA) project officially began in 2006. It involved analyzing rural intersection crashes, identifying intersections with high crash rates, and design and simulation of a rural intersection surveillance and data acquisition system. The CICAS-SSA project concluded in 2010. The project was extended for a five-year field-test, which began in 2010. Initial testing was staged near Cannon Falls, Minnesota (US-52 and County State Aid Highway 9) and Spooner, Wisconsin (US-53 and Wisconsin Highway 77). In June 2011, two additional tests began near the Minnesota cities of Marshall (Minnesota Highway 23 and County State Aid Highway 7) and Milaca (US-169 and County State Aid Highway 11). Testing is scheduled to occur at these intersections through 2015.[104]

[103] Starr 2008.
[104] ITS Institute 2012.

Initial results indicated the technology seems to cause confusion with motorists and does not lead to a change in behavior. Researchers tested in-vehicle signage to determine if such warnings would be more effective. The field tests used seven local drivers. The in-vehicle signage system was able to provide timely warning messages and proved viable and reliable. It is not certain whether such a system is better at preventing collisions.[105]

UNIVERSITY OF MINNESOTA - INTELLIGENT VEHICLES LABORATORY

The ITS Institute at the University of Minnesota contains several laboratories that work on ITS-related activities, though most of those laboratories are engaged with driver psychology, urban planning, policy, traffic observation/data gathering, and traffic simulation, rather than CAV-related work. The ITS Institute's Intelligent Vehicles Laboratory conducts a variety of CAV activities in the areas of driver assistive systems; highway and intersection safety; vehicle instrumentation; systems research, design, and development services. In the area of driver assistance systems, the Intelligent Vehicles Laboratory is involved with systems to enhance vision, improve digital mapping, provide collision warnings, automatically avoid collisions, and guide large vehicles in difficult conditions (e.g., in narrow lanes, at night, in inclement weather). In the area of highway and intersection safety, the laboratory has worked on the CICAS project. Under the category of vehicle instrumentation, the laboratory has developed and tested new safety equipment for motor cycles, passenger cars, and commercial vehicles. The laboratory's systems research, design, and development services leverage the laboratory's engineering expertise to adapt and develop technologies such as real time controls, digital mapping, vehicle/object detection systems, wireless communications, and mechanical systems.[106]

[105] Pierce and Smith 2012.
[106] UofM 2014.

2.8 MONTANA

WESTERN TRANSPORTATION INSTITUTE (WTI) ACTIVITIES

The Western Transportation Institute (WTI) was founded in 1994 by Montana State University (MSU), the Montana Department of Transportation, and the California Department of Transportation. WTI's main facility is located next to the MSU campus, where it is a department in MSU's College of Engineering. In 1998, WTI was designated one of the USDOT RITA National University Transportation Centers (UTC), with the recognition renewed in 2005. In addition, WTI is the nation's largest UTC focused on rural transportation. While the focus of WTI is rural transportation issues, the institute also works on projects addressing urban environments and sustainability.[107]

There are eight research groups within WTI: Safety & Operations, Winter Maintenance & Effects, Road Ecology, Infrastructure Maintenance & Materials, Systems Engineering Development & Integration, Mobility & Public Transportation, Logistics & Freight Management, and Transportation Planning & Economics. In its work, WTI often partners with MSU faculty, other universities, transportation agencies, and private sector partners. Besides its research labs on MSU's campus, WTI has other offices in Alberta, Washington, and Montana.

All of the connected vehicle projects documented in Montana were connected to WTI, either as the sole research institution for the project or as a research partner. Generally, these were scoped as rural projects, or have obvious applications for rural areas. The national connected vehicle (formerly VII or *IntelliDrive*) initiative, mobile ad hoc networks, dissemination of traveler information, ant colony optimization (an artificial intelligence algorithm that mimics the behavior of ants searching for food, used in this case for selecting the optimal placement of communications infrastructure), and animal-vehicle crashes (mitigation and road kill documentation) were among the topics covered in WTI projects.[108]

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[107] WTI 2011.
[108] WTI 2011.

2.9 NEW YORK

NEW YORK WORLD CONGRESS VII TEST BED

The New York World Congress VII Test Bed was created for the 2008 World Congress in New York City. There were 23 5.9 GHz locations placed along I-495. Eight of these are integrated with traffic signals. The connected vehicle applications that were used during the 2008 World Congress included travel time information, DMS messages, emissions calculations, intersection safety, transit priority, multimodal information, connected vehicle probe data, work zone safety warning, warning sign enhancement, curve warning, commercial vehicle routing information, and vehicle restrictions. On top of the DSRC roadside units that were already in place, in 2011 an additional 13 DSRC units were deployed along NYS Thruway I-87. By April 2011, two DSRC units were installed along I-90 at Schodack commercial vehicle integrated screening site.[109]

COMMERCIAL VEHICLE INFRASTRUCTURE INTEGRATION (CVII)

The *Commercial Vehicle Infrastructure Integration* (CVII) program was created to demonstrate connected vehicle applications for commercial vehicles in the New York City region. The CVII program developed, tested, and demonstrated commercial vehicle based data communication with 5.9 GHz DSRC roadside and on-board equipment and software. Test corridors included 13 miles along the I-87 Spring Valley Corridor and 42 miles along the I-495 Long Island Expressway. The project received $1.5 million in funding from the I-95 Corridor Coalition for 2007 and 2008 with an additional $400,000 available for 2009 and 2010.[110] The team doing the work was led by Volvo Technology of America, and partners included Kapsch, Booz Allen, Cambridge Systematics, Southwest Research Institute, and Fitzgerald & Halliday. Phase 1 of the program began in May 2009 and finished in May 2011. The final report for Phase 1 was submitted in December 2011. Additional phases had been proposed for the project. A second phase would have included testing heavy-duty to light-duty vehicle driver safety warnings and grade crossing driver warnings. A third phase would have focused on real

[109] IntellidriveUSA 2010a.
[110] I-95 Corridor Coalition 2013.

time routing with driver warnings. There is no indication that there has been further activity on this project since the end of 2011.[111]

2.10 TENNESSEE

OAK RIDGE NATIONAL LABORATORY (ORNL) ACTIVITIES

Oak Ridge National Laboratory (ORNL) in Tennessee is involved in transportation-related activities largely through the National Transportation Research Center (NTRC), which is staffed by both ORNL and University of Tennessee researchers. NTRC studies a wide array of transportation system concerns, including fuels and emissions, geographic information systems, heavy-vehicle safety, electronics, logistics, materials, structures, and systems analysis. NTRC is also home to the National Transportation Research Center, Inc. (NTRCI), a nonprofit organization that houses a federally funded UTC and the Heavy Vehicle Research Center. In addition to the two partners involved in NTRC, NTRCI also includes Battelle Memorial Labs and the economic development wing of Knox County as partners.

Given its connections with both NTRC and NTRCI, ORNL has a particular interest in connected vehicle technologies for heavy trucks (commercial vehicles). The NTRCI UTC funds primarily truck-related research projects at a level of about $750,000 per year, and it has an interest in connected vehicle technology as an approach for enhancing truck safety. Connected vehicles, however, are not the sole, or even primary, focus of research within this UTC. Given its rural surroundings (not counting Knoxville proper), ORNL is also concerned with rural transportation issues, including concerns about difficulties in rural DSRC deployment. Thus, it has looked at cellular technology for traffic probe data collection as an alternative to DSRC or other systems dependent on roadside infrastructure.[112]

While DSRC may not be the focus of ORNL's connected vehicle work, ORNL researchers associated with the NTRC have obtained and tested a number of Technocom DSRC units on heavy trucks. This activity has resulted in some basic familiarity with how DSRC works and in a small number of applications field tested.

[111] I-95 Corridor Coalition 2013.
[112] Knee et al. 2003.

2.11 TEXAS

ACCELERATE TEXAS CENTER

Housed within the Texas A&M Transportation Institute (TTI), the Accelerate Texas Center will provide a common space to develop, test, and implement automated vehicle and related technologies. Its position within TTI will allow the center to have access to some of the top researchers in Texas. The center is being constructed in response to a Texas DOT task force recommendation that the state create a public-private partnership to facilitate transportation-sector technology development, testing, and implementation. The new center was announced in 2014.[113]

AUTONOMOUS MOBILITY APPLIQUE SYSTEM (AMAS) DEMONSTRATION

In January 2014, a Fort Hood, Texas site hosted an AMAS automated convoy system demonstration in an urban environment with multiple vehicles of different models. The demonstration included road intersections, oncoming traffic, stalled and passing vehicles, pedestrians, and traffic circles. Equipment installed in the demonstration vehicles included a LiDAR sensor and a GPS receiver. The project was jointly funded by U.S. Army and Lockheed Martin.[114]

AUTONOMOUS INTERSECTION MANAGEMENT

One project in Texas related to connected and automated vehicles is titled *Autonomous Intersection Management*. The project, which is conducted in the AI Laboratory of the Department of Computer Sciences at the University of Texas at Austin, investigates how intersection control mechanisms can use autonomous vehicles in order to improve both safety and efficiency. The research uses the concept of "space-time reservation" to direct autonomous vehicles through intersections.[115] By using V2I communications capabilities, vehicles can request time slots for using intersections. By using this reservation system, automated vehicles can use the intersection without colliding with each other. The research involved simulation as well as the use

[113] Reed 2014.
[114] Lockheed Martin 2014.
[115] Unnikrishnan 2009.

of actual robots and ultimately a full size vehicle. An image of the simulator interface can be seen in Figure 10. The project has led to numerous publications in the form of workshop papers, technical reports, and journal articles.[116]

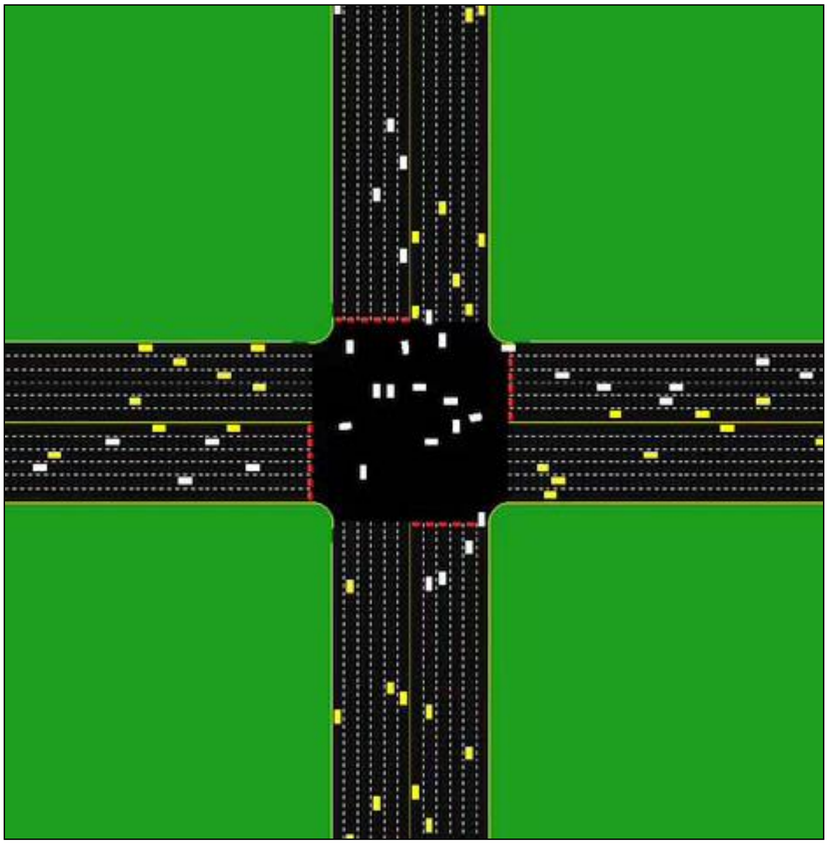

FIGURE 10: IMAGE OF CUSTOM SIMULATOR FOR AUTONOMOUS INTERSECTION MANAGEMENT PROJECT[117]

2.12 VIRGINIA

VIRGINIA CONNECTED TEST BED

The *Virginia Connected Test Bed* was officially launched in early June 2013. The test bed operates as a public-private partnership of the Connected Vehicle-Infrastructure University Transportation Center, which is led by the Virginia Tech Transportation Institute (VTTI).

[116] AIM 2013.
[117] Unnikrishnan 2009.

The project has a $14 million budget, which is funded through a four-year, $6 million federal grant by the U.S. Department of Transportation; a $4 million cost share from the Virginia Department of Transportation, and $2 million from VTTI, with additional funding coming from the other partners.

The test bed involves a total of more than 50 RSEs, including 43 connected intersections, in Merrifield, Virginia, along Interstate 66 and state Highways 29 and 50. The test fleet is composed of 12 vehicles, including six cars, four motorcycles, a bus, and a semi-truck. These vehicles collect information such as acceleration, braking, curve handling, and emissions.[118]

VIRGINIA TECH TRANSPORTATION INSTITUTE ACTIVITIES

The Virginia Tech Transportation Institute (VTTI) is a research organization whose primary goal is to develop the tools and technologies to solve transportation safety and mobility issues. VTTI includes several different centers within its realm, and each has a specific focus within the transportation sector. As lessons on best practices in VII and VII-related areas, two of these centers are relevant:

VIRGINIA SMART ROAD

The *Virginia Smart Road* is a full-scale closed test-bed research facility managed by VTTI but owned and maintained by Virginia Department of Transportation (VDOT). The *Smart Road* is a 2.2 mile two-lane road that will eventually be made part of the public transportation system surrounding Blacksburg, Virginia.[119] The *Smart Road* offers many different simulations and services for interested parties to test their equipment. Examples include:[120]

- Weather-making capabilities: Researchers can make rain, snow, wind, and ice
- Variable lighting test-bed: Can reproduce 95 percent of all lighting situations a driver may encounter on U.S. roads
- Pavement markings
- On-site data acquisition system
- Road weather information systems

[118] CVI-UTC 2013.
[119] VTTI 2011a.
[120] VTTI 2011a.

- Differential GPS system
- Road access and surveillance
- Signalized intersection: A reconfigurable intersection that consists of two high-speed and two low-speed approaches. It is also equipped with customized controllers, vehicle presence sensors, and wireless communications.

In addition to the services listed above, the *Smart Road* features four hundred electronic sensors buried in the pavement that can determine the weight and speed of vehicles, as well as the stress on the pavement. The road is equipped with an advanced communication system including a wireless local area network (LAN) that works with a fiber optic backbone. The network interfaces with several on-site data acquisition systems and road feature controls, and also has the ability to transfer data between the vehicle, research building, and infrastructure within the road.[121] The *Smart Road* has many applications for companies and organizations interested in testing and evaluating various items.

CENTER FOR VEHICLE-INFRASTRUCTURE SAFETY AND THE CENTER FOR ADVANCED AUTOMOTIVE RESEARCH

The focus of the Center for Vehicle-Infrastructure Safety at VTTI was cooperative safety systems, intersection collision avoidance, roadway delineation, and roadway and vehicle lighting.[122] Two different research groups, the Cooperative Safety Systems (CSS) group and the Lighting and Infrastructure Technology (LIT) group, helped the center achieve its goal of providing solutions to real-world issues. The CSS group focused on algorithms, warning methods, and driver behavior associated with cooperative safety systems at traffic signal and stop-controlled intersections.[123] The LIT group investigated how different lighting techniques and applications affect driver safety. It also studied road-user safety in adverse weather conditions. Work included the CICAS for Violations (CICAS-V) program, which aimed to reduce and prevent vehicle crashes at intersections by providing warnings to violating drivers.[124] This work has resulted in a number of papers related to

[121] VTTI 2011a.
[122] VTTI 2011b.
[123] VTTI 2011b.
[124] VTTI 2011b.

intersection violation warning systems and intersection decision support systems.[125] The Center for Vehicle-Infrastructure Safety has been replaced by the Connected & Advanced Vehicle Systems group within the Center for Advanced Automotive Research, which carried on CAV research at VTTI.

In addition to CICAS-V work, the Center for Advanced Automotive Research has completed work relating to speed limit, cross traffic, and curve warning advisories; human factors research for CAV applications; and research into connected motorcycle crash warning interfaces and system performance, and connected vehicle interface requirements. The center also conducts analysis work to support the *USDOT Safety Pilot Model Deployment* and *Driver Clinics*.[126] Recently, VTTI was awarded a NHTSA contract worth up to $25 million to study topics related to automated vehicles. Under that contract, VTTI will study automated vehicle electronic systems, protection from vehicle hacking, and safety issues, including fail-safe systems.[127]

VTTI's *Automated Vehicle Systems* (AVS) initiative involves research related to automation in both light-duty and heavy-duty vehicles. Completed projects include *Human Performance Evaluation of Light Vehicle Brake Assist Systems* and *Assessment of a Drowsy Driver Warning System for Heavy Vehicle Drivers*. Current projects include *Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts*, *Evaluation of Heavy Vehicle Collision Warning Interfaces*, and *Field Study of Heavy-Vehicle Collision Avoidance Systems*.[128]

UNIVERSITY OF VIRGINIA CENTER FOR TRANSPORTATION STUDIES ACTIVITIES

The University of Virginia is also actively involved in researching connected vehicle technologies through their Center for Transportation Studies. Among the research are several connected vehicle projects.

One project that concluded in 2007 was *Real-Time Accident Management across Multiple Agencies Using Ad-Hoc Wireless Networks*. The project proposes a system of ad-hoc wireless networks which will create real-time accident information sharing between the vehicles involved in an accident,

[125] Neale et al. 2006 and Neale et al. 2007.
[126] VTTI 2013.
[127] VTTI 2014.
[128] VTTI 2013.

rescue squads, a crash evaluation system, the Virginia Department of Transportation, hospitals, police, and other parties. The system is initiated when a vehicle crashes, automatically triggering the emission of accelerometer data wirelessly to the remote vehicle crash model facility. There, vehicle models interpret the data and determine the severity of the accident and likely injuries, sending the data to VDOT, rescue squads, and hospitals, which then use the information to determine an appropriate response. This information can be used not only to improve response time for first responders, but also by VDOT to manage traffic (through variable message signs, signal timing, reversible lanes, etc.), reducing congestion and further improving accident response time.[129]

Another project conducted by the Center for Transportation Studies completed in 2009 was the *Research Foundation to Support Cooperative Infrastructure/Vehicle Surface Transportation Control/Management*. This project's key objectives were to develop an integrated modeling environment that allows existing component models to emulate a cooperative infrastructure/vehicle control/management system, create and explore cooperative control strategies, and evaluate tradeoffs relating to transportation system performance measures.[130]

A recently finished project, *Advanced Freeway Merge Assistance: Harnessing the Potential of IntelliDrive*, attempted to develop a connected vehicle simulation environment capable of replicating vehicular movements, incorporating wireless communications—Wireless Access in Vehicular Environments (WAVE)/DSRC standards—and simulate message sets (Society of Automotive Engineers (SAE) J2735 standard).[131] Additional simulations could be conducted in further research. Success in simulation testing could result in prototype testing on a closed course. Course testing would be used to identify technical questions, assess human factors, and support technology transfer.[132] The study began in October 2009 and ended in June 2012. The project was funded by the FHWA EAR program with a budget of $500,000.[133]

Several projects at the University of Virginia have been part of the *Cooperative Transportation Systems Pooled Fund Study*. The study was

[129] Kripalani and Scherer 2007.
[130] Smith 2009.
[131] Smith and Park 2011.
[132] FHWA 2011.
[133] Ferlis 2012.

created by a group of transportation agencies. Besides Virginia DOT, the participating agencies are FHWA, and the departments of transportation in California, Florida, Michigan, New York, Texas, and Washington. Virginia DOT is the lead agency, with the University of Virginia Center for Transportation Studies serving as technical leadership provider.[134] The current pooled study projects include *Multi-Modal Intelligent Traffic Signal System: Development of Concept of Operations, System Requirements, System Design and a Test Plan*; *Traffic Management Centers in a Connected Vehicle Environment*; and *5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application*. Previously completed projects under the Cooperative Transportation Systems Pooled Fund Study include *Aftermarket On-Board Equipment for Cooperative Transportation Systems: Enabling Accelerated Installation of Aftermarket On-Board Equipment for Cooperative Transportation Systems*; *Certification Program for Cooperative Transportation Systems: Preparing to Develop a Standards Compliance and Interoperability Certification Program for Cooperative Transportation Systems Hardware and Software*; *IntelliDrive Traffic Signal Control Algorithms*; *Investigation of Pavement Maintenance Support Applications of IntelliDrive*; and *Investigating the Potential Benefits of Broadcasted Signal Phase and Timing Data under IntelliDrive*.[135]

2.13 CANADA

ONTARIO AUTOMATED DRIVING PILOT

In December 2013, the Ministry of Transportation (MTO) issued a notice informing Ontario residents that a proposal to test automated vehicles safely on public roads in Ontario had been submitted. The notice gave the public 45 days to submit feedback on the proposal. The proposed pilot would last for five years, and the proposal set requirements for drivers, vehicles, and testing.[136]

ITS FOR RAPID BUS SERVICE

While the U.S. has been the location for the majority of connected vehicle work in North America, Canada also is working on CAV projects. The

[134] Center for Transportation Studies 2013.
[135] Center for Transportation Studies 2013.
[136] MTO 2013.

Intelligent Transportation Systems in 98 B-Line Rapid Bus Service: Advanced Technology at Work project improves bus efficiency. The 98 B-Line is 16 kilometers long with as many as 24 buses in operation at the same time. Busses stop every 5 to 6 minutes in peak periods and every 15 minutes in the evening. Among the measures taken to increase transit efficiency, traffic signals have been installed that give priority to B-Line buses when they are behind schedule. Most of the signalized intersections (87 percent) along the 98 B-Line can give priority to buses by minimizing the need to stop or the duration of red signals. An on-board computer sends a signal using bus-mounted transponders to request priority from roadside traffic signal controllers.[137]

The ITS system for the buses uses automatic vehicle location and schedule adherence monitoring which is enabled by a differential global positioning system and the on-board computer that has schedule information and can process GPS data. Bus operators can view their real-time schedule adherence on a mobile data terminal. The terminal also supports two-way messaging between buses and the control center. The system allows transit controllers to identify and respond to traffic conditions and operational needs by communicating with drivers.

Real-time information on bus arrivals is displayed on buses and at stations through dynamic message signs and speakers that announce the station being approached. The station information is determined using information from the GPS unit. Dynamic message signs installed at stations, such as the one shown in Figure 11, display arrival times for the next B-Line buses approaching the station, based on real-time vehicle positions and speeds. Such applications are becoming common for bus systems. For instance in Ireland, Dublin's *Automatic Vehicle Location System* and in Michigan, the University of Michigan's *Magic Bus* provide real-time bus location data and estimated arrival times to passengers.[138]

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[137] Kitasaka 2011.
[138] NTA 2011 and University of Michigan 2011.

FIGURE 11: REAL-TIME PASSENGER INFORMATION DISPLAY AT BUS TERMINALS[139]

COMMERCIAL VEHICLE BORDER WAIT TIME PROJECT

Transport Canada invested in a smarter border in Ontario by conducting the Commercial Vehicle Border Wait Time Project. The project was a collaboration of Transport Canada and trucking associations. The goal of the project was to estimate commercial border crossing times by gathering data from trucks at five border crossing locations along the Ontario border. Monitoring began in 2006 and continued through 2010.

At the Ontario border crossings, Bluetooth readers were deployed. These readers could read and record digital signals from a distance of a ten meters. The acquired data was sent over the Internet. The readers can get signal information from all Bluetooth-enabled cell phones, hands-free headsets, and car in-dash units, which continuously emit a signal when turned on. This means that every Bluetooth device that passed a reader created a data entry with a time stamp and unique identifier specific to that device. The series of deployed Bluetooth readers were used to measure queue and crossing times for border traffic.[140]

[139] Kitasaka 2011.
[140] Sabean and Jones 2008.

By the end of the project, nearly 650,000 observations had been collected from GPS data logs and Bluetooth devices. More than 330,000 of these records were from commercial vehicles at Ontario's four major border crossings, and more than 310,000 observations came from passenger vehicles crossing through the Detroit-Windsor Tunnel.[141] These observations can be used to improve traffic management and border efficiency.[142]

[141] Shallow 2011.
[142] Shallow 2008.

3 CONNECTED VEHICLE EFFORTS IN ASIA AND OCEANIA

Japan has been the home for the majority of connected vehicle research and infrastructure deployment in Asian and Oceania, 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. Companies that have gained experience in connected vehicle technologies (mostly in Japan, but also in Taiwan and Australia) have applied their knowledge to aiding research and deployment efforts in other countries as well.

Figure 12 shows the geographical distribution of projects throughout Asia and Oceania.

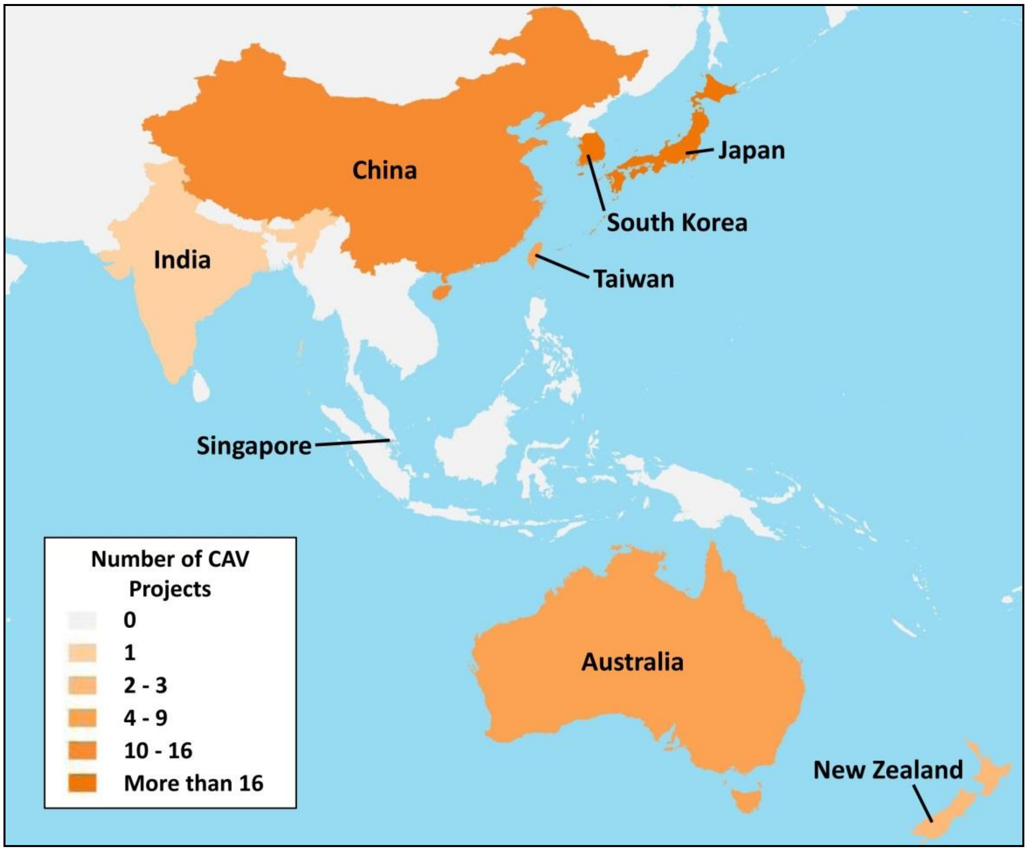

FIGURE 12: CONNECTED VEHICLE PROJECTS IN ASIA AND OCEANIA[143]

[143] CAR 2014.

3.1 JAPAN

HISTORY OF ITS IN JAPAN

Japan has a long history of ITS and connected vehicle technology. Early research and development on Japanese ITS systems included work on the *Comprehensive Automobile Traffic Control System* (CACS) which began in 1973, the *Road Automobile Communication System* (RACS) which began in 1984, the *Advanced Mobile Traffic Information and Communication System* (AMTICS) which began in 1989, and the *Advanced Safety Vehicle* (ASV) which began in 1991.[144]

VEHICLE INFORMATION AND COMMUNICATION SYSTEM (VICS)

These projects led to the development of the *Vehicle Information and Communication System* (VICS). Three government agencies (Ministry of Construction, National Police Agency, and the former Ministry of Post and Telecommunications) began collaborating on VICS in 1990, and in 1991, began working with industry. In 1996, VICS service began. VICS delivers traffic and travel information such as traffic congestion data, data on availability of service and parking areas, and information on road construction and traffic collisions to drivers. It can be transmitted using IR; microwaves on industrial, scientific, and medical (ISM) radio band (2.4 GHz); or Frequency Modulation (FM). VICS can be displayed as simple text data, simple diagrams, or maps on navigation units.[145]

ITS JAPAN

The Vehicle, Road and Traffic Intelligence Society (VERTIS) was formed in 1994 and brought together government entities, university experts, industry, and associations. In 1996, the overall framework for ITS in Japan was created. VERTIS became ITS Japan in 2001 and also in that year, the IT Strategic Headquarters was formed as part of the government of Japan's Cabinet.[146] The purpose of this headquarters is to help Japan keep pace with the telecommunication technology and to promote advanced information and telecommunications networks.

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[144] MLIT 2007.
[145] VICS 2011.
[146] Cabinet Secretariat 2011.

ELECTRONIC TOLLING

Electronic toll collection (ETC) service in Japan began in 2001. The toll service uses a 5.8 GHz antenna to manage transactions. As of 2014, 90 percent of all toll transactions were conducted using ETC.[147] On board equipment originally cost around US$400 when the service began, but as of 2008, the cost was around US$150. Some models of Japanese cars come with the on-board unit (OBU) for ETC already installed. Over 40 million toll transponders are in use in Japan (up from 24 million in 2008) and there are around 5.6 million toll transactions per day. Japan uses one standard electronic toll system for the whole country so one transponder and payment card can be used on any toll network in the country.[148] In addition, almost all Japanese highways are toll roads, making this system rather ubiquitous.[149]

JAPAN'S ITS PLAN

In January of 2006, the IT Strategic Headquarters developed a document entitled the *New IT Reform Strategy*, which outlines the overall IT plan. This plan discusses collaboration between the public and private sectors to "realize advanced ITS that can integrate pedestrians, roads, and vehicles and lead Japan into the world's safest road traffic society." The goals of this plan are to reduce traffic fatalities and serious injuries by deploying *Driving Safety Support Systems* (DSSS) and to reduce the time between when an accident occurs and when the person is admitted to a medical facility.

ITS SPOT SERVICE

In March 2011, Japan began a nationwide *ITS Spot Service*. ITS Spots are roadside units that can transmit and receive messages. So far, 1,670 Spot units have been installed across the country, and more than 220,000 OBUs have been sold.[150] These Spots can be used to inform drivers of road obstacles, weather events, or other hazardous conditions. Figure 13 depicts the *Spot Service* infrastructure unit (1) and in-vehicle unit (2).

The three basic services provided by ITS Spots include dynamic route guidance, safety driving support (warnings), and electronic toll collection. The Spots also collect probe vehicle data, and by early 2013, nearly three million

[147] Suzuki et al. 2014.
[148] Ogata 2008.
[149] Fukushima 2011a.
[150] Suzuki et al. 2013, Suzuki et al. 2014.

vehicle kilometers traveled worth of probe data was being collected per month.[151]

In one case where this technology has been deployed near a curve on a major expressway running through Tokyo, accidents have been reduced by 60 percent. Another example of the usefulness of *Spot Service* occurred after the earthquake that hit Japan in March 2011. Using data from the *Spot Service*, ITS Japan was able to obtain information on which roads were closed, which was then used to assist in rescue operations. Warning information was also broadcast from ITS Spots immediately following the earthquake.[152]

FIGURE 13: ITS SPOT SERVICE IN JAPAN[153]

[151] Suzuki et al. 2013.
[152] Japan 2012.
[153] Japan 2012.

DRIVING SAFETY SUPPORT SYSTEMS (DSSS), ADVANCED SAFETY VEHICLE (ASV), AND SMARTWAY

The DSSS system is a typical connected vehicle system in which vehicles obtain information from roadside units (RSUs), other vehicles, or pedestrians, and those devices can also pass information back to the vehicle enabling a driver to respond to traffic conditions. The V2I system is based on the same IR light beacon RSUs used for VICS.[154]

Within the National Police Agency of Japan, the Universal Traffic Management Society of Japan (UTMS) is working on the DSSS project. The project has allowed automakers, including Honda, Toyota, Nissan, Mitsubishi, and Mazda, to use public roadways to test inter-vehicle and road-to-vehicle communications. As part of deployment, the National Police Agency of Japan planned to install RSUs at around 1,000 dangerous intersections across Japan but in mid-2009, a regime change led to police infrastructure budget cuts, shelving many of the RSU plans. Some intersections in Tokyo and Kanagawa were still approved, and automotive manufacturers have been lobbying to get funding for RSUs back.[155]

Honda began its DSSS testing with two vehicles, a Forza scooter and an Odyssey, to verify inter-vehicle and road-to-vehicle communication functions (ASV-4), DSSS functions, and to collect and present data to contribute to evaluating system effectiveness. Overall, Honda is hoping to prevent rear-end collisions, collisions involving a vehicle turning into oncoming traffic, and collisions from vehicles passing each other. After completing these initial tests, Honda participated in joint government and private-sector large-scale verification testing from March 24 to March 28, 2008 in Utsunomiya City, Tochigi Prefecture, Japan.[156] More recently, Honda demonstrated its DSSS and ASV equipped vehicles, including an Odyssey minivan, Forza motorcycle, and IT Mopal 4 electric cart. These demonstrations occurred while Honda participated in *ITS-Safety 2010*, a large-scale verification testing project for DSSS, ASV, and *Smartway*. ITS-Safety 2010 ran from December 2008 to March 2009 and had the goal of achieving practical application of vehicle-infrastructure cooperative systems by March 2011.[157]

[154] European Commission 2009 and Fukushima 2011a.
[155] Fukushima 2011a.
[156] Honda 2008.
[157] Toyota 2009.

Toyota has also participated in DSSS tests on public roads. It used 100 vehicles equipped with drive recorders to determine whether communication devices on traffic signals and stop signs affect traffic accident rates at high-risk intersections. To test this, Toyota used IR beacons placed at five intersections that communicate with on-board navigation display systems in the participating vehicles. These tests began in December of 2006 were completed in June of 2007.[158] Toyota participated in additional tests in early 2009 which were part of the *ITS-Safety 2010* intelligent transport systems testing program.[159] They involved 200 participants, half of which were Toyota employees, and half of which were members selected from the general public. Toyota demonstrated ITS technologies that it developed at a public event hosted by the Universal Traffic Management Society of Japan in April of 2009.

In January of 2009, Nissan announced that it would participate in the *ITS-Safety 2010* tests. Nissan's advanced vehicle-to-infrastructure communications system was among the items to be tested at the event. The system had been undergoing testing within the company since 2006 with the participation of 2,000 people.[160] Mazda was also a demonstration participant, showing the Mazda MPV and Mazda Atenza and had been involved in validation trials for ITS technologies on public roads since 2006.[161] Other *ITS-Safety 2010* demonstration participants included Mitsubishi, NEC Corporation, Panasonic, Yamaha, Kawasaki, and Suzuki.[162]

The *Smartway 2007* project was designed to create a road system that could exchange information among cars, drivers, pedestrians, and users using DSRC.[163] It was originally a field test of various road warning applications, such as merge assist, curve warning, congestion warning, and weather information. In the original test, sensors were placed in vehicles which received input from the applications on the road. In 2008, there were additional field tests, with the intent of leaving the infrastructure in place as was the case with the 2007 test. In 2009, these test beds were expanded and made available to the public.[164] By 2010, around 1,600 ITS Spot units were

[158] Toyota 2006.
[159] Toyota 2009.
[160] Nissan 2009.
[161] Mazda 2009.
[162] Nippon News 2009.
[163] Harris 2010.
[164] IntelliDriveUSA 2010b.

installed with most located on expressways. For instance, on the Tokyo Metropolitan Expressway, 32 Spot units were installed in 2009 and another 166 units were installed in 2010. The plan is to install a unit every 10 to 15 kilometers, and every four kilometers on urban expressways.[165] As of November 2010, Toyota, Pioneer, Mitsubishi Electric Co., Panasonic, and Mitsubishi Heavy Industries had released systems that interact with ITS Spot units.[166] Since then, several other automakers (e.g., Audi, Citroen, Mazda, Mercedes-Benz, Mitsubishi Motors, Nissan, Peugeot, Suzuki, and Volkswagen) and navigation system manufacturers (e.g., Alpine and Clarion) have released systems.[167]

Though the three systems tested at the *ITS-Safety 2010 Industry-Wide Tests* were all connected vehicle systems, they are uniquely different. DSSS uses V2I communications with vehicle sensors and optical beacons sending information from infrastructure to drivers, warning them of potentially dangerous situations. Features of DSSS include alerts for traffic signals and stop signs; rear-end, crossing, and turning collision avoidance; and information on other vehicles turning and changing lanes. The ASV system uses both 5.8 GHz DSRC and 700 MHz communications for V2V communications to warn drivers of potential collisions with other drivers.[168] Features of ASV include rear-end, crossing, and turning collision avoidance and information on nearby emergency vehicles. *Smartway* uses 5.8 GHz DSRC V2I communication to gather information about congestion or road obstacles and relays that information to other vehicles, helping them avoid congested areas. *Smartway* features include information on obstacles and conditions ahead, merge assist, and location information via electronic signs.[169] Figure 14, Figure 15, Figure 16 diagrammatically display the function of DSS, *Smartway*, and ASV respectively.

[165] Harris 2010.
[166] Adams 2010.
[167] Suzuki et al. 2013.
[168] Fukushima 2011a.
[169] Nissan 2009.

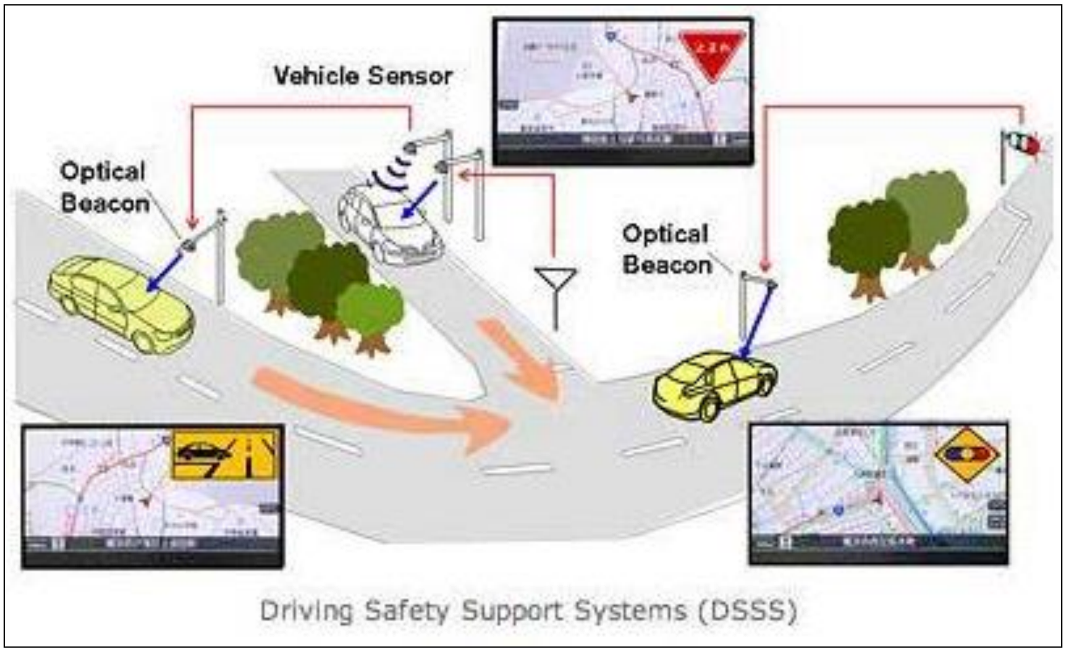

FIGURE 14: COMPONENTS OF THE DRIVING SAFETY SUPPORT SYSTEMS[170]

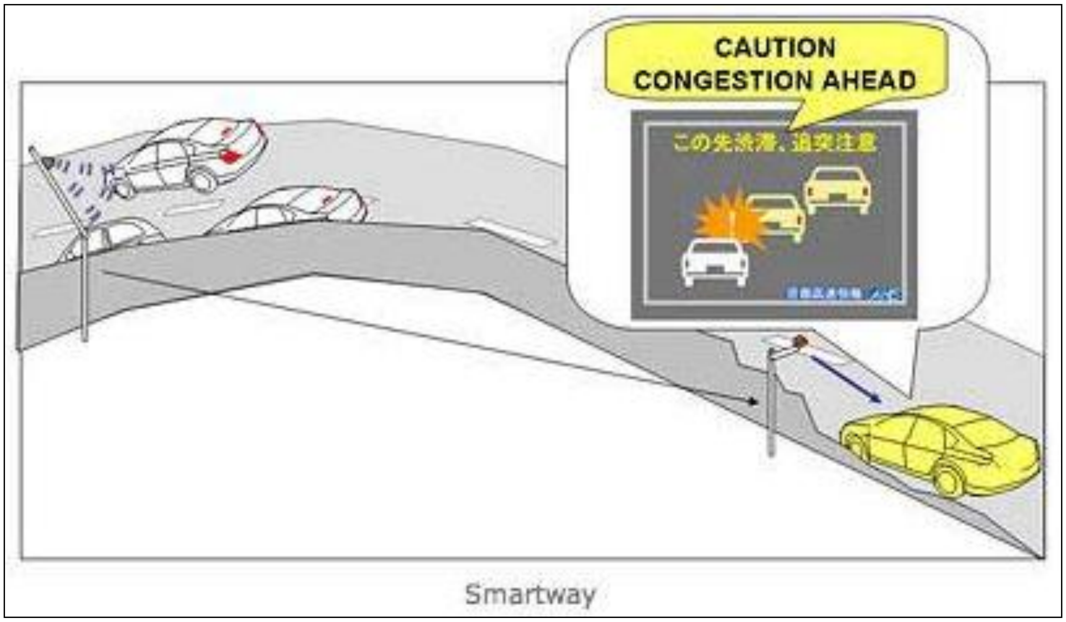

FIGURE 15: DIAGRAM OF SMARTWAY SYSTEM[171]

[170] Nissan 2009.
[171] Nissan 2009.

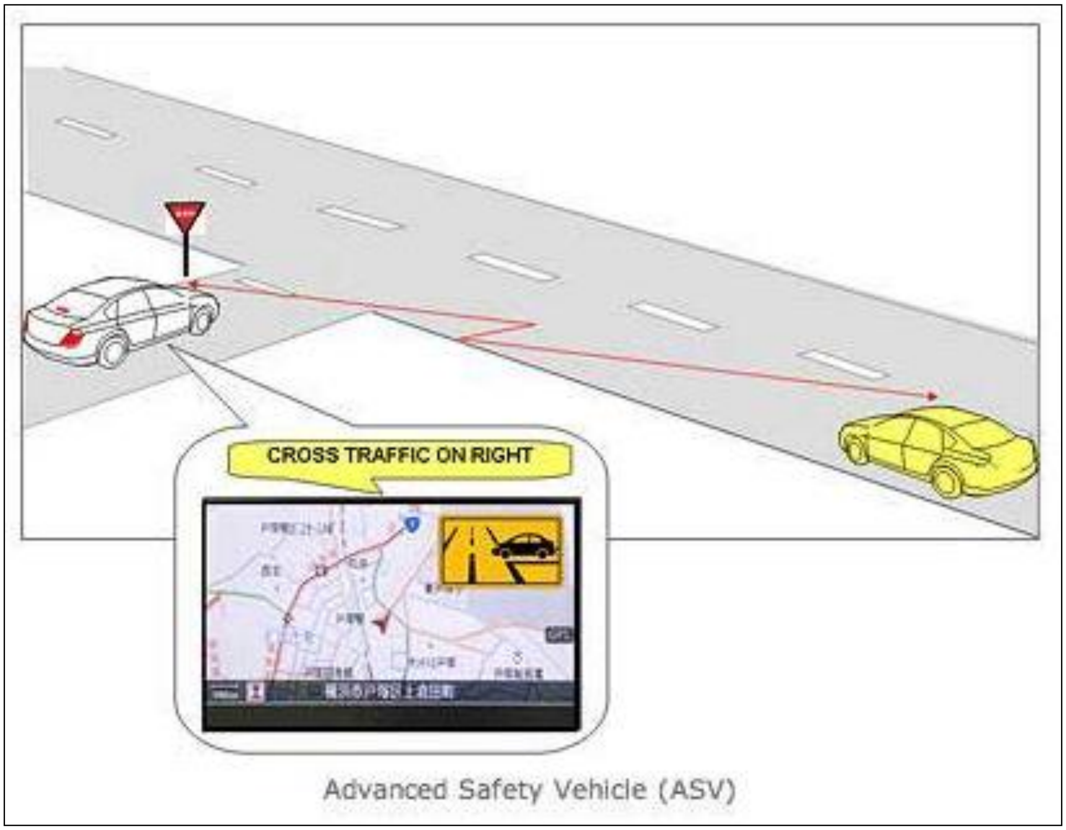

FIGURE 16: DIAGRAM OF ADVANCED SAFETY VEHICLE SYSTEM[172]

START ITS FROM KANAGAWA, YOKOHAMA (SKY) PROJECT

The *Start ITS from Kanagawa, Yokohama* (SKY) project was another Japanese initiative. Project goals were to ease traffic congestion and reduce accidents. The project began in October 2004 in Yokohama, Japan and focused on collecting real world vehicle data from other users. Nissan, Panasonic, NTT Docomo, and Clarion worked with various units of the Japanese government on this project. Testing occurred from 2006 through 2009 and public service for intersection collision avoidance was made available in July 2011.[173] A similar Nissan effort is underway called *Carwings*, which connects mobile phones and navigation systems to promote fuel-efficient driving and ease congestion. Like the SKY project, *Carwings* obtains information from other users to plot energy efficient driving routes.[174]

[172] Nissan 2009
[173] Fukushima 2011b.
[174] Nissan 2011a.

CARWINGS PROJECT

In 2008, Japan gave the annual Energy Conservation Prize to Nissan's *Carwings*, an on-board computer navigation system. On top of simply navigating, the system tracks fuel efficiency and provides suggestions on how to improve fuel efficiency. The service was also provided in the United States for owners of the Nissan Leaf. In the United States, the system tracks energy usage information and displays daily, monthly, and annual reports, which include distances traveled and energy consumption.[175] Besides just tracking information, *Carwings* sends and receives data though a built-in general packet radio service (GPRS) radio. Using information received through the communications device, it tracks the driver's efficiency ranking compared to other Leaf drivers globally and regionally.[176] The U.S. version of *Carwings*, which debuted in 2010, does not yet have the same ability to leverage a readily available nationwide database of real-time traffic conditions as it has in Japan. This database is operated by the Japanese Transportation Ministry and the police, and an equivalent does not currently exist in the United States. In 2014, Nissan discussed expanding Carwings service to include battery health monitoring for the Nissan Leaf models equipped with Carwings.[177]

ENERGY ITS PROJECT - AUTOMATED TRUCK PLATOON

As part of its Energy ITS Project, the New Energy and Industrial Technology Development Organization (NEDO) in Japan tested platoons of trucks that use radar, LiDAR, cameras, and 5.8GHz wireless communications to remain in formation.[178] In the *Automated Truck Platoon* system, the lead vehicle is driven by a professional driver, but the following vehicles are unmanned. Project partners included Mitsubishi Electric, NEC, Oki Electric Industry, Denso, Hino Motors, the University of Tokyo, and Nihon University.[179]

The project began in 2008 with a budget of ¥4.4 billion. In September 2010, NEDO ran road tests of platoons at 80 kilometers per hour with a following distance of 15 meters between vehicles. Recent tests in 2013 used platoons at the same speed, but with a following distance of only 4 meters. Shorter following distance reduces air resistance and improves fuel economy of the

[175] Yoney 2010.
[176] Austin 2011.
[177] Schweinsberg 2014.
[178] Kariatsumari 2013.
[179] Owano 2013.

vehicles. NEDO is working to produce a practical version of the system by 2020. Similar platooning tests have been run in Europe under the *Development and Analysis of Electronically Coupled Truck Platoons* (KONVOI) and *Safe Road Trains for the Environment* (SARTRE) projects. The final report for the project was presented in Fall 2013.[180]

NISSAN AUTOMATED VEHICLE PUBLIC ROAD TESTING

In November 2013, Nissan was the first automaker to conduct automated vehicle testing on public roads in Japan. The test occurred on the Sagami Expressway in Kanagawa prefecture, near the Sagami Robot Industry Special Zone, which hosts robotics projects such as life-assist robots, artificial intelligence, and control systems. The prototype used for testing was a Nissan Leaf that was equipped with technology to detect road condition and operate the car's main controls (i.e., steering, braking and acceleration). On the expressway, the prototype can merge into traffic, change lanes, and maintain a safe operating distance from other vehicles.[181]

3.2 CHINA

STAR WINGS PROJECT

Beijing Transportation Information Center and Nissan developed *Star Wings*, a navigation system designed to reduce congestion and decrease travel times. Using probe data collected from 10,000 taxis, the system aggregates real-time traffic information that is then transmitted to vehicles to plan the fastest route and avoid congested areas.[182] Research suggests it can reduce travel time by 16 to 20 percent.[183] Star Wings service first became available in Beijing in 2008, just months before the Olympic Games were held.

NEW TRAFFIC INFORMATION SYSTEM MODEL PROJECT

More recently, Nissan and China have partnered to pilot a route guidance system through their work on *New Traffic Information System Model Project*, which was launched in the Wangjing district of Beijing City in January 2012. The project involves the use of 12,000 user-equipped portable navigation

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[180] Tsugawa 2013.
[181] Nissan 2013a.
[182] DueMotori 2007.
[183] Nissan 2008.

devices and 600 Nissan vehicles equipped with devices to record detailed driving data.[184] The technology was expected to reduce traffic congestion and greenhouse gas emissions, and after one year of testing, Nissan released results showing that the use of its dynamic route guidance system reduced average travel time by 5.1 percent and increased fuel economy by 7.6 percent. In addition, Nissan's Eco-Drive Management System helped increase fuel economy by 6.8 percent.[185]

REAL-TIME INFORMATION

In January 2013, INRIX, a global leader in traffic information and driver services, announced that it would partner with CenNavi, a leading traffic information provider in China, to deliver improved real-time and predictive traffic information in 28 cities across China.[186] Information will be made available in vehicles, on smartphones, and through broadcast news reports. The information will also be used in intelligent transportation systems where it will be used to manage traffic congestion.

CONNECTED TAXI APPLICATIONS

There are several cab-calling applications for mobile devices that are available in Beijing. As of March 2013, the popular application, "Didi Taxi," is in use by more than 600,000 users and 12,000 drivers, nearly one fifth of Beijing's approximately 66,000 taxis. The application launched just five months earlier in September 2012 with just 200 test cabs and a few hundred users.[187] The application records the user's current location and destination, then it sends this information to taxi drivers who can respond to the request. The application allows users to bid an extra amount above the metered fare for the taxi, a feature that can be used during high traffic periods to more quickly secure a taxi.

[184] Nissan 2011b.
[185] Nissan 2013b.
[186] INRIX 2013.
[187] Lu 2013.

GENERAL MOTORS AND SHANGHAI AUTOMOTIVE INDUSTRY CORPORATION (SAIC) AUTOMATED VEHICLE ACTIVITIES

In 2010 the General Motors Electric Networked-Vehicle (EN-V) concept was displayed at the Shanghai Expo (Figure 17).[188] The vehicle was jointly designed by General Motors and Shanghai Automotive Industry Corporation (SAIC). The EN-V is capable of being driven normally or using an automated driving mode, in which the vehicle uses sensors and computing power to direct itself to the desired destination. The EN-V can also park itself and be summoned from its parking space using a mobile device.

In April 2011 General Motors agreed to integrate EN-Vs into the Tianjin Eco-City, and in June 2012, the company delivered its first vehicle.[189] The Tianjin Eco-City is the first of several cities worldwide where the EN-V will be field-tested. In June 2014, GM brought the Chevrolet EN-V 2.0 to the Tianjin Eco-City for testing. The vehicles will be deployed in the Eco-Business Park and the National Animation Industry Park.[190]

FIGURE 17: GM'S EN-V 2.0 ELECTRIC NETWORK-VEHICLE IN THE ECO-BUSINESS PARK OF THE TIANJIN ECO-CITY[191]

AUTOMATED "NEW ENERGY" VEHICLES PARTNERSHIP

In February 2014, the Hefei Institute of Physical Science (part of the Chinese Academy of Sciences) and the Automotive Engineering Institute of

[188] Economist 2010.
[189] GM Media 2012.
[190] SSTEC 2014.
[191] SSTEC 2014.

Guangzhou Automobile Group Co. announced they would partner to develop automated "new energy" vehicles. The term new energy vehicles is used in China to refer to electric, plug-in hybrid, and fuel-cell vehicles (and sometimes compressed natural gas vehicles). In 2013, Guangzhou Automobile Group Co. announced that it had created a self-driving system and a concept automated vehicle. Its partnership with the Hefei Institute will allow the company to continue development of such systems.[192]

3.3 SINGAPORE

REAL-TIME INFORMATION

In 1998, Singapore installed an electronic congestion pricing system. Ten years later, Singapore launched a parking guidance system. By 2010, the country had 5,000 probe vehicles to generate and disseminate real-time traffic information. The information generated by the probes is sent to Singapore's highly sophisticated and integrated backend, the *i-Transport System*, which uses both historic and real-time traffic data.[193]

In addition to probe data, the *i-Transport System* is connected to the Expressway Monitoring Advisory System (EMAS), Green Link Determining System (GLIDE), Parking Guidance System (PGS) and the TrafficScan.[194] The collected data from these systems is primarily used for traffic monitoring and incident management as well as traffic analysis and planning. Singapore also makes the real-time data available to industry. The available data includes webcam images, textual traffic information (e.g., incidents, traffic speeds, estimated travel times, and construction locations), and parking availability in major parking lots.[195]

Throughout Singapore, adaptive computerized traffic signals have been deployed. In addition, at most bus stops, there are traffic information data terminals that show real-time bus status.[196]

[192] Zheng 2014.
[193] Ezell 2010.
[194] LTA 2013.
[195] LTA 2013.
[196] Ezell 2010.

AUTOMATED ELECTRIC VEHICLES PARTNERSHIP

A partnership similar to the one between Hefei Institute and the Guangzhou Automobile Group in China has been formed between BYD and Singapore's Agency for Science, Technology, and Research (A*STAR) Institute for Infocomm Research (I^2R). The two organizations are working on automated electric vehicles.[197] The partnership will build on BYD's electric vehicle expertise and I^2R's expertise in in integrating automated vehicle technologies to deploy more than 100 automated electric vehicles for testing purposes. The partnership was announced in January 2014. As part of the project, BYD will invest S$24 million ($19.2 million) cash into the I^2R-BYD Joint Laboratory.[198]

SINGAPORE-MIT ALLIANCE FOR RESEARCH AND TECHNOLOGY (SMART)

The Singapore-MIT Alliance for Research and Technology (SMART) is working to develop an automated vehicle that will operate on public roads. SMART is working with 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).[199]

The Singapore team has developed an automated vehicle prototype named *Shared Computer Operated Transport* (SCOT),[200] 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. 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). The SCOT prototype could be tested on public roads in as soon as two years. During an earlier test in 2011, NUS and SMART ran an automated golf cart through a closed course on the NUS campus.[201]

ONE-NORTH PUBLIC ROADS AUTOMATED VEHICLE DEPLOYMENT

One-North is a 200 hectare (500 acre) development in Singapore that was designed to host high-tech research, engineering, and business facilities.

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197 BYD 2014.
198 Yang 2014.
199 SMART 2014.
200 Manibo 2014.
201 Lee 2014.

Beginning in January 2015, the Land Transport Authority of Singapore and the JTC Corporation will deploy a fleet of automated vehicles on test routes connecting areas within One-North: Biopolis, Fusionopolis, and Mediapolis. This will be Singapore's first automated vehicle deployment on public roads outside of university campuses. The initial phase of the trial will last for one year.[202]

3.4 SOUTH KOREA

NATIONAL ITS 21 PLAN

Through its *National ITS 21 Plan*, South Korea will invest $3.2 billion in ITS deployment from 2008 to 2020. The country's ITS infrastructure was built by establishing four initial *ITS Model Cities*, which used adaptive traffic signal control, real-time traffic information, public transportation management, and automated speed violation enforcement. There are now 29 cities with ITS technologies deployed. When these systems were initially deployed, it was found that average vehicle speed increased by 20 percent and delay time at major intersections decreased by nearly 40 percent.[203]

As of the beginning of 2010, over 9,000 buses and 300 bus stops had been outfitted with operation management systems and traffic information data terminals. Public transit systems have now instituted an electronic payment system that uses cards or a mobile phone application to conduct transactions. Installation of these e-pay systems on mass transit was completed by the end of 2011. In 2010, electronic toll collection was available for half of all highway roads and was projected to continue its expansion to cover 70 percent of highways by the end of 2013.[204]

UBIQUITOUS CITY (U-CITY)

South Korea has embraced the concept of the "Ubiquitous City" (U-City) as part of their national urban development policy. The government finalized the first Comprehensive U-City Plan (2009-2013) to outline and support this policy. The core of the U-City vision is the integration of information and communication technologies with the urban landscape to create a system where information is available anywhere and city management is efficient and

[202] LTA 2014.
[203] Ezell 2010.
[204] Ezell 2010.

informed. As part of the U-City vision, transportation systems are connected.[205] The vision for U-Transportation in U-Cities includes a traffic information service, public transportation information service, real-time traffic control, U-parking applications, and traffic information on roads connecting suburbs.[206]

The first U-City to be completed was Hwaseong-Dongtan which was finished in September 2008. The Ministry of Land, Transport and Maritime Affairs reports that a total of 36 local governments are developing U-City projects, including existing cities (e.g., Seoul, Busan and Jeju) and new cities (e.g., Incheon-Songdo and Paju-Woonjeong) that were constructed with the U-City concept in mind.[207] The largest U-City will be Incheon-Songdo, which currently has more than 25,000 residents. Construction on the project is scheduled to be completed by 2016.[208]

3.5 TAIWAN

AUTOMOTIVE RESEARCH AND TESTING CENTER (ARTC) ACTIVITIES

Taiwan is home to several organizations that are advancing vehicle and technology research, most notably the Automotive Research and Testing Center (ARTC), founded in 1990 by the Taiwanese Ministry of Economic Affairs with the joint efforts of the Ministry of Transportation and the Communication, Environmental Protection Administration.[209] ARTC is particularly focused on helping Taiwanese automotive-related companies test products so that they can successfully launch them on the market. The center offers testing laboratories, test equipment, and a proving ground and provides a collaborative environment for the industrial, academic, and research communities.[210]

The ARTC has several connected vehicle-related initiatives, primarily revolving around safety. ARTC is researching lane-departure warnings, forward collision warnings, parking assist systems, blind spot information

[205] Korea Herald 2010.
[206] Bang 2011.
[207] Korea Herald 2010.
[208] Arndt 2013.
[209] ARTC 2011a.
[210] ARTC 2011a.

systems, and vehicle safety and security systems, among others.[211] Both the lane-departure and forward collision warning technologies involve a camera mounted behind the rear-view mirror that can detect lane markings or the vehicle ahead and alert the driver accordingly.[212] The parking assist system can, in real time, calculate the reverse trajectory using a signal from the steering angle sensor, which displays the image on a monitor in the vehicle.[213] This sensor provides the driver assistance with both backward and parallel parking.

ARTC offers several state-of-the-art laboratories. One in particular is the electro-magnetic compatibility (EMC) lab. The lab won certification of the American Association for Laboratory Accreditation/Automotive EMC Laboratory Accreditation Program and validation from General Motors, Ford, and Chrysler.[214] Therefore, the Center is able to certify companies' products for compatibility. ARTC also offers a proving ground with nine test tracks, including test hills; a curvy and bumpy "Belgium Road" track constructed with granite blocks; a coast-down test track; a noise, vibration, and harshness surface test track; a brake performance test track; a pass-by noise test track; a general durability test track; a high-speed circuit; and a general performance test track.[215]

INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE (ITRI) ACTIVITIES

Another organization that is researching cutting edge connected vehicle technology is the Industrial Technology Research Institute (ITRI) of Taiwan. ITRI has developed a WAVE/DSRC Communication Unit (IWCU) that provides V2V and V2I communication capabilities enabling ITS. In 2010, ITRI won a bid from CAMP for its IWCU technology to support the *Vehicle-to-Vehicle Interoperability* project, a connected vehicle project in the U.S. which is part of NHTSA's *Vehicle-to-Vehicle Safety Application Research plan*. The Ministry of Economic Affairs has strongly supported telematics research projects in Taiwan beginning in 2008, and winning the bid is seen as a result of this support.[216]

[211] ARTC 2011b.
[212] ARTC 2011b.
[213] ARTC 2011b.
[214] CENS 2008.
[215] CENS 2008.
[216] ITRI 2010.

3.6 AUSTRALIA

SECURING 5.9 GHZ BANDWIDTH FOR ITS

Since 2008, Austroads, an organization composed of six state and two territory road transport and traffic authorities has conducted a series of studies making the case for securing 5.9 GHz bandwidth for ITS applications, developing management arrangements for applications using the spectrum, and identifying pilot applications once the DSRC bandwidth has been secured.[217] As of the publication of the *2012 Policy Framework for Intelligent Transportation Systems in Australia*, the 5.9 GHz band has yet to be allocated for cooperative vehicle safety and mobility applications, though Australia is expected to allocate the 5.9 GHz band.[218]

In 2009, the Australian Communications Media Authority (ACMA) outlined proposals to secure the 5.9 GHz band of the spectrum for ITS.[219] Australia currently has several services allocated to the 5.9 GHz band, including fixed satellite services and mobile services to support the introduction of ITS technologies.

INTELLIGENT SPEED ADAPTATION TRIAL

In 2009, the New South Wales (NSW) Centre for Road Safety conducted an *Intelligent Speed Adaptation Trial*. Over 100 vehicles were connected to a centralized computer system which supplied drivers with information about changes to speed zones. These test vehicles provided more than 2 million individual speed compliance records. Initial results from the trial showed that using the technology decreased the proportion of time drivers spent traveling over the speed limit. These findings were presented at the 2009 Intelligent Speed Adaptation Conference in Sydney.[220]

COHDA WIRELESS ACTIVITIES

Cohda Wireless is a technology company that was spun-off from the University of South Australia in 2004[221] and has developed a signal processing technology that improves transmission quality of the 802.11p

[217] Austroads 2009.
[218] Australia 2012.
[219] ACMA 2010.
[220] Wall et al. 2009.
[221] Leung 2012.

radios used in connected vehicles.[222] The technology increases receiver sensitivity, transmission range, data speed, and connection reliability, thus providing a robust, low-latency radio connection that could potentially be used for safety applications. Cohda's technology also allows signals to be bounced around corners, improving data reception, especially in urban environments.[223]

The technology has so far been tested in over 17,000 kilometers of on-road trials which have involved the transmission of more than 200GB of data.[224] Cohda technology has been used for connected vehicle testing in Australia, Austria, Germany, Italy, Sweden, and the United States as part of large deployments such as Germany's sim^{TD} in Frankfurt, Germany and the *Safety Pilot Model Deployment* in Ann Arbor, Michigan.[225]

A large scale, three-month test of Cohda Wireless technology was approved in 2011. The test involved V2V and V2I technology and was run by South Australia's Motor Accident Commission, the Department for Transport, Energy, and Infrastructure; and the University of South Australia's Institute for Telecommunications Research. The initial tests included a fleet of ten vehicles collecting data in normal driving conditions with data being uploaded via roadside equipment at the Norwood Traffic Management Center.[226]

Cooperative Intelligent Transport Initiative (CITI)

The NSW 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, 85 mobile units to be installed in trucks and 10 stationary units to be installed along the highway. The roadside units will communicate with traffic lights to provide vehicles with SPaT data.[227]

Intelligent Access Program (IAP)

In 2006, Australia's national government passed legislation providing the legal foundation for the *Intelligent Access Program* (IAP). The IAP provides improved access to the Australian road network for heavy-duty commercial

[222] Stone 2009.
[223] Cohda 2012.
[224] Cohda 2012.
[225] TTT 2009a and Cohda 2012.
[226] TTT 2011.
[227] Barwick 2014.

vehicles. The program uses a combination of satellite tracking and wireless communications technology to monitor heavy vehicles on the road network. The program can notify the appropriate government agencies if a vehicle deviates from approved routes or times. Participation in the program is voluntary.

Hardware installed for IAP includes an in-vehicle unit and a self-declaration input device. The in-vehicle unit automatically monitors and stores data, such as date, time, vehicle position, vehicle speed, potential malfunctions, and attempts at tampering. Government agencies can access the data to ensure that vehicles and operators are complying with pertinent rules and regulations. The self-declaration input device allows the vehicle operator to input information and explain behavior that may appear to be non-compliant to the Department of Planning, Transport and Infrastructure.[228]

AUTOMATED VEHICLES PARTNERSHIP

In February 2014, the University of New South Wales (UNSW) and GoGet, a car sharing service, announced that they are working together to develop an automated driving algorithm. The partnership will result in an experimental prototype vehicle with four radar sensors, a video camera, and an on-board computer. The sensors and video camera can recognize pedestrians, bicycles, other vehicles, and other obstacles.[229] Through a $35,000 grant from its Civil and Environmental Engineering Department, UNSW provided funding to equip the prototype, a Toyota Yaris hatchback named Ethel.[230] GoGet provided the vehicle and gave researchers access to data generated by its current vehicle fleet.[231]

3.7 NEW ZEALAND

NATIONAL ITS ARCHITECTURE

The New Zealand Transport Agency produced a research report in March 2010 that proposed a framework for a national ITS architecture. This report reviewed international ITS models and research in the United States, Canada, Europe, and Australia and proposed a framework for developing an ITS

[228] TCA 2012.
[229] Grubb 2014.
[230] Hopewell 2014.
[231] Grubb 2014.

architecture for New Zealand which included some connected vehicle technologies such as the use of DSRC and connected vehicles as probes for dynamic route guidance.[232]

At the ITS New Zealand Summit 2012, several speakers discussed new safety applications in New Zealand. These included the national traffic management system, live traffic information services, and IP-based communications services.[233]

In June of 2013, the Ministry of Transportation began working with the company AraFlow Limited to run a trial involving real-time traffic information collection and dissemination along State Highway 2 between Auckland and Tauranga. The project ran until April 2014 and used Bluetooth traffic sensors to collect anonymous data from passing vehicles, including average speeds, journey times, traffic incidents, and congestion. The collected information will be transmitted to drivers of commercial vehicles using dedicated roadside transmitters and in-cab units.[234]

In May 2014 the Ministry of Transport created the New Zealand government's Intelligent Transport System Technology Action Plan. The plan defines the role of government and outlines the introduction of ITS in New Zealand from 2014 to 2018. The plan discusses the use of wireless sensors as well as mobile phone positioning and crowd sourced data. The plan also addresses the need for internationally harmonized spectrum allocation and communication protocols to support connected vehicle technology. Within the New Zealand government, the Ministry of Business Innovation and Employment has a radio spectrum management team responsible for developing and implementing communications technology standards. The team has not yet formally reserved the 5.9 GHz frequency for connected vehicles, but the spectrum is available and the team is monitoring demand for its use.[235]

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[232] James et al. 2010.
[233] McCombs 2012.
[234] Ministry of Transport 2013.
[235] Ministry of Transport 2014.

4 CONNECTED VEHICLE EFFORTS IN EUROPE AND THE MIDDLE EAST

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 18 shows the geographical distribution of projects throughout Europe/Middle East. Many projects in Europe are spread across several countries; for mapping purposes, such projects are assigned to the country of their lead coordinator.

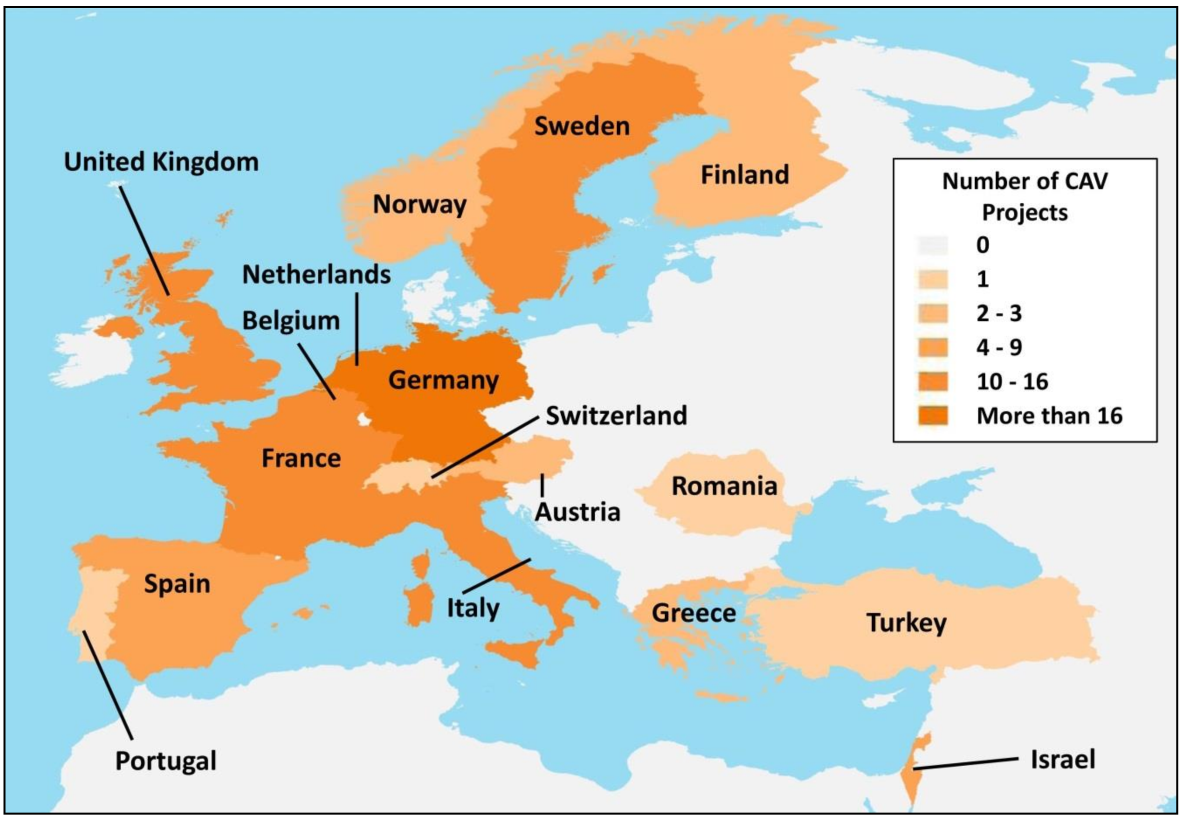

FIGURE 18: CONNECTED VEHICLE PROJECTS IN EUROPE AND THE MIDDLE EAST[236]

[236] CAR 2014.

4.1 EUROPE-WIDE PROJECTS

EUROPEAN ROAD TRANSPORT TELEMATICS IMPLEMENTATION CO-ORDINATION ORGANIZATION (ERTICO-ITS EUROPE)

The European Road Transport Telematics Implementation Co-ordination Organization (ERTICO) is Europe's premier ITS organization (akin to ITS America in the U.S.). It brings together several European countries, automotive companies, suppliers, and other organizations and fosters research in various ITS-related activities. The organization has several activities in the safety, security, efficiency, and environment realms.

In the safety realm, ERTICO is firmly committed to the tremendous effect that ITS-related technology can have on reducing the number of motor vehicle accidents. ERTICO estimates the cost of motor vehicle crashes in Europe to be €200 billion per year and thus views crashes as a significant cost to society.[237] In the realm of security, priority areas include border control, the fight against terrorism, and civilian emergency and critical infrastructure protection. In addition Europe is certainly not immune to the issue of congestion and all the problems it causes. As a result of these numerous issues, ERTICO is involved in several different types of ITS-related initiatives. ERTICO's website provides a full listing of these initiatives.[238] ERTICO divides its projects between the topics of safe mobility, smart mobility, and eco-mobility.[239]

Current and recently completed CAV-relevant projects include:

- *Sustainability and Efficiency of City Logistics* (CITYLOG) (January 2010-December 2012), which was focused on increasing the efficiency of deliveries using adaptive and integrated mission management and innovative vehicle solutions.[240]
- The *Communications for eSafety 2* (COMeSafety2) project (January 2011-December 2013) involves coordinating activities related to the deployment of cooperative ITS on European roads. The focus of these projects includes standardization issues; best practices from European, Japanese,

[237] Commission of the European Communities 2006.
[238] ERTICO 2012.
[239] ERTICO 2014.
[240] ERTICO 2014.

and US field operational tests (FOTs); a cooperative multimodal ITS architecture concept; and needs analysis among others.[241]

- *Support Action for a Transport ICT European* large scale action (SATIE) (September 2011-August 2014) is intended to serve a consulting role to the European Commission with regards to planning large-scale actions. Information Communications Technology (ICT) is a term commonly used in Europe to refer to advanced vehicle systems, such as CAV technologies.[242]
- The *Europe-Wide Platform for Connected Mobility Services* (MOBiNET) service platform (November 2012-June 2016) is an €11 million project involving 34 partners. Its goal is to simplify the Europe-wide deployment of connected transport services and create an "Internet of Mobility" and promote openness, harmonization, interoperability, and quality.[243]
- 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 the cities of Bordeaux, Copenhagen, Helmond, Newcastle, Thessaloniki, Verona and Vigo. The project will work to deploy required infrastructure in addition to developing business models, cost-benefit analysis, and exploitation plans.[244]
- The *Instant Mobility - Future Internet for Smart, Efficient & Green Mobility* project (April 2011-March 2013) focused on improving mobility/multi-modal transport using the Internet to deliver real-time information and services from a variety of sources (e.g., vehicles, travelers, goods and infrastructure).[245]
- The *79 GHz* project (July 2011-June 2014) is a harmonization effort related to standardizing vehicular radar frequency. Project partners included Bosch, Continental, Autocruise, Renault, BMW, Fiat, Daimler,

[241] ERTICO 2014.
[242] ERTICO 2014.
[243] ERTICO 2014.
[244] ERTICO 2014.
[245] ERTICO 2014.

PSA Peugeot Citroën, Autoliv, Delphi, Valeo, Infineon, ST Electronics, and UMS.[246]

- The goal of the *iMobility Challenge* (October 2012-September 2014) and *iMobility Support* (January 2013-December 2014) projects is to demonstrate and promote ICT system deployment efficient and sustainable mobility. *iMobility Challenge* events last one to three days and have been held across Europe in Belgium, Finland, France, Germany, Luxembourg, Netherlands, and Turkey. The next event will be held in Barcelona, Spain in October 2014.[247] The *iMobility Support* project organizes activities, such as stakeholder networking events, deployment support, awareness raising events and dissemination of results.[248]
- The *Co-Gistics* project (January 2014-December 2017) will deploy cooperative logistics services pilots in seven European cities. These pilots will examine ways to increase energy efficiency and sustainable mobility of goods. The pilots will involve installing equipment on 325 trucks and vans.[249]

COOPERATIVE ITS CORRIDOR (ROTTERDAM - FRANKFURT/MAIN - VIENNA)

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 with RSUs required to provide cooperative services to vehicles traveling the route. The services will be offered beginning in 2015 and will include road warnings and probe vehicle data. The equipment deployed will utilize DSRC (i.e., 802.11p, 5.9 GHz) and cellular networks (e.g., 3G or 4G). The route will be the first deployment of a cooperative intelligent transport system between multiple countries. The deployment will require cooperation between the relevant ministries in each country, highway operators, and the vehicle manufacturers.[250]

[246] ERTICO 2014.
[247] iMobility 2014.
[248] ERTICO 2014.
[249] ERTICO 2014.
[250] BMVBS 2013.

DRIVING IMPLEMENTATION AND EVALUATION OF C2X COMMUNICATION TECHNOLOGY (DRIVE C2X)

The *PREparation for DRIVing implementation and Evaluation of C2X communication technology* (PRE-DRIVE C2X) project was an FOT that used European COMeSafety architecture to create a V2X communication system. The project developed specifications for the system and created a functional prototype that could be used in future FOTs. A major goal of PRE-DRIVE C2X was to develop a simulation model to estimate the benefits of a cooperative system in terms of safety, efficiency, and environment. This model includes the tools and methods needed to perform functional verification and testing of cooperative systems in both the laboratory and on the road. The PRE-DRIVE C2X project ran from 2008 to 2010. The budget was €8.4 million and the project received funding of €5.0 million from the European Commission Information Society and Media as part of the 7th Framework Programme. The project was also supported by the European Council for Automotive R&D (EUCAR).[251]

The goal of the follow-up project to PRE-DRIVE C2X, *DRIVing implementation and Evaluation of C2X communication technology* (DRIVE C2X), was to create a Europe-wide testing environment for C2X technologies. The project was designed to raise public awareness of connected vehicle technologies, inform standardization organizations, and initiate new public-private ventures. It was envisioned that these activities would create a better environment for the commercialization of connected vehicles in Europe.[252]

DRIVE C2X, which ran from 2011 to 2013, had 31 partners and 15 support partners. The final event was hosted in Gothenburg, Sweden on June 13-14, 2013.[253] The total budget for DRIVE C2X was €18.8 million, with €12.4 million coming from the European Commission. The DRIVE C2X test deployment included:

- Dutch Integrated Testsite Cooperative Mobility (DITCM) (Helmond, Netherlands)
- Safe and Intelligent Mobility Test Germany (sim^{TD}) (Frankfurt/Main, Germany)

[251] PRE-DRIVE C2X 2011.
[252] DRIVE C2X 2012.
[253] DRIVE C2X 2013.

- System Coopératif Routier Expérimental Français (SCORE@F) (Yvelines, France)
- Cooperative Test Site Finland (Coop TS Finland) (Tampere, Finland)
- Vehicle and Traffic Safety Center (SAFER) (Gothenburg, Sweden)
- SIStemas COoperativos Galicia (SISCOGA) (Galicia, Spain)
- Test Site Italy (Brenner Motorway, Italy)

The lead coordinator on the project was Daimler and partners included ten other automakers, eight suppliers, 16 research institutions, and 11 other organizations.[254] The functions tested relate to traffic flow, traffic management, local danger alert, driving assistance, internet access and local information services, and test site-specific functions that were defined independently by each test site.[255] The test sites are shown in Figure 19, and detailed information on individual projects can be found in the country sections found on subsequent pages.

FIGURE 19: DRIVE C2X PROJECTS THROUGHOUT EUROPE[256]

[254] EICT 2011 and DRIVE C2X 2012.
[255] Flament 2011.
[256] DRIVE C2X 2012.

HARMONIZED ECALL EUROPEAN PILOT (HEERO)

The objective of the *Harmonized eCall European Pilot* (HeEro) is to prepare the infrastructure necessary for a European in-vehicle emergency communication service that will harmonize the disparate national services and ensure cross-border interoperability. The pilot participants will then share their experiences and best practices with other countries and help expand the program.[257] This service uses "112," the single European emergency number.

In the event of a serious automobile accident, the system will automatically notify emergency services. The system will transmit location information on the accident, as well as allow voice contact between operators and crash victims.

Several countries are working together to develop this emergency call service. The HeERO consortium consists of:

- Croatia
- Czech Republic
- Finland
- Germany
- Greece
- Netherlands
- Italy
- Romania
- Sweden

These countries are carrying out the work needed to start up the system that will soon be used across the European Union as well as in the countries of Iceland, Norway and Switzerland.[258]

Ideally, the HeERO technology will cost around €100 per vehicle once it is implemented in all new vehicles. Part of the rationale for standardizing the technology across all of Europe is to take advantage of economies of scale and reduce cost. In addition to being used for emergency calls, the in-vehicle

[257] HeERO 2012.
[258] HeERO 2012.

devices could be used for commercial uses such as usage-based insurance, electronic tolling, and stolen vehicle tracking.[259]

The first phase of the project started in January 2011 and continued through December 2013. The budget was €10 million, €5 million of which was provided by the European Commission under the *Information and Communication Technologies Policy Support Program* (ICT PSP).[260]

The project has been extended to a second phase, HeERO2, which began in January 2013 and will run until December 2015. The project has an overall budget of €6.1 million, €3 million of which has been provided by the European Commission. The project's goals will be to prepare and carry-out pre-deployment pilots as well as encourage wider adoption.[261] Belgium, Bulgaria, Denmark, Luxembourg, Spain and Turkey have joined the project.[262]

COOPERATIVE VEHICLE INFRASTRUCTURE SYSTEMS (CVIS)

The *Cooperative Vehicle Infrastructure Systems* (CVIS) project was an ERTICO program with 61 partners and was coordinated in Belgium. The goals of CVIS were to design, develop, and test vehicle communication technologies. CVIS used a hybrid of CALM microwave medium at 5 GHz (M5), IR, 2G/3G, and DSRC for communication, and Global Navigation Satellite System (GNSS) for positioning.[263] It was demonstrated that CVIS could increase road safety and efficiency while decreasing the environmental impact of road transport. Deliverables from CVIS included a standardized networking terminal for V2V and V2I communications, techniques for improving dynamic maps, new systems for vehicle and roadside equipment, development of cooperative applications, and a toolkit addressing key non-technical challenges to deployment. The CVIS activities took place at test sites in France, Germany, Netherlands-Belgium, Italy, Sweden, United Kingdom, and Norway. The types of tests that took place at each test location are shown in Table 1. Local road authorities and operators, system integrators, suppliers, vehicle manufacturers, and service providers participated at each

[259] HeERO 2012.
[260] HeERO 2012.
[261] HeERO 2013.
[262] HeERO 2014.
[263] Eriksen et al 2006.

test site.[264] The project was launched in February 2006 and was completed in mid-2010. The project budget was €41 million, with roughly half contributed by the European Union.

TABLE 1: LOCUS OF TESTING OF THE CVIS SYSTEM[265]

Application Sub-Project	France	Germany	Italy	Netherlands-Belgium	Sweden	United Kingdom
Monitoring		x	x	x	x	
Urban						
Cooperative Network Management			x	x		
Cooperative Area Routing			x			
Cooperative Local Traffic Control		x	x	x		
Dynamic Bus Lanes			x			
Interurban						
Enhanced Driver Awareness	x	x			x	
Cooperative Traveller's Assistance		x	x	x		
Freight and Fleet						
Dangerous Goods			x		x	
Booking and Monitoring of Parking Zones	x			x		x
Vehicle Access Control for Sensitive Zones	x		x			

Note: Test Site Norway joined CVIS as an associated test site towards the end of the project and was not a primary site for CVIS testing. Test Site Norway application areas included road safety, infrastructure performance, environmental performance, infotainment, and other services.

FIELD OPERATIONAL TEST NETWORK (FOT-NET)

The aim of the *Field Operational Test Network* (FOT-Net*) project* is to gather European and international researchers with FOT experience together to present results of FOTs and promote the *Field Operational Test Support Action* (FESTA) methodology as a common approach for FOTs. FOTs are large-scale testing programs for the assessment of the efficiency, quality, robustness and acceptance of information and communication technologies (e.g. navigation, traffic information, advanced driver assistance, and cooperative systems). FOT-Net is jointly funded by the European Commission DG Information Society and Media under the Seventh Framework Programme. The FOT-NET website contains a plethora of information on FOTs that have occurred or are planned in Europe, North America, and Asia.[266]

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[264] CVIS 2012.
[265] CVIS 2012
[266] FOT-NET 2011.

CO-OPERATIVE SYSTEMS FOR SUSTAINABLE MOBILITY AND ENERGY EFFICIENCY (COSMO)

Co-Operative Systems for Sustainable Mobility and Energy Efficiency (COSMO) was a 32 month pilot project which began in November 2010 and ran through mid-2013. The project's goal was to demonstrate the benefits of cooperative traffic management applications. Pilot sites in Salerno, Italy; Vienna, Austria; and Gothenburg, Sweden are being used for this demonstration. These sites are implementing cooperative technologies developed in the recent European projects such as *Co-Operative Systems for Intelligent Road Safety* (COOPERS), CVIS, and *Smart Vehicles on Smart Roads* (SAFESPOT). Partners included Mizar Automazione, SWARCO FUTURIT Verkehrssignalsysteme GmbH, ASFINAG Service GmbH, Kapsch TrafficCom, Geo Solutions, ERTICO–ITS Europe, Societé pour le Developpement de l'Innovation dans les Transports, Università degli Studi di Salerno, Centro Ricerche Fiat, Volvo Technology, Lindholmen Science Park, and Tecnalia-Transporte. The budget for the project was €3.8 million, €1.9 million from the European Commission.[267] On May 15-16, 2013, COSMO held its final event where it presented the results and outcomes of the project.[268] COSMO also ran a demonstration in mid-June during the final event for the DRIVE C2X project.[269]

INFORMATION COMMUNICATIONS TECHNOLOGY (ICT) FOR ELECTRO-MOBILITY

Four European electro-mobility pilot projects were launched together on February 8, 2012. The projects each use ICT to enhance driving experiences for electric vehicle users.

The *Smart Connected Electro Mobility* (smartCEM) project is designed to demonstrate how ICT solutions can make commuting in electric vehicles more practical and overcome shortcomings associated with them.[270] SmartCEM services being tested include:

- Navigation
- Efficient driving

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[267] COSMO 2012.
[268] ERTICO 2013.
[269] COSMO 2013.
[270] smartCEM 2012.

- Trip management
- Charging station management
- Vehicle sharing managements

The Barcelona, Spain pilot is focused on electric motorcycles and scooters. The major mobility application being tested is an advanced open sharing service for vehicles. The pilot involves 45 motorcycles and 234 charging locations. The Gipuzkoa-San Sebastian, Spain pilot tests a hybrid bus application and a car sharing application. Testing will involve one hybrid bus, 30 electric cars, and 33 charging points. The Newcastle, United Kingdom pilot will test an eco-driving interface for 44 electric cars which can be charged at 1,300 eventual charging points (though just over 200 charging points currently exist). The Turin, Italy pilot is focused on a sharing service for electric delivery vans. The test will involve ten delivery vans, five minivans, and two charging points.[271] The smartCEM project budget is €4.9 million (€2.5 million from the European Union). The project will run through the end of 2014.[272]

ICT 4 EVEU

The project Information and Communication Technologies for Electric Vehicles European Union (ICT 4 EVEU) project uses communications technologies to:

- Monitor use status of charging points
- Monitor status of vehicles
- Remotely reserve charging points
- Integrate payment methods for users
- Create a network of charging points

While specific technology is not specified on the website, it is made clear that the system being tested will make use of V2I communication technology. The pilots will take place at Bristol, United Kingdom; Pamplona and Vitoria, Spain; and Ljubljana and Maribor, Slovenia.[273] The *ICT 4 EVEU* project budget is €4.4 million (€2.2 million from the European Union). The project will run through the end of 2014.[274]

[271] smartCEM 2012.
[272] Europa 2014.
[273] ICT 4 EVU 2012.
[274] Europa 2014.

MOBI.EUROPE

Mobility services offered under *Integrated and Interoperable ICT Applications for Electro-Mobility in Europe* (MOBI.Europe) include remote information on parking availability, remote parking reservations, and enhanced car sharing. The pilots will take place in Ireland, the Netherlands, Portugal, and Spain and will involve 1,200 electric vehicles and 1,850 charging points.[275] The project will use Wi-Fi and 3G communications technologies. The *MOBI.Europe* project budget is €5.1 million (€2.4 million from the European Union). The project will run through the end of 2014.[276]

MOLECULES

Services being tested under the Mobility based on eLEctric Connected vehicles in Urban and interurban smart, cLean, EnvironmentS (MOLECULES) pilot project include:

- Personal trip planning
- Electric Vehicle sharing/pooling
- Personal recharging advisor
- Personal carbon footprint advisor
- Electro-mobility billing support
- Incentives to electro-mobility
- Network strategies

The pilot sites for MOLECULES are in Barcelona, Spain; Berlin, Germany; and Grand Paris, France.[277] The MOLECULES project budget is €4.3 million (€2.1 million from the European Union). The project will run through the end of 2014.[278]

CO-CITIES

The *Co-Cities* project started in January 2011 and ran until December 2013. It was coordinated by AustriaTech and involved Brimatech Services, Fluidtime Data Services, Softeco Sismat, Regione Toscana, MemEx, Telematix Software, the Regional Organiser of Prague Integrated Transport, TomTom,

[275] MOBI.Europe 2012.
[276] Europa 2014.
[277] MOLECULES 2012.
[278] Europa 2014.

POLIS, Atos, Asociación Cluster del Transporte y la Logistica de Euskadi, PTV Planung Transport Verkehr, and the Reading Borough Council.[279]

Pilots were conducted in the cities of Bilbao, Spain; Florence, Italy; Munich, Germany; Prague, Czech Republic; Reading, United Kingdom; and Vienna, Austria. Each pilot offered cooperative mobility services (e.g., dynamic navigation, intermodal routing, and real-time traffic advice). The Co-Cities project budget was €3.9 million (€2.0 million from the European Union). The project will run through the end of 2014.[280]

EUROPEAN FIELD OPERATIONAL TEST ON SAFE, INTELLIGENT AND SUSTAINABLE ROAD OPERATION (FOTSIS)

The *European Field Operational Test on Safe, Intelligent and Sustainable Road Operation* (FOTsis) is a Europe-wide project that is running from April 2011 through September 2014. It is a partnership of Aalto University Foundation, ACB Systems, Association Europeenne des concessionnaires d'autoroutes et d'ouvrages a peage, Center for research and technology Hellas, Centro de innovación de infraestructuras inteligentes, European Union Road Federation, Federation International de l'automobile, France Telecom, Geoville, GMV Sistemas, GMVIS Skysoft, Ilmatieteen Laitos, Indra, Iridium, Marestrada, Nea Odos, OHL Concesiones, Optimus, Planestrada, Sice, Terna Energy, Transver, Universidad de Murcia, and Universidad Politécnica de Madrid.

The project is a large-scale field test of the road infrastructure management systems needed for the operation of several close-to-market cooperative communications technologies. These include:

- Emergency Management
- Safety Incident Management
- Intelligent Congestion Control
- Dynamic Route Planning
- Special Vehicle Tracking
- Advanced Enforcement
- Infrastructure Safety Assessment

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[279] Co-Cities 2013.
[280] Europa 2014.

The tests will involve pilot communities in Spain, Portugal, Germany, and Greece. The budget for the project is €13.8 million with €7.8 million being provided by the European Commission.[281]

PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety (PROMETHEUS)

Europe's largest automated vehicle project, the *PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety* (PROMETHEUS) ran from 1987 to 1995. The project cost nearly €750 million and involved the United Kingdom, Sweden, Norway, the Netherlands, Italy, France, Finland, Germany, Switzerland, Belgium, and Austria.[282] The PROMETHEUS program was headed by many automakers (including BMW, Fiat, Ford, Jaguar, MAN, Matra, Peugeot, Porsche, Renault, Rolls Royce, Saab, Volkswagen, Volvo, Daimler Benz, Opel, Saab Scania, and Volvo) from across Europe. Other participants were drawn from automotive suppliers, the electronics industry, universities and research institutes, traffic engineering firms, and public agencies. The objectives of the program were to reduce road accidents and to improve traffic efficiency. By the end of the project in the mid-1990s, prototype automated vehicles had been developed and tested on Parisian highways and the German Autobahn. The PROMETHEUS program paved the way for subsequent initiatives such as Italy's ARGO project (1996-2000) and more recent automated vehicle work.[283]

CityMobil

The *CityMobil* project began in May 2006, and the final event was held in Brussels in December 2011. The project budget was €40 million, with €11 million provided by the European Commission. The project had 29 partner organizations.[284]

The project emphasized public transit applications of automated vehicles rather than automobile or trucking applications. *CityMobil* included implementation of advanced transport systems in Heathrow, United Kingdom; Rome, Italy; and Castellón, Spain. A conference was held in the City of La Rochelle, which involved a presentations and demonstrations.

281 FOTsis 2013.
282 EUREKA 2013.
283 ARGO 2013
284 CityMobil 2013

Vehicle systems demonstrated as part of the project included low-speed, driverless “CyberCars” that provide taxi-like services (Rome and La Rochelle); vision-guided bus technology (Castellón); automated personal rapid transit that requires a dedicated infrastructure (Heathrow Airport); and dual mode vehicles (normal vehicles with automated driving capabilities).

The follow-up project, *CityMobil2*, began in September 2013 and is scheduled to run until August 2016. The project will create a pilot platform for automated transportation systems, and implement it in several urban areas across Europe. Eventually, five sites will be selected to host a 6-month demonstration. The project will also research technical, financial, cultural, behavioral, and legal aspects related to automated transportation. The project has 45 partners, including system suppliers, city/local partners, research organizations, and networking organizations.[285]

AUTOMATED VEHICLE LEGISLATION

In Europe, several countries have allowed automated vehicles to be tested on public roads for large public deployment projects. For example, the *City Network for Fair Mobility* (CITYNETMOBIL) deployed automated vehicles in several cities in France, Italy, and Belgium.[286] The SARTRE project involved a platoon of automated vehicles following a manned lead vehicle that drove for over 200 kilometers (125 miles) on a public highway near Barcelona, Spain.[287] Public driving tests of automated vehicles have also occurred in the Netherlands and Germany.[288] Finland and Greece also have some degree of legislation governing the use of automated vehicles on public roads.[289] In July 2014, both the French and UK government announced that automated vehicle testing will be allowed on public roads beginning in 2015.[290]

UN CONVENTION ON ROAD TRAFFIC AMENDMENT

In April 2014, the United Nations Convention on Road Traffic agreed to an amendment that would let drivers take their hands off the steering wheel of an

[285] CityMobil2 2014.
[286] CORDIS 2012.
[287] SARTRE 2014.
[288] Wallace et al. 2013.
[289] Houses of Parliament 2013.
[290] Connexion 2014 and BBC 2014.

automated vehicle.[291] Article 8 of the 1968 United Nations Convention on Road Traffic stipulates that: "Every driver shall at all times be able to control his vehicle or to guide his animals." The new amendment would allow automated vehicles but require that the system "can be overridden or switched off by the driver." Under the new amendment, an occupant must be in the vehicle and able to assume control of the vehicle at all times during operation. The amendment was submitted by Germany, Italy, France, Belgium, and Austria; all countries that have been active in supporting CAV research and deployment projects.

SPARC – THE PARTNERSHIP FOR ROBOTICS IN EUROPE

In June 2014, at the AUTOMATICA 2014 conference in Munich, the European Commission announced that it would launch SPARC – The Partnership for Robotics in Europe, the world's largest civilian robotics research program, which would be funded at €2.8 billion ($3.8 billion). The majority of the funding (75 percent) will come from private sources, and the remaining amount (25 percent) will be provided by the European Commission. The private funding will come from the 180 companies and research organizations supporting the project. The SPARC initiative includes application areas in transportation, manufacturing and industry, healthcare, home care, agriculture, security, environment, and entertainment.[292]

4.2 GERMANY

AUTOMATED DRIVING APPLICATIONS & TECHNOLOGIES FOR INTELLIGENT VEHICLES (ADAPTIVE)

The *Automated Driving Applications & Technologies for Intelligent Vehicles* (AdaptIVe) project will design, implement, and evaluate many integrated applications for automated driving. The focus of the project is automation, but cooperative aspects (V2V, V2I) are also included in the scope of work. The project will:

- Demonstrate automated driving in complex environments
- Focus on communication capabilities
- Create implementation guidelines for cooperative and automated controls

[291] Reuters 2014.
[292] European Commission 2014.

- Define and validate evaluation methodologies.
- Assess the effect of automated driving
- Propose a legal framework overcoming implementation barriers

The AdaptIVe project is being coordinated by Volkswagen Group Research. Partners include Volkswagen AG, BMW AG, BMW Group Research and Technology, Centro Ricerche Fiat, Daimler AG, Ford R&A Europe, Adam Opel AG, Peugeot Citroën Automobiles, Renault, Volvo Cars Corporation, Volvo Group, Robert Bosch GmbH, Continental, Delphi Deutschland GmbH, BASt, CTAG, Chalmers, DLR, ICCS, IKA,TNO, University of Leeds, Lund University, University of Trento, Julius-Maximilians Universität Würzburg, Alcor, EICT, and WIVW. The consortium will create and use eight demonstration vehicles which will be outfitted with CAV equipment, including seven passenger cars and one truck. The project began in January 2014 and will run until June 2017. The total cost of the project will be €25 million, with €14.3 million being provided from European Union.[293]

SAFE AND INTELLIGENT MOBILITY TEST GERMANY (SIM^{TD})

As part of Drive C2X, the German state of Hessen and the city of Frankfurt worked with several automakers, Tier 1 suppliers, and communication companies on a four-year test involving vehicles and roadside units with wireless communication capabilities. The project involved the testing of car-to-x communication, which includes V2V and V2I communication.

The project, which started in 2008 and was planned to run for four years, is called *Safe and Intelligent Mobility Test Germany* (sim^{TD}). The project had a €53 million budget, €30 million of which was paid by the German government.[294] In addition to the €53 million, the project was further supported with an infrastructure investment from German government agencies and the state of Hessen. The technology used in the project is based on the wireless local area network (WLAN) standard 802.11p and 802.11b/g.[295] Other communications technologies are also integrated into the system, such as Universal Mobile Telecommunications System (UMTS) and GPRS.

[293] AdaptIVe 2014.
[294] TN 2012.
[295] DRIVE C2X 2012.

The project was headed up by Daimler and other private-sector partners included Audi, BMW, Bosch, Continental, Deutsche Telekom, Ford, Opel, and Volkswagen. Automaker partners provided equipped vehicles for the testing. For example, Ford provided 20 S-Max models.[296] Research partners included Fraunhofer-Gesellschaft, German Research Center for Artificial Intelligence, Technical University of Berlin, Munich University of Technology, Saarland University of Applied Sciences, and University of Würzburg. Public-sector partners included the Federal Ministry of Transport, Building, and Urban Affairs, the Federal Ministry of Education and Research, the Federal Ministry of Economics and Technology, the Hessen State Office for Road and Transport, and the City of Frankfurt.[297]

The vision for sim^{TD} was to create a system that could enhance road safety, improve traffic efficiency, and integrate value-added services. Applications tested under the project included:[298]

- Electronic brake light
- Obstacle warning system
- Traffic sign assistance
- Public traffic management
- In-car internet access

The project field test occurred from July to December 2012. Testing occurred on urban roads and rural highways using 120 test vehicles, which included cars and motorcycles.[299] The test field was located in the Frankfurt-Rhine-Main area and included 104 RSUs, 69 of which are linked with traffic lights and another 21 positioned at intersections. The testing area included 96 kilometers of highway, 53 kilometers of rural road, and 24 kilometers of urban road. An additional closed testing site was located at Ray Barracks in Friedberg. That site plan for the closed site included three RSUs, one of which was linked to a traffic light.[300]

In total, the project used 500 test drivers who logged more than 41,000 testing hours over 1,650,000 kilometers. The collected test data required more than

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[296] TN 2012.
[297] sim^{TD} 2013.
[298] TN 2012.
[299] sim^{TD} 2013.
[300] DRIVE C2X 2012.

30 TB of storage.[301] After processing and analyzing the data, researchers concluded that the sim^{TD} system can improve knowledge of traffic conditions, lead to faster detection of traffic-related events, and improve transportation system safety.

In addition, the sim^{TD} project results indicate that penetration rates of 20 percent have significant positive effects on the overall traffic condition. Drivers of equipped vehicles can adapt their speed, distance, and driving behavior to match traffic conditions more quickly.[302]

In October 2012, sim^{TD} team members presented project results at the ITS World Congress in Vienna, Austria. At the event, there was a motorcycle equipped with the sim^{TD} system. Attendees could experience a virtual ride on the motorcycle, which involved a viewing screen which displayed the vehicle route and demonstrated various functions, including intersection and cross traffic assistant, road work information, and emergency vehicle warnings.[303]

The final event for sim^{TD} was held on June 20th, 2013. Team members presented on the system and architecture and gave an overview of project results. The exhibition also included a demonstration that allowed participants to take a ride in a vehicle from the test fleet.[304] As part of finalizing the project, a German-language fact sheet was uploaded to the simTD website.[305]

DYNAMIC INFORMATION AND APPLICATIONS FOR ASSURED MOBILITY WITH ADAPTIVE NETWORKS AND TELEMATICS INFRASTRUCTURE (DIAMANT)

Also in Hessen, the Hessian State Office of Road and Traffic Affairs (HLSV) conducted Dynamische Informationen und Anwendungen zur Mobilitätssicherung mit Adaptiven Netzwerken und Telematikanwendungen or Dynamic Information and Applications for assured Mobility with Adaptive Networks and Telematics infrastructure (DIAMANT). Project partners included Adam Opel GmbH, Continental AG, Dambach-Werke GmbH. and the state of Hessen. The project had a five-year runtime (2008 to 2013), and total costs of €5.2 million. There was no external funding; each of the project partners is bearing their own costs. The vehicles used for testing were

[301] sim^{TD} 2013.
[302] sim^{TD} 2013.
[303] sim^{TD} 2013.
[304] sim^{TD} 2013.
[305] The fact sheet can be viewed here.

supplied by Adam Opel GmbH, the on-board units were from Continental AG, the roadside communication points were manufactured by Dambach-Werke GmbH, and the HLSV managed the road. Together this consortium attempted to promote C2X safety and efficiency applications in hopes of bringing them rapidly onto the market. Between them, the partners had the ability and expertise to conduct connected vehicle field tests.[306] Applications tested under this program provided information and warnings for drivers as well as allow for traffic management. The one-year test period was completed in 2011, and was followed by a period of data analysis.[307]

ADAPTIVE AND COOPERATIVE TECHNOLOGIES FOR INTELLIGENT TRAFFIC (AKTIV)

The German *Adaptive and Cooperative Technologies for Intelligent Traffic* (AKTIV) initiative, backed by a consortium of 29 partners, developed an assistance system under its *Cooperative Cars* (CoCar) project. The goal of the initiative is to prevent accidents using intelligent traffic management systems and mobile communications technologies for connected vehicles. The project was funded in part by the Federal Ministry of Economics and Technology. The Hessen test bed was used to evaluate applications such as traffic modeling and in-vehicle signing.[308] Among the technologies used in AKTIV were cameras, radar, and laser sensors.[309] The AKTIV Communication Unit, developed as part of the project, complies with the IEEE 802.11p wireless standard for 5.9 GHz. The device is also available for WLAN standards IEEE 802.11a-g for 5.8 and 2.4 GHz.[310] AKTIV also used cellular mobile communication technologies, including Universal Mobile Telecommunications System (UMTS), High-Speed Packet Access (HSPA), and 3G Long Term Evolution (LTE), for communications tests.[311] The four-year project was completed in 2010.[312]

306 Hessen 2009.
307 Opel 2011.
308 Hessen 2009.
309 Abuelsamid 2010.
310 AKTIV 2011.
311 ETH 2009.
312 AKTIV 2013.

WIRELESS WOLFSBURG

The *Wireless Wolfsburg* project was a concept that would provide internet connectivity to vehicles in the city. The network went live in 2008. At that time, the concept consisted of 66 wireless access points in part of the city, with each one costing approximately €2,000. At that point, the plan was to eventually install 400 access points across the city. In addition, the project was considering expanding to include other cities. The network was created to serve the Volkswagen Research Group in testing new vehicle information applications and to provide vehicle passengers with access to local information about events, cultural attractions, points of interests, weather, and traffic conditions.[313] Currently, the official website is up and running and has a map of access areas. For more information, visit the *Wireless Wolfsburg* website.[314] Figure 20 displays the WLAN coverage area for *Wireless Wolfsburg*.

FIGURE 20: WLAN COVERAGE AREA FOR WIRELESS WOLFSBURG[315]

[313] TTT 2008.
[314] Wireless Wolfsburg 2012.
[315] Wireless Wolfsburg 2011

HIGHLY AUTOMATED VEHICLES FOR INTELLIGENT TRANSPORT (HAVEIT)

The *Highly Automated Vehicles for Intelligent Transport* (HAVEit) project concentrated on partially automated vehicles and explored how drivers interact with vehicles with different levels of automation. The project ran from February 2008 to June 2011. The final event was held at the Volvo test track in Sweden. It had a total budget of €27.5 million, €17 million provided by the European Commission. The project had 17 partner organizations and was led by the automotive supplier Continental. The primary automaker partners were Volkswagen and Volvo Technology. The technology developed under HAVEit was validated and demonstrated using six prototype vehicles.[316]

THE COOPERATIVE SENSOR SYSTEMS AND COOPERATIVE PERCEPTION SYSTEMS FOR PREVENTIVE ROAD SAFETY (KO-FAS)

The Cooperative Sensor Systems and Cooperative Perception Systems for Preventive Road Safety (Ko-FAS) research initiative involved three different projects: Cooperative Transponders (Ko-TAG), Cooperative Perception (Ko-PER), and Cooperative Components (Ko-KOMP). The overall goal of the initiative was to improve road safety by developing new technology, components, and systems related to cooperative sensor and perception systems. The Ko-TAG project was largely focused on vehicle communications aspects, including V2V safety applications for vehicles in road traffic and a V2X pedestrian protection application. The Ko-PER project was focused on collecting data from distributed sensor networks and subsequently merging them (i.e., data fusion). Sensors were both mobile (vehicle-based) and stationary (RSE-based). The Ko-KOMP project was involved with the assessment of the effectiveness and value of different cooperative sensor technology approaches. These assessments involved both real-world trials and in virtual simulations.

Ko-FAS was launched on September 18, 2009 and the final event was held on September 19, 2013. The project was sponsored by the German Federal Ministry of Economics and Technology and had a budget of €25.5 million. Project partners included BMW, Continental, Daimler, Delphi, Fraunhofer Institute for Integrated Circuits, Fraunhofer institute for Communications, University of Applied Sciences in Aschaffenburg, Karlsruhe Institute of

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[316] HAVEit 2013.

Technology, Interdisciplinary Center for Traffic Sciences, SICK AG, Steinbeis Innovation Center Embedded Design and Networking, Technical University of Munich, University of Passau, and University of Ulm.[317]

DEVELOPMENT AND ANALYSIS OF ELECTRONICALLY COUPLED TRUCK PLATOONS (KONVOI)

The KONVOI (a German acronym for *Development and Analysis of Electronically Coupled Truck Platoons*) project focused on the use of Advanced Driver Assistance Systems (ADAS) to form truck platoons of up to four vehicles on public roads that could improve traffic flow, fuel consumption, and environmental performance of heavy-duty highway vehicles. This project had a €5.5 million budget, with €4 million provided by the German Federal Ministry of Economics and Technology.[318] The research team included RWTH Aachen University institutes, automotive industry partners, freight forwarding companies, a trade school, and public agencies.

The KONVOI system was composed of a LiDAR unit, radar sensors, and GPS. The system also made use of WLAN and 3G communications technologies. Using these inputs, the vehicles behind the lead vehicle in the platoon could be automatically driven using adaptive cruise control and automatic guidance applications.[319]

The KONVOI project ran from May 2005 to May 2009. Over the course of the project, platoons of two to four vehicles logged more than 3,000 kilometers in public traffic.[320] There is no direct follow-up project, however the SARTRE project based in Sweden has also focused on platoons led by commercial trucks supported by connected and automated vehicle technologies.

FUTURE TRUCK 2025

In July 2014, Daimler Trucks demonstrated its *Future Truck 2025* prototype, a truck prototype equipped with a highway pilot system on the German Autobahn. The truck uses radar as well as equipment already installed in current production vehicles (e.g., sensors and actuators used to enable

[317] Ko-FAS 2013.
[318] Shladover 2012.
[319] Jeschke et al. 2013.
[320] Deutschle et al. 2010.

automatic braking, stability control, and lane-warning features). The company plans to launch a roadworthy version of the truck by 2025.[321]

4.3 BELGIUM

ITS TEST BEDS

The *ITS Test Beds* project was created to design an ITS framework that promotes sharing among various ITS projects. The test environment was envisioned as a basis for large FOTs. The prototype software designed by *ITS Test Beds* allows test sites to centrally store test data and information so work done by one test site can be accessed and re-used by another one.[322] The environment was designed to be flexible by allowing interested parties to "plug in" their applications and components to run field tests. The resulting test environment can be used to observe performance and validate compliance of applications with European and national standards. The project is conducted by members of national ITS organizations, European research organizations, and industrial partners such as NXP Semiconductors, Technolution, TC-Matix, and Q-Free.[323] The project ran from February 2009 through September 2011.[324] The project had a €3.4 million budget, €2.3 million of which was paid by the European Union.

NEXT GENERATION INTELLIGENT TRANSPORT SYSTEMS (NEXTGENITS)

The *Next Generation Intelligent Transport Systems* (NextGenITS) project brought together some of the most prominent stakeholders in Belgium's ICT sector. The goal of the project was to create an environment where the private sector, research institutes, and governments could cooperatively come together to develop and demonstrate various intelligent transportation technologies. Partners included Alcatel-Lucent Bell, VRT-medialab, Be-Mobile, Tele Atlas, Touring, NXP Semiconductors, Group4Securicor, ITS Belgium, Mobistar, Nimera, Belgacom Group/Proximus, and Flemisch Traffic Center. Under NextGenITS, there were several subprojects for the applications to be tested including e-call, traffic information, intelligent speed

[321] Prigg 2014.
[322] Vermassen 2010.
[323] ITS Test Beds 2011.
[324] CORDIS 2013.

adaptation, road charging, and cooperative vehicle systems. The cooperative systems subproject involved determining a suitable communication platform for V2V and V2I applications. The focus of this subproject was the Communications, Air-interface, Long and Medium range (CALM) platform.[325] The NextGenITS closing event was held in March 2010.

COOPERATIVE MOBILITY SYSTEMS AND SERVICES FOR ENERGY EFFICIENCY (ECOMOVE)

The environmental initiative, *Cooperative Mobility Systems and Services for Energy Efficiency* (eCoMove), was a European Commission sponsored connected vehicle project. Its vision was the application of V2V and V2I communications technology to provide driving support and traffic management to reduce vehicular energy waste and emissions.[326]

Applications tested under eCoMove included:

- Pre-trip planning
- Dynamic driver coaching
- Traffic information
- Smart navigation assistance
- Traffic signal optimization
- Traffic management tools

The project has more than 30 partners including automakers BMW, Fiat, Ford, and Volvo. It began in April 2010 and ran through May 2013. The project's total budget was €22.5 million, €13.7 million provided by the European Commission.[327]

4.4 FRANCE

PLATEFORME AVANCÉE DE MOBILITÉ URBAINE (PAMU)/ ADVANCED URBAN MOBILITY PLATFORM (AUMP)

The Renault project *Plateforme Avancée de Mobilité Urbaine* (PAMU), or in English, the *Advanced Urban Mobility Platform* (AUMP), was designed for taxi pool applications. In brief, the concept for the platform is:

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[325] IBBT 2011.
[326] eCoMove 2012.
[327] eCoMove 2013.

- Users can reserve a vehicle through a website by inputting their departure and arrival locations.
- Once the vehicle arrives, the user is notified via text and can approach the vehicle; after the user's identity is verified, he or she can enter the vehicle and drive off.
- After the user arrives at the destination, the user can exit the vehicle, which then reenters the fleet of available taxis.

The platform is under development at Renault, which has partnered with several other organizations, including Université Technologique de Compiègne, IFSTTAR, INRIA, ENSTA ParisTech, Viveris, AcuMine, Viametris, Tecris, Cohda Wireless, and Mobileye. PAMU is being financed by the Conseil Général des Yvelines, and testing will occur on the roads of Renault's Technocentre in Guyancourt, France.[328]

SYSTÈME COOPÉRATIF ROUTIER EXPÉRIMENTAL FRANÇAIS (SCORE@F)

Similar to Germany's sim[TD], France has conducted its own field operational test for cooperative systems, known as *System Coopératif Routier Expérimental Français* (SCORE@F) (Figure 21). This project was conducted in collaboration with the DRIVE C2X project. The project is led by Renault and contains 12 industry partners, seven laboratories, and a local community.[329] The project used 30 equipped vehicles for testing. The applications studied include road safety, traffic efficiency management, and comfort uses (e.g. co-operative navigation and Internet access). The goals for the SCORE@F project are to quantify benefits of the system, identify stakeholders, validate or evolve standards and applications, develop qualification tests to ensure interoperability, and calculate deployment costs. Use cases include cooperative awareness, longitudinal risk warning, intersection collision risk warning, traffic light violation warning, green light optimal speed advisory, and electric vehicle (EV) charging, automotive sharing, and intermodal trip planning. Data collection has been done in accordance with FESTA methodology.[330]

[328] Vautier 2013.
[329] SCORE@F 2013.
[330] Segarra 2011.

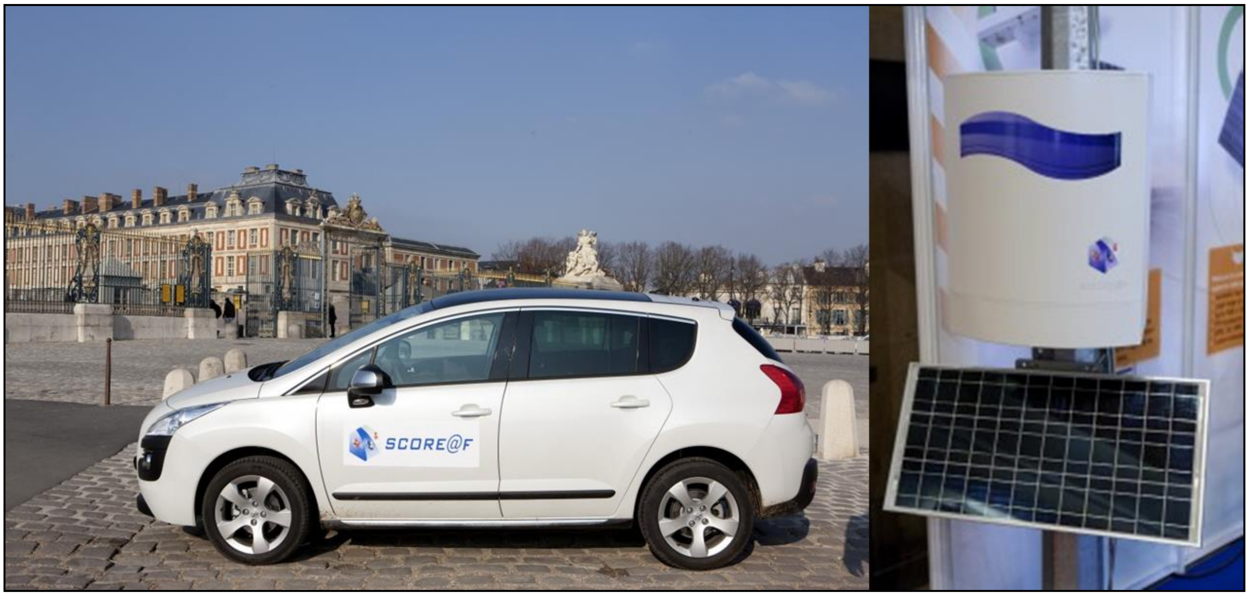

FIGURE 21: SCORE@F VEHICLE AND SOLAR ROADSIDE INFRASTRUCTURE ON DISPLAY AT ATEXPO 2012 IN VERSAILLES, FRANCE[331]

The project used simulation, test track facilities, open highways, and suburban and urban roadways.[332] The project tests are being conducted at Mov'eo-Lab, Union Technique de l'Automobile du motocycle et du Cycle, and Cofiroute SA-A10 Highway.[333] The project was launched in September 2010.[334] Development for the project took place from March 2011 to March 2012. The evaluation phase was completed in 2013. The final event for SCORE@F was held on September 24, 2013.[335]

The technology used for the project was based on 802.11p and 2G/3G technologies.[336] The total budget for the project was €5.6 million, with €2.7 million from public sources and €2.9 million from private sources.[337]

CYBERCARS

CyberCars-2 was the follow-up to the *CyberCars* and *CyberMove* projects. All three included components relating to V2V and V2I communications. In particular, the CyberCars-2 addressed V2V communications between vehicles

[331] SCORE@F 2012.
[332] SCORE@F 2013.
[333] COMeSafety 2010.
[334] COMeSafety 2010.
[335] SCORE@F 2013.
[336] INRIA 2012.
[337] SCORE@F 2013.

running at close range (platooning) and V2I communications at intersections (merging, crossing). CyberCars-2 is based on a cooperative cybernetic transport system architecture that is compatible with Car2Car Communication Consortium and CALM standards. The project's vision was based on the idea that eventually urban vehicles will be fully automated. For testing, the project used existing vehicles from the French National Institute for Research in Computer Science and Control (INRIA). The communication technologies and control algorithms installed in those eight vehicles were upgraded for the project. In addition, other Cybercars available in Spain, China, and Australia were used for the project. The project included the construction of a small-scale system which was prototyped based on a fleet of Cybercars. Road testing occurred in La Rochelle, France. The project began in January 2006. Runs at the test track occurred in September 2008. The final report for the project was submitted in February 2009.[338] The project resulted in the development of dual-mode vehicle prototypes capable of autonomous and co-operative driving, a communication architecture that was implemented in testing, algorithms for various maneuvers, a management center to support communications, and a simulation for evaluating the impact of larger deployments.

SECURE VEHICULAR COMMUNICATION (SEVECOM)

Secure Vehicular Communication (Sevecom) was an EU-funded project that ran from 2006 to 2009. The focus of the Sevecom was to provide, define, and implement security requirements for vehicular communications. Sevecom addresses security of vehicle communication networks, including both V2V and V2I data security. The project defined security architecture of networks and proposed a roadmap for integrating security functions. The Sevecom baseline architecture is not based on a fixed platform; it was created to be flexible so it could adapt to future changes in applications or technologies. This flexibility in design was required because protocols, system architectures, and security mechanisms are continuously changing.[339] There were three major aspects that were emphasized in the project: threats, (bogus information, denial of service, or identity cheating), requirements (authentication, availability, and privacy), and operational properties (network

[338] CyberCars2 2009.
[339] Kargl et al. 2008.

scale, privacy, cost, and trust). Sevecom presented a demo at a at the 2009 ITS World Congress.[340]

AUTOMATISATION BASSE VITESSE (ABV)

Automatisation Basse Vitesse (ABV) focused on automation for low-speed vehicles. The project had a €5.5 million budget and was financed by the French National Agency for Research (€2.2 million). It was also supported by the French automotive cluster Mov'eo and a consortium of INRETS, Continental, IBISC, IEF, Induct, INRIA, LAMIH, Viametris, UHA – MIPS, and Véolia Environnement Recherche & Innovation. The project's goal was to use automation to improve fuel economy for vehicles driving in congested traffic on urban and suburban freeways. The project produced two prototypes, simulation tools, and an impact study. The project began in October 2009 and was scheduled to finish in October 2012.[341]

4.5 ITALY

INTELLIGENT CO-OPERATIVE SYSTEM IN CARS FOR ROAD SAFETY (I-WAY)

In Italy, safety has been the motivation for connected vehicle-related activities as well. One of these projects was the *Intelligent Co-Operative System in Cars for Road Safety* (I-WAY) project, which had the goal of enhancing driver perception of the road, thereby improving safety. The project encompassed both V2V and V2I communications and lasted from February 2006 to January 2009. It integrated in-vehicle subsystems with the external transport system with the goal of greater safety. I-WAY's driving platform monitors and recognizes the road environment and the driver's state in real time using data obtained from three sources: a vehicle sensing system, data from road infrastructure, and data from neighboring cars. The I-WAY platform combined two independent sub-systems, the in-vehicle subsystem and the external transport subsystem. The in-vehicle subsystem includes modules for vehicle sensing, data acquisition, mobile interfaces of the vehicle, situation assessment, and communication. The external transport system includes the roadside equipment and the road management system. Funded under the Sixth

[340] Sevecom 2011.
[341] ABV 2013.

Framework Programme, the total cost for the project was €4.59 million, €2.6 million from the European Commission.[342]

TEST SITE ITALY

Located in northern Italy, the Brennero test site used for the DRIVE C2X project is a 49 kilometer stretch of the Autostrada del Brennero (A22). The site was operated by Fiat and the motorway operator Autostrada del Brennero SpA. The stretch is a two-lane tollway with room for a provisional third lane on the shoulder. A shorter nine kilometer section has higher equipment density for tests involving V2I communication. The speed limit along the test site is 130 kilometers per hour.[343]

Applications tested include:[344]

- Traffic warnings
- Construction warnings
- Car breakdown assistance
- Slow vehicle warnings
- Traffic sign assistance
- Point of interest notification

The test fleet used at the site included ten equipped vehicles. Network coverage along the site included UMTS/3G, GPRS, and 802.11p. Equipment along the stretch included five roadside units, variable message signs, TVCC cameras, traffic loops, Ethernet connectivity (traffic control center and roadside units), and on-site processing modules.[345] All of the Brennero testing has been done on the public road. Closed testing areas are proximate to the A22 stretch.

SMART VEHICLES ON SMART ROADS (SAFESPOT)

Smart Vehicles on Smart Roads (SAFESPOT), was another connected vehicle project conducted in Italy. It was co-financed by the EU's Sixth Framework Programme for Research and Technological Development. The project brought together more than 50 partners including original equipment manufacturers (OEMs), operators, and research organizations from across

[342] European Commission 2011a.
[343] DRIVE C2X 2012.
[344] DRIVE C2X 2012.
[345] DRIVE C2X 2012.

Europe. The SAFESPOT project was one of the European flagship projects for cooperative mobility. It aimed to prevent crashes by using a safety margin assistant that detects an appropriate following distance between cars. As with I-WAY, SAFESPOT employed both V2V and V2I communication to enhance the vehicle's field of view. The SAFESPOT architecture complies with the European ITS architecture which allocates the 30 MHz frequency band in the 5.9 GHz range to connected vehicle safety applications.[346] The project tested applications and scenarios through work done at six different test sites, each in a different country that had infrastructure equipped with SAFESPOT systems. Four of these test sites were shared with the CVIS project. All six sites are displayed in Figure 22. The Cooperative Mobility Showcase 2010, which took place in Amsterdam on 23-26 March 2010, was one of the world's largest demonstrations of connected vehicle technologies and applications. SAFESPOT demonstrated there and had a very strong presence.[347]

FIGURE 22: SAFESPOT TEST SITE LOCATIONS[348]

[346] Brakemeier et al 2009.
[347] SAFESPOT 2011.
[348] SAFESPOT 2011.

FIELD OPERATIONAL TEST SUPPORT ACTION (FESTA)

Italy also hosted the *Field Operational Test Support Action* (FESTA), which was a comprehensive research program assessing the impacts of information and communication technology systems on driver behavior, covering both individual safety benefits and broader socio-economic benefits. While the work on FESTA finished in April 2008, it laid the foundation for many other European FOTs. The objectives for FESTA included generating expertise and experience to promote the creation of a best practice handbook for the design and implementation of FOTs, providing additional guidance on how FOTs should be undertaken and reported, and involving major stakeholders to create a common vision. The project was coordinated by Centro Ricerche Fiat and consisted of a broad consortium of partners including A.D.C. Automotive Distance Control Systems GmbH, BMW Forschung und Technik GmbH, Bundesanstalt fuer Strassenwesen, Chalmers University of Technology, DaimlerChrysler AG, Delphi France, ERTICO – ITS Europe, Gie Recherches et Etudes, PSA Renault, Infoblu S.p.A., Institut National de Recherche sur les Transports et leur Sécurité, Loughborough University, Orange France, Robert Bosch GmbH, Statens Väg-och Transportforskningsinstitut, Netherlands Organization for Applied Research (TNO), Universitaet zu Koeln, University of Leeds, Valtion Teknillinen, Volvo Car Corporation, and Volvo Technology Corporation.[349]

VISLAB INTERCONTINENTAL AUTONOMOUS CHALLENGE

The VisLab Intercontinental Autonomous Challenge is similar to events like the DARPA Grand Challenge. It involved a fleet of four automated vehicles traveling with little to no human intervention from Parma, Italy to Shanghai, China. The nearly 16,000 kilometer journey began on July 20, 2010 and ended on October 28, 2010. The idea for this challenge originated in 2007, but work on the project did not begin until January 2009. Funding for the project was provided by the European Research Council and VisLab.[350]

[349] ERTICO 2012.
[350] VisLab 2013.

4.6 NETHERLANDS

DUTCH INTEGRATED TESTSITE FOR COOPERATIVE MOBILITY (DITCM)

The portion of the DRIVE C2X project conducted in the Netherlands is the *Dutch Integrated Testsite for Cooperative Mobility* (DITCM). The DITCM was located on a stretch of highway containing several intersections. It had full coverage from both 802.11p and cameras. The Netherlands site was used as the "master" test site where all applications under DRIVE C2X were tested before being deployed at the other six sites.[351]

The test site was 4.2 kilometers of highway and 1.8 kilometers of urban roadway, along which 20 vehicles with installed on-board units conducted tests. The stretch contained two traffic lights, four viaducts, an entrance and exit, and a bus entrance. There were 48 poles for equipment installation, which currently includes 11 communications units (802.11p), 47 fixed cameras, and nine dome cameras. Network coverage includes UMTS/3G, 802.11p, and dGPS.[352]

CONNECTED CRUISE CONTROL (CCC)

The €4 million *Connected Cruise Control* (CCC) project sought to create a built-in solution to provide driving advice regarding speed, headway, and lane so drivers can anticipate and prevent congestion.[353] The technology uses in-vehicle and roadside systems to improve traffic flow. The plans are to initially market it as a nomadic aftermarket device in order to increase penetration rate and make the technology attractive for inclusion in OEM vehicle systems. The project began in December 2009.[354] The final event for the project was held in March 2013.[355] Testing and evaluation occurred during 2012 and product development began in 2012 and ran through 2013. The partnership was headed up by TU Delft and included Navteq, NXP Semiconductors, TNO, Universiteit Twente, SAM, Technolution, and Clifford.[356]

[351] DRIVE C2X 2012.
[352] DRIVE C2X 2012.
[353] HTAS 2012.
[354] University of Twente 2012.
[355] TUDelft 2013.
[356] HTAS 2012.

STRATEGIC PLATFORM FOR INTELLIGENT TRAFFIC SYSTEMS (SPITS)

The goal of the *Strategic Platform for Intelligent Traffic Systems* (SPITS) project was to build the next generation of on-board technology for connected vehicles and to make it open and easily configurable for OEM specific requirements. The units created were upgradeable, allowing for improvements during the lifetime of an automobile, and decreasing the amount of time required for the adoption of new technologies. The project also focused on creating the next generation of roadside units and back office equipment.[357] Project partners included Logica, NXP Semiconductors, Catena, GreenCat, Peek Traffic, Nspyre, Fourtress, TNO, and TomTom, as well as several universities throughout the Netherlands.[358] Experimental testing for SPITS was conducted on the A270 highway in the Netherlands between Helmond and Eindhoven. A total of 48 video cameras were mounted along a 5-km stretch of the A270. Those cameras provide overlapping coverage of all vehicle movements along that stretch. The project was funded by the Dutch Ministry of Economic Affairs and 13 partners. The project officially ended in May 2011.[359]

The SPITS A270 test site was also used for field tests of *Advisory Acceleration Control* (AAC) and *Shock Wave Mitigation with Mixed Equipped and Unequipped Vehicles*. The AAC test occurred in February 2010 and involved 48 vehicles equipped with communications technology and a display capable of advising drivers to accelerate, decelerate, or maintain their current speed. The advisory speeds were determined using real-time traffic data provided by the cameras monitoring the road. The goal of the test was to determine if communications technology could dampen traffic shock waves on the highway. The test was designed such that one lane contained the equipped vehicles, and another lane contained another 48 unequipped vehicles. The lead vehicles in both lanes drove with speed variations intended to create shock waves. The results demonstrated that the AAC system was able to smooth traffic flow without requiring vehicles to be equipped with expensive adaptive cruise control systems.

The second field test, *Shock Wave Mitigation with Mixed Equipped and Unequipped Vehicles*, occurred in 2011. As with the AAC tests, advisory

[357] CVIS 2012.
[358] SPITS 2012.
[359] SPITS 2012

speeds were generated from real-time camera-based traffic data. The test involved 70 vehicles. Of those vehicles, eight were equipped with cooperative adaptive cruise control technology and twelve had the AAC driver advisory displays. Even with mixed vehicles on the same road, the equipped vehicles were able to help reduce shockwaves. Vehicles with cooperative adaptive cruise control were somewhat more effective at mitigating shockwaves than vehicles with just the driver display.[360]

OPEN PLATFORM FOR INTELLIGENT MOBILITY (OPIM)

The follow up to SPITS is the *Open Platform for Intelligent Mobility* (OPIM) project, which is working to define an open platform for ITS systems across Europe. Among the program's goals are to keep the system affordable and flexible so it can be applied to the full range of transport vehicles, including cars, coaches, light trucks, and heavy goods vehicles. OPIM builds on lessons learned by the SPITS Project as well as programs and projects in which partners have participated - including CVIS, COOPERS, SAFESPOT, PRE-DRIVE C2X, ITS Test Beds, AUTOMATICS (France), AKTIV (Germany), sim^{TD} (Germany), NextGenITS (Belgium/Flanders). The project is designed to become the realistic start of ITS on a broad scale.[361]

SENSOR CITY

Sensor City was a pilot for sensor-based mobility services in and around the city of Assen in the Netherlands.[362] The pilot project makes use of data recorded by infrastructure as well as in-vehicle devices to support mobility applications.

The project involved TNO, Goudappel Coffeng, Quest Traffic Consultancy, DySI, NXP, ParkingWare, Elevation Concepts, Reisinformatiegroep, Peek Traffic, Mobuy, Magicview, Univé, TomTom, City of Assen, Province of Drenthe.

The *Sensor City* project began in January 2010 and ran through the end of 2013. The pilot itself took place in 2012 and the beginning of 2013. It involved 1,000 test users with in-car systems and 500 users with smartphone applications (partial overlap).

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360 Shladover 2012.
361 HTAS 2012.
362 Sensor City 2013.

PREPARING SECURE VEHICLE-TO-X COMMUNICATION SYSTEMS (PRESERVE)

The *Preparing Secure Vehicle-to-X Communication Systems* (PRESERVE) project will run from January 2011 through December 2014. The partners are escrypt, Fraunhofer Institute for Secure Information Technology, Kungliga Tekniska Högskolan, Renault, Trialog, and University of Twente. The project's advisory board includes Audi, BMW, Daimler, Denso, Infineon, and Volkswagen. CAMP Consortium and sim^{TD} are supporting members of the project.

The project is focused on the security and privacy of connected vehicle systems and will involve addressing critical issues like performance, scalability, and deployability of connected vehicle security systems. PRESERVE will make use of field testing to investigate a number of important scalability and feasibility issues. The budget for the project is €5.4 million, €3.9 million from the European Commission.[363]

GRAND COOPERATIVE DRIVING CHALLENGE

Inspired by the DARPA Grand Challenges in the United States, the *Grand Cooperative Driving Challenge* in the Netherlands required competing teams to develop a vehicle equipped with the most effective CACC system. The May 2011event was organized by TNO and the Dutch High Tech Automotive Systems (HTAS) innovation program. The competition attracted nine international teams. It was structured to focus on the application of automated vehicle following in normal traffic, which distinguished the challenge from platooning projects, which tend to be more structured and uniform.[364]

4.7 SPAIN

SISTEMAS COOPERATIVOS GALICIA (SISCOGA)

The *SIStemas COoperativos Galicia* (SISCOGA) project participated in DRIVE C2X with its test site in northwestern Spain. The test site runs along two highway corridors (A-52 and A-55) and is around 60 kilometers long. This road network is displayed on a map in Figure 23. Centro Tecnológico de

[363] PRESERVE 2013.
[364] Ploeg et al. 2012.

Automoción de Galicia (CTAG) and Dirección General de Tráfico (DGT)—the Spanish Ministry of Traffic—have created and operate the site.[365]

Applications tested included:[366]

- Construction warnings
- Car breakdown assistance
- Traffic warnings
- Post-crash warnings
- Emergency brake warnings
- Cooperative merging assistance
- Weather warnings
- Traffic sign assistance
- Speed limit notification
- Traffic information and recommended itinerary
- Floating Car data

365 DRIVE C2X 2012.
366 DRIVE C2X 2012.

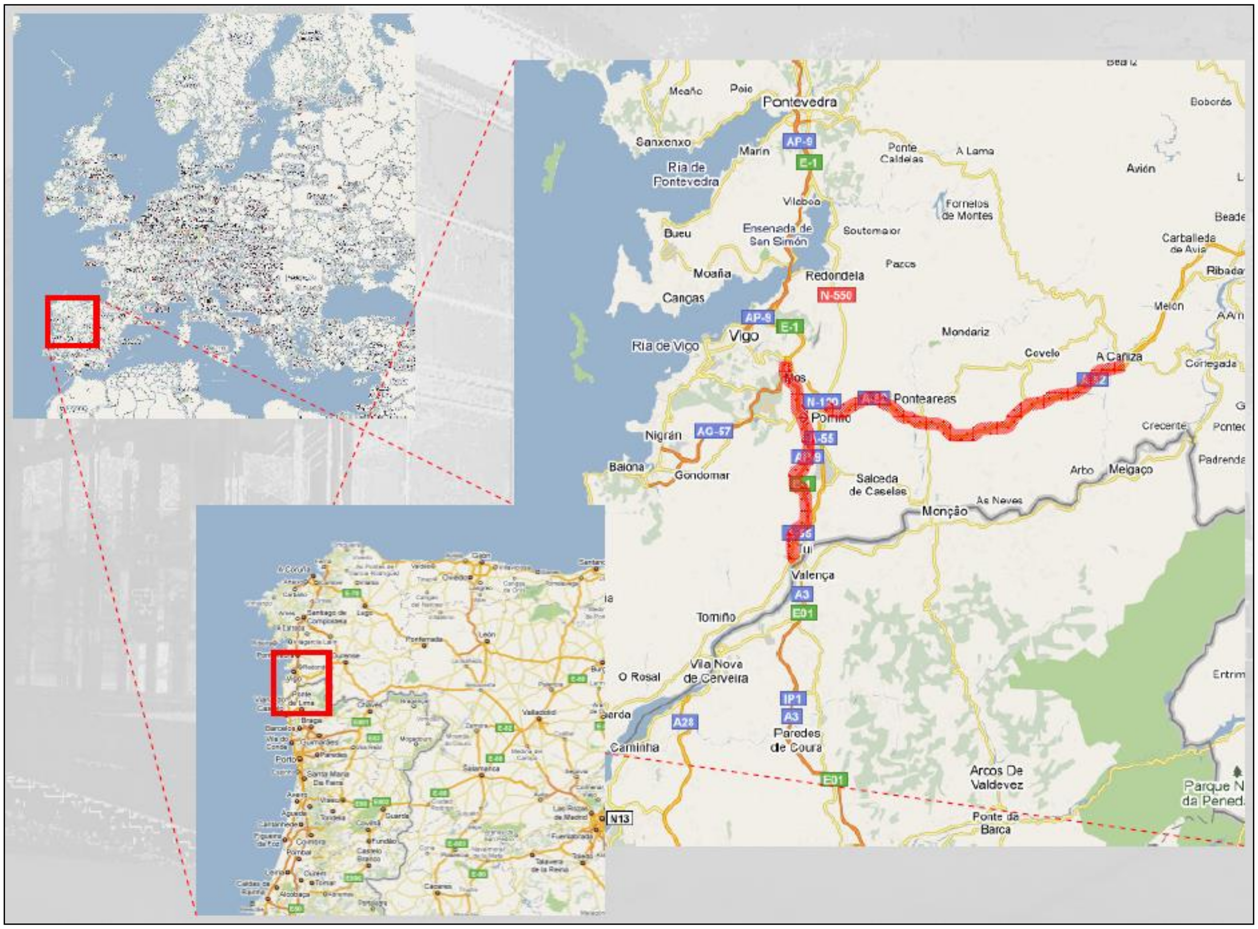

FIGURE 23: MAP OF SISCOGA TEST AREA[367]

The speed limit along the test corridors is generally 120 kilometers per hour, but in places decreases due to features such as curves or visibility limitations. The test area contains 15 roadside units (5.9 GHz, 802.11p), with another 30 planned for deployment. In addition, there are 19 variable message signs, seven meteorological stations, 21 camera units, and inductive wiring spots located along the corridors. Network technology includes GPRS, UMTS, and 802.11p. The test area currently contains only highways, but current plans involve extending the test site to include urban areas.[368] Some of the equipment used in testing is displayed in Figure 24.

[367] Sánchez Fernández 2010
[368] DRIVE C2X 2012.

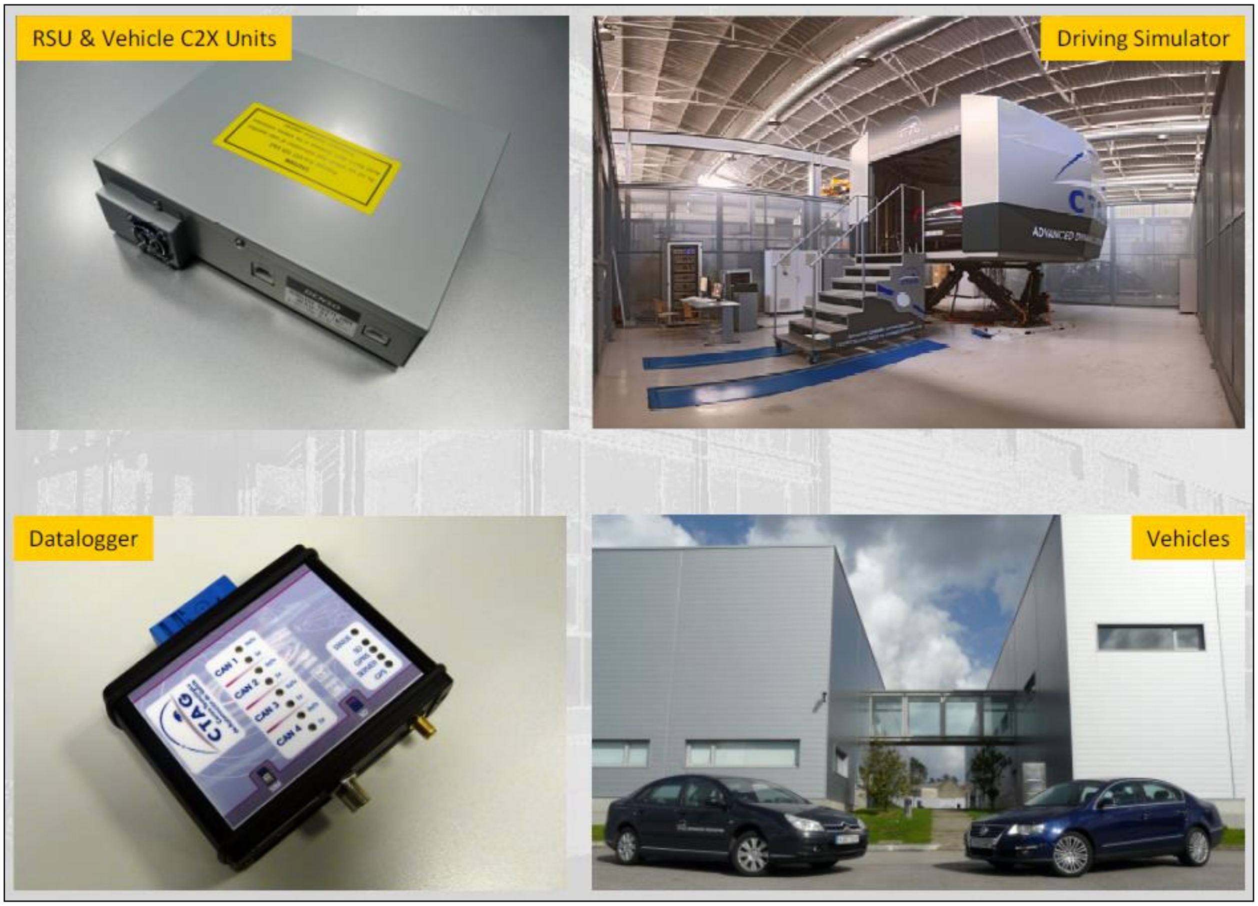

FIGURE 24: SISCOGA EQUIPMENT[369]

Initially, there were seven vehicles (three prototypes and four personal vehicles) used to conduct tests, but the plan was to eventually expand the fleet to include 20 vehicles used to conduct tests, with the majority being personal vehicles.[370] Those 20 vehicles were equipped with 5.9 GHz on-board communication units, GPS, specific human-machine interface (HMI), and controller area network (CAN) logging. The test also included 80 vehicles equipped with just GPS and UMTS units. SISCOGA was a follow-up project to C2ECom, which was also led by CTAG.[371] The project ran from September 2009 to September 2011. The testing occurred from August 2010 to July 2011.[372]

[369] Sánchez Fernández 2010
[370] DRIVE C2X 2012.
[371] Sánchez Fernández 2010.
[372] FOT-NET 2013.

4.8 SWEDEN

DRIVE ME – SELF-DRIVING CARS FOR SUSTAINABLE MOBILITY

In spring 2014, Volvo announced its *Drive Me – Self-Driving Cars for Sustainable Mobility* pilot project, which will ultimately have 100 highly-automated vehicles driving alongside regular traffic on 50 kilometers (30 miles) of public roads in and around the city of Gothenburg, Sweden.[373] The project is currently in the customer research and technology development phase. The full-scale test will begin in 2017.[374]

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.[375] The stakeholders in the project are Volvo Car Group, the city government of Gothenburg, legislators, transportation authorities (including the Swedish Transport Administration and the Swedish Transport Agency), Lindholmen Science Park, and the customers who will eventually be using the 100 test vehicles.[376]

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 Gothenburg, Sweden. Volvo, along with its industry and university partners, will use the AstraZero 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.[377]

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). The proving ground is surrounded by

373 Volvo 2014a.
374 Newcomb 2014.
375 Newcomb 2014.
376 Volvo 2014a.
377 Volvo 2014b.

a 5.7 kilometer (3.5 mile) highway. Test environments include rural roads, city areas, multilane roads, and a high-speed area.[378]

SAFER (DRIVE C2X GOTHENBURG SITE)

The SAFER Vehicle and Traffic Safety Centre at Chalmers University is "a joint research unit where 24 partners from the Swedish automotive industry, academia and authorities cooperate to make a center of excellence within the field of vehicle and traffic safety".[379] Research at SAFER covers a broad range of fields relating to traffic safety and includes connected vehicle technologies.[380] The SAFER Vehicle and Traffic Safety Centre managed the Gothenburg test site used during the DRIVE C2X project.

The large-scale test site in Gothenburg was located in southern Sweden. The city is the nexus of three major highways. In addition to the open road track, the project also used closed testing facilities. SAFER has operated the test site since 2008.

The open road portion of the testing area consists of more than 100 kilometers of highway, 100 kilometers of urban roadway, and more than 50 kilometers rural roadway. These stretches have more than 100 traffic light controlled intersections.

The closed testing facilities used for the DRIVE C2X project included Stora Holm and the City Race Track. Stora Holm is a Volvo test track that is used for testing safety critical applications and other applications involving non-traffic regulation compliant performance. The City Race Track opened in October 2009 and has hosted numerous demonstrations of cooperative systems.[381]

Functions tested at the Gothenburg site included:[382]

- Traffic warnings
- Construction warnings
- Car breakdown assistance
- Traffic sign assistance
- Optimal speed advisory for traffic lights,

[378] Volvo 2014b.
[379] Chalmers 2012.
[380] Chalmers 2010a.
[381] DRIVE C2X 2012.
[382] DRIVE C2X 2012.

- Floating car data

The testing made use of seven roadside units as well as three traffic light controllers using 802.11p and VMSs on the main highway. On-board units were provided by Delphi, and equipment from EuroFOT included touch screens, naturalistic loggers and cameras. Network technologies used included UMTS, 3G, GPRS, and 802.11p. The Gothenburg test fleet was composed of 20 cars.[383]

In June 2013, the last major demonstration event for the project was held. In addition to the demonstrations themselves, the event involved several workshops.[384]

TEST SITE SWEDEN (TSS)

Another major project carried out at SAFER was *Test Site Sweden* (TSS) which ended in 2008. TSS was a joint project between Autoliv, Chalmers, Volvo Car Corporation and AB Volvo. The project was very important for building-up competence in and establishing tools for conducting FOTs. Driving data was collected using two vehicles driven by 100 different drivers over the course of six months. The two test vehicles were provided by Volvo and included a car (Volvo S80) and a truck (Volvo FH12). These vehicles and the equipment installed in them can be seen in Figure 25 and Figure 26. The project was very useful in positioning Sweden to take a strong role in proposal phases for a number of important European projects including FESTA, Sweden-Michigan Naturalistic Field Operational Tests (SeMiFOT), and EuroFOT as well as future FOT-related projects.[385]

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[383] DRIVE C2X 2012.
[384] DRIVE C2X 2013.
[385] SAFER 2008.

FIGURE 25: VOLVO FH12, CAMERAS, AND LOCATION FOR SYSTEM INSTALLATION IN SIDE COMPARTMENT[386]

FIGURE 26: VOLVO S80, CAMERAS, AND LOGGER INSTALLATION IN LUGGAGE COMPARTMENT[387]

BASFOT

Another FOT that SAFER has been involved with is Sweden's BasFOT. The BasFOT activities began in 2007.[388] The original BasFOT project is complete, but plans for a follow-up project were released. Phase 1, the original BasFOT project, which involved building-up competence in conducting an FOT, occurred in the 2009 through 2010.[389] Limited information is available on BasFOT2, the second phase of the project, which began in 2010. BasFOT2 involves continuing to build competency and working on strategy and platform management. It also includes secondary analysis and doctor of philosophy (PhD) projects.[390] Potential for a phase three remains.[391]

386 SAFER 2008.
387 SAFER 2008.
388 FOT-NET 2010.
389 Bärgman 2010.
390 Victor 2010.
391 Bärgman 2010.

SWEDEN-MICHIGAN NATURALISTIC FIELD OPERATIONAL TESTS (SEMIFOT)

In 2007, MDOT, the Michigan Economic Development Corporation (MEDC), the Swedish Governmental Agency for Innovation Systems, and the Swedish Road Administration (Vägverket) signed a cooperative VII research agreement[392] that was intended to foster cooperative, international research efforts between these organizations. Such efforts are underway, especially in the area of road weather information systems (RWIS).

The work with MDOT led to the *Sweden-Michigan Naturalistic Field Operational Test*s (SeMiFOT and SeMiFOT2). SeMiFOT was intended to be a pilot project for a larger FOT, but resulted in several large scale FOTs including EuroFOT and TeleFOT. Projects that have benefited from the work done on SeMiFOT include FESTA, EuroFOT, FOT-NET, BasFOT, TeleFOT, and DREAMi. Testing involved seven Volvo cars, three SAAB cars, two Volvo trucks, and two Scania trucks. Over the six months of testing, there were nearly 8,000 trips totaling over 170,000 km and lasting nearly 3,000 hours. There were 39 different drivers. Equipment that was installed on vehicles included eye trackers, CAN-gateways, cameras, IR illumination, accelerometers, Ethernet devices, GPS devices, wireless communications devices (GPRS/3G), and hard drives. The follow-up project, SeMiFOT2 began in January 2010.[393]

SAFE ROAD TRAINS FOR THE ENVIRONMENT (SARTRE)

The *Safe Road Trains for the Environment* (SARTRE) project was led by Volvo and Ricardo. Other members included Idiada (Spain), Robotiker (Spain), the Institut für Kraftfahrwesen Aachen (Germany), and the SP Technical Research Institute of Sweden (Sweden). The project's budget was €6.4 million with around 60 percent of the funding being provided by the European Commission.[394] The main goal of the project was to develop and test vehicles that can autonomously drive in long convoys or road trains. A visualization of the concept can be seen in Figure 27. The project began in September 2009 and was scheduled to be completed by the end of August

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392 MDOT 2007.
393 Chalmers 2010b.
394 McKeegan 2012.

2012.[395] The first demonstrations were conducted at the Volvo Proving Ground near Gothenburg in Sweden in 2010.[396]

In May 2012, a demonstration on public roads occurred outside Barcelona, Spain. The public roads demonstration featured a Volvo XC60, a Volvo V60, a Volvo S60 and a truck following a lead vehicle at 85 kilometers per hour with tested distances between vehicles ranging between five and 15 meters. Testing involved having the vehicles drive 200 kilometers in a single day. During testing, the follower vehicles were able to accelerate, brake, and turn synchronized with the lead vehicle, maintaining a consistent following distance despite these maneuvers.[397]

The test vehicles were equipped with cameras, radar, laser sensors, navigation systems, and transmitter/receiver units installed that will allow them to take measurements and communicate with each other. Because the system is V2V only, no infrastructure testing is involved.[398] The system itself has been designed such that it does not require expensive additions to the vehicles.The only difference between SARTRE cars and those in today's showrooms is the wireless network equipment installed in the vehicles. In addition, the system design allows existing vehicles to be retrofitted with the technology.

[395] SARTRE 2014.
[396] SARTRE 2014 and McKeegan 2012.
[397] McKeegan 2012.
[398] TTT 2009a and McKeegan 2012.

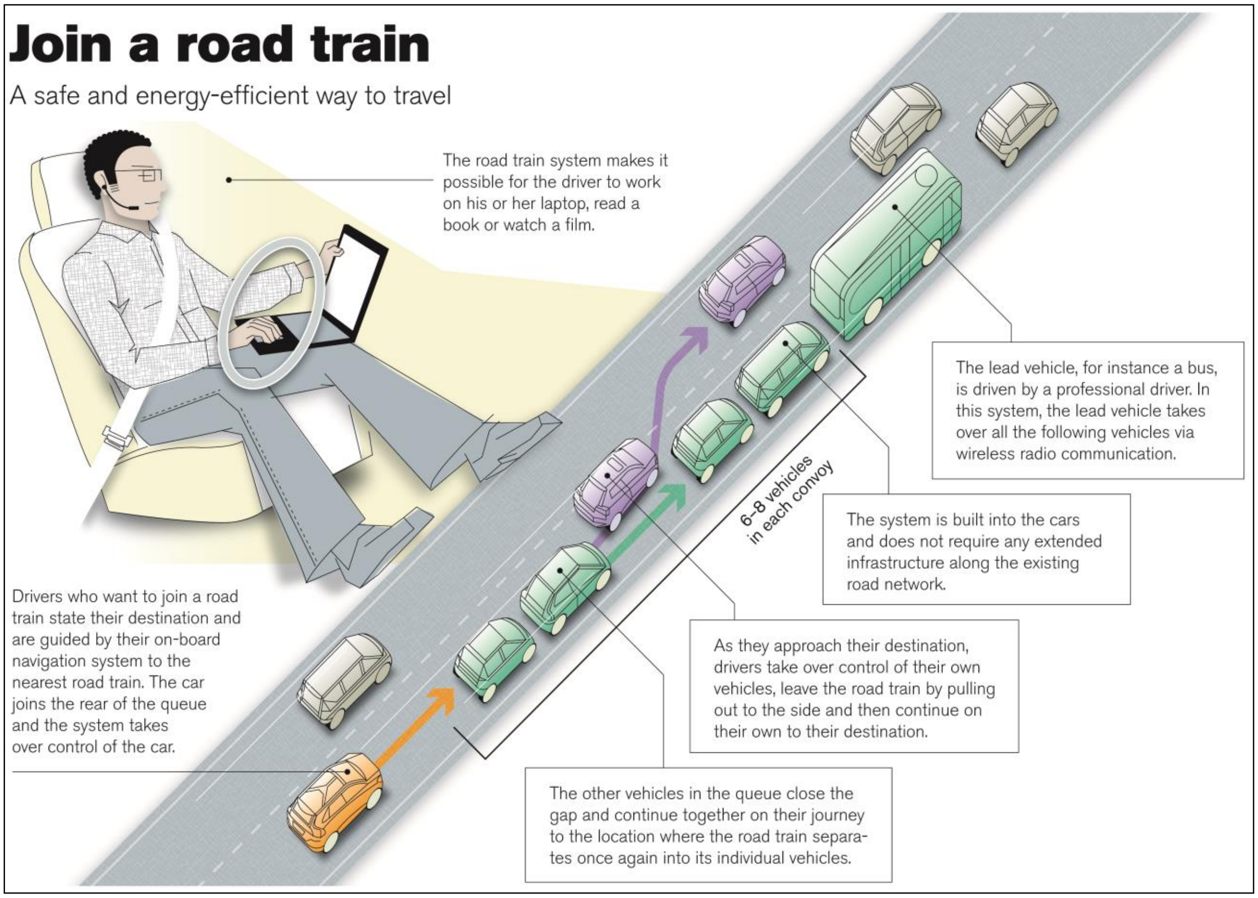

FIGURE 27: SAFE ROAD TRAINS FOR THE ENVIRONMENT PLATOONING CONCEPT[399]

SAFETY IN 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* that is intended to eliminate traffic-related deaths and incapacitating crashes.[400] This program is managed by the Swedish Road Administration. While the program recognizes that it is impossible to prevent all crashes from occurring, it focuses on protecting the vehicle passengers as much as possible. Essentially, *Vision Zero* places a greater responsibility for road safety on those who design road networks and build vehicles as opposed to placing most of the responsibility on the driver. Specific approaches include installing central safety barriers to reduce the number of head-on collisions, building more roundabouts, and

[399] SARTRE 2014.
[400] Whitelegg and Haq 2006.

lowering speed limits in urban areas.[401] Approaches under consideration include redesigning intersections and removing rigid roadside objects like trees and large rocks.

Sweden also integrates advanced automotive electronics into its *Vision Zero* plan. One example of this integration is Sweden's *Slippery Road Information System* (SRIS). Led by Vägverket, in cooperation with Volvo and Saab, this program places sensors in the vehicles that detect slippery spots on the road. These sensors then send information back to traffic management centers, which therefore can better manage plowing snow, salting roads, and alerting drivers of icy spots. In addition, SRIS compares the vehicle-based sensor data with information obtained from RWIS, such as air and surface temperatures, humidity, and barometric pressure, to validate the vehicle sensor data.[402] During the winter of 2007-2008, the SRIS partners conducted tests using 100 vehicles, and these tests clearly demonstrated that SRIS is cost effective and increases safety on the roads.[403] The SRIS project is expected to help Sweden meet its *Vision Zero* objectives.

Another advanced automotive electronics development arising from Sweden is Volvo's optional collision avoidance package, as well as its blind spot detection and front and back parking assistance applications.[404] Several other promising safety technologies are under development, such as built-in alcohol sensors, night vision systems, and adaptive cruise control, to ensure that drivers maintain a safe distance from vehicles ahead. While these examples largely represent autonomous, as opposed to cooperative, technologies, the latter also are under development in Sweden.

While Sweden already had a very low number of traffic fatalities compared to other countries before *Vision Zero* went into effect, the program appears to have worked well. Between 1997 and 2007, the first ten years of *Vision Zero,* the number traffic fatalities decreased by more than 20 percent, from 541 to 431.[405]

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[401] Whitelegg and Haq 2006.
[402] Vägverket Document 2007.
[403] SRA 2008.
[404] Volvo 2011.
[405] Wiles 2007.

4.9 AUSTRIA

CO-OPERATIVE SYSTEMS FOR INTELLIGENT ROAD SAFETY (COOPERS)

Headed up by AustriaTech in Austria, the *Co-operative Systems for Intelligent Road Safety* (COOPERS) project used existing equipment and infrastructure as a foundation when developing standardized wireless bidirectional infrastructure-vehicle technology.[406] The project included 39 partners and ran from 2006 to 2010. The project included several demonstration sites across Europe including stretches of roadway in Austria, Belgium, France, Germany, Italy, and Netherlands. These sites are marked on the map in Figure 28. COOPERS service messages were generated out of existing data sources and no additional sensor installations were needed. The *Traffic Information Platform* (PVIS) for COOPERS was a common platform for easier access to all the traffic information sources and systems, such as traffic messages, travel times, weather data, and variable message sign states.[407]

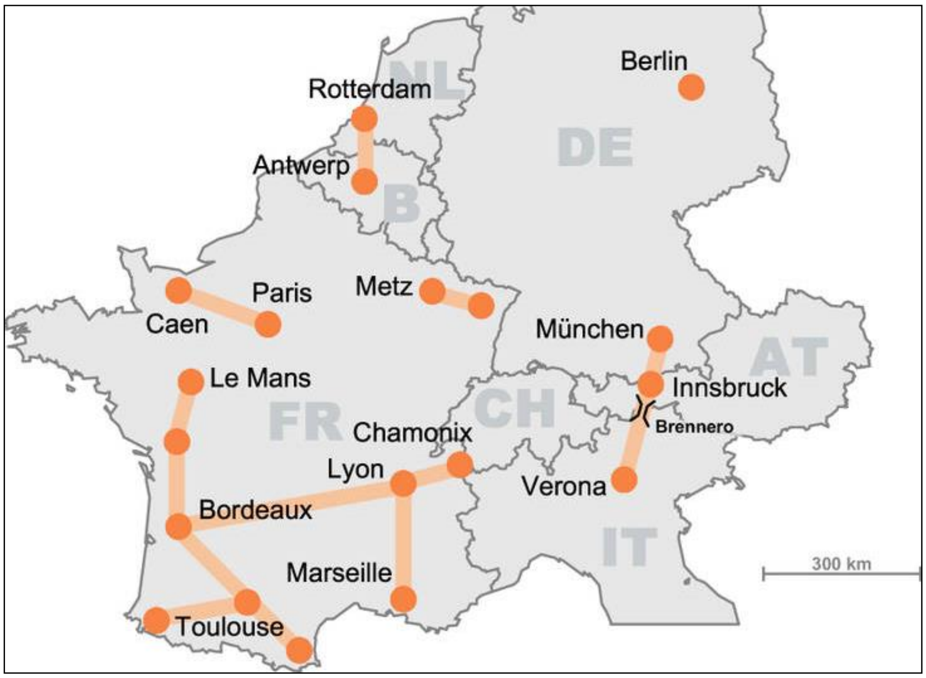

FIGURE 28: LOCATIONS OF COOPERS TEST SITES[408]

[406] Schalk 2011.
[407] Meckel 2008.
[408] COOPERS 2011

TESTFELD TELEMATIK

The *Testfeld Telematik* project began in March 2011 and ran through October 2013.[409] The area covered by the project is near Vienna and includes highways A4, A23, and S1. During a one-year test period, approximately 3,000 Vienna-area drivers were involved in testing cooperative, connected vehicle services. The project had 14 project partners and was been funded by Klima- und Energiefond (KLiEn), the Austrian Climate and Energy Fund.[410]

Testfeld Telematik used a variety of technologies and equipment, including navigation devices, smartphone applications, on-board equipment, and the COOPERS operating platform. The project tested a large number of cooperative services, including:

- In-vehicle traffic signs
- Real-time traffic data
- Warnings (e.g., events, road condition, congestion, road work, and weather)
- Real-time routing
- Travel dates and times, status messages, and routing updates
- Flight delay status
- Location and availability of parking facilities
- Public transport recommendations

4.10 FINLAND

COOPERATIVE TEST SITE FINLAND (COOP TS FINLAND)

The Finnish test site for DRIVE C2X included an eight kilometer open road stretch from Tampere to Hervanta as well as a closed test area. The open road section contained three roadside ITS units (802.11p) and one moveable roadside unit (3G/802.11p). The route also contained a motorway junction, which will be used to monitor ramp issues.[411] The layout of the open road test site can be seen in Figure 29.

[409] Testfeld Telematik 2014.
[410] Testfeld Telematik 2014.
[411] Laitinen 2012.

The closed test facility was Nokian Tyres Proving Ground in Ivalo, Finland. The Nokian Tyres facility can simulate almost any driving situation. The track includes an 1,800 meter long lap, a 400 meter long straight, five intersections, and a reduced-visibility turn. The track tests made use of the moveable roadside unit for V2I tests[412] as well as two fully instrumented VTT vehicles.[413]

The tests used three DRIVE C2X compliant vehicles with another 40 vehicles outfitted with 3G connectivity.[414] Applications tested included:[415]

- Road weather warnings
- Construction warnings
- Traffic sign assistance
- Car breakdown assistance
- Slow vehicle warnings
- Emergency vehicle warnings

On September 20, 2012 an ITS seminar was held in Tampere. The seminar included demonstrations and a presentation of the test site.[416]

412 Laitinen 2012.
413 Tarkiainen 2010.
414 DRIVE C2X 2013.
415 Laitinen 2012.
416 DRIVE C2X 2013.

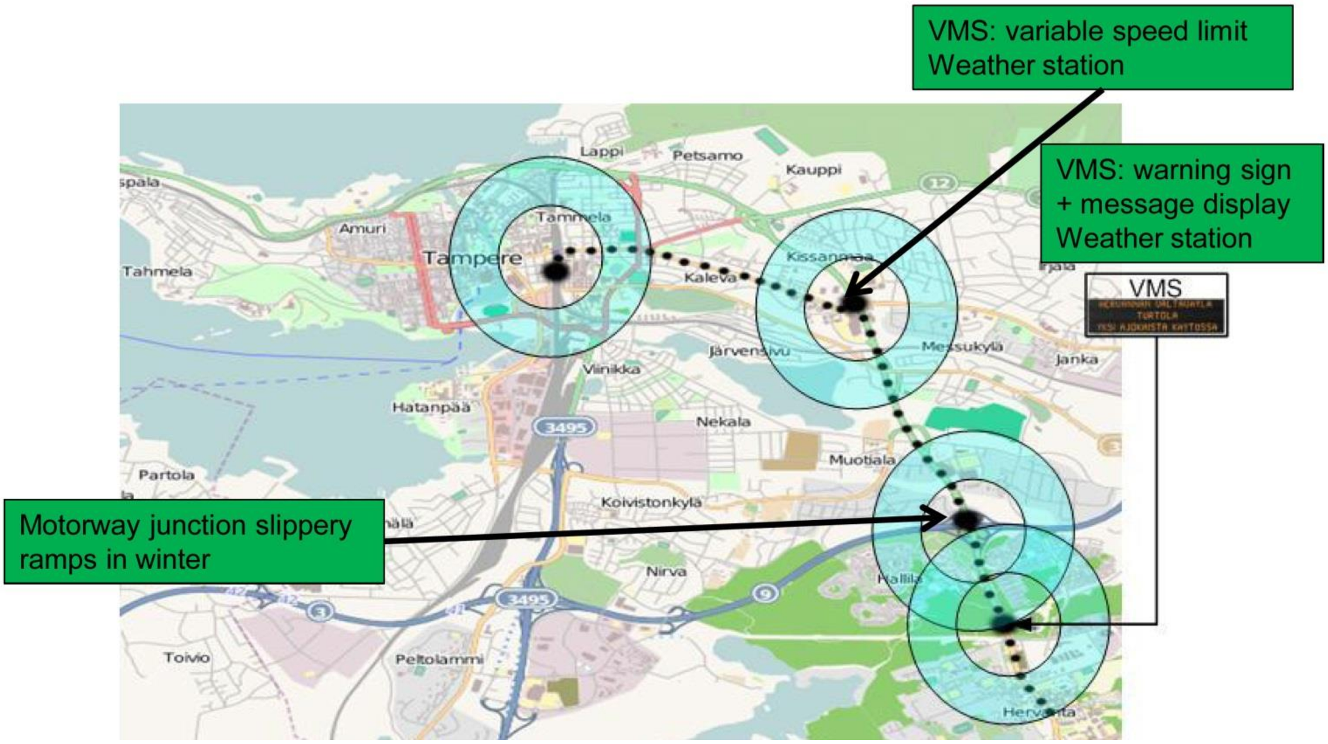

FIGURE 29: OPEN ROAD TEST SITE FOR COOP TS FINLAND (TAMPERE TO HERVANTA)[417]

FIELD OPERATIONAL TESTS OF AFTERMARKET AND NOMADIC DEVICES IN VEHICLES (TELEFOT)

The *Field Operational Tests of Aftermarket and Nomadic Devices in Vehicles* (TeleFOT) project, funded by the Seventh Framework Programme and the European Commission DG Information Society and Media, focused on developing information and communication technologies for cooperative systems. The project began in June 2008 and lasted 48 months. The purpose of the project was to test driver support functions with large fleets of test drivers in real-world driving conditions. The project focused on aftermarket and nomadic devices. TeleFOT involved approximately 3,000 drivers in TeleFOT-equipped vehicles and spanned Finland, Sweden, Germany, United Kingdom, France, Greece, Italy, and Spain.[418] While the tests were conducted in three test regions (Finland/Sweden, Germany/France/UK, and Greece/Italy/Spain), the project was coordinated out of the VTT Technical

[417] Laitinen 2012.
[418] TeleFOT 2013.

Research Centre of Finland. The final event was held in late November 2012.[419]

SEMANTIC DRIVEN COOPERATIVE VEHICLE INFRASTRUCTURE SYSTEMS FOR ADVANCED ESAFETY APPLICATIONS (COVER)

Another project that was conducted in Finland was *Semantic Driven Cooperative Vehicle Infrastructure Systems for Advanced eSafety Applications* (COVER). The central focus of COVER was V2I applications such as intelligent speed adaptation (static, temporary, and dynamic speed limits) and cooperative early information. The project ran from March 2006 to February 2009. COVER conducted two field trials. One was carried out on roads (E18 Corridor) in Finland and focused on truck drivers. The other was carried out on a road segment (Turin-Florence) in Italy and focused on non-professional drivers.[420]

4.11 NORWAY

SMART FREIGHT TRANSPORT IN URBAN AREAS (SMARTFREIGHT)

The *Smart Freight Transport in Urban Areas* (SMARTFREIGHT) project aimed to improve urban freight transport efficiency, environmental impact, and safety through use of distribution networks. The project researched the integration of urban traffic management systems with freight management and onboard systems. SMARTFREIGHT could lead to improved freight operations by providing access to real travel time and traffic status information through use of onboard units, sensors, smart tags, and wireless. In addition, those technologies enable monitoring of goods transport, loading, and unloading. The program evaluated technical solutions, through real and simulated test applications. Participants included Asociacion para el Desarrollo de la Logistica (Spain), Dublin Transportation Office (Ireland), Statens Vegvesen Vegdirektoratet (Norway), Comune di Bologna (Italy), Polis - Promotion of Operational Links with Integrated Services aisbl (Belgium), University of Southampton (United Kingdom), Q-free ASA (Norway), Chalmers Tekniska Hoegskola Aktiebolag (Sweden), and Etra

[419] TeleFOT 2013.
[420] Ellmén 2006.

Investigacion y Desarrollo, S.A (Spain). Work on SMARTFREIGHT began in January 2008, and was scheduled to end in June 2010.[421]

4.12 UNITED KINGDOM

UNITED KINGDOM GOVERNMENT AUTOMATED VEHICLE ACTIVITIES

The United Kingdom Department for Transport highlighted the automated vehicle research at Oxford in a 2013 report.[422] The same report highlighted connected vehicle technology, noting that in the future, "vehicles will communicate not only with the road infrastructure, but increasingly with each other," and that cooperative approaches, such as platooning, could be important for heavy vehicles.

In July 2014, the government of the United Kingdom 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. The review will address the need for automated vehicles to comply with existing safety and traffic laws, and identify areas where the law must be changed. Civil servants have until the end of 2014 to release the review.[423]

The government also plans to conduct three automated vehicle trials and is soliciting applications from cities that are interested in hosting the trials. Cities that wish to host a trial are encouraged to partner with private business and research organizations.[424] Applications to host an automated vehicle trial are due by the beginning of October 2014. The selected proposals will each get a share of the £10 million ($16.9 million) fund the government has allocated for the trials. The trials are expected to begin in January 2015 and last for 18-36 months.[425]

MILTON KEYNES AUTOMATED VEHICLE DEPLOYMENT

In late 2013, it was announced that the town of Milton Keynes would host a fleet of automated vehicles. The automated, electric-powered vehicles to be deployed will be capable of driving 12 miles per hour, and will be limited to

[421] European Commission 2011b.
[422] Department of Transport 2013.
[423] BBC 2014.
[424] Mozée 2014.
[425] BBC 2014.

driving only on designated pathways. The vehicles will be booked using a smartphone application and will be able to fit two passengers.

Under the deployment plan, there will be 20 driver-operated vehicles operating by 2015, but by 2017, the goal is to have 100 fully automated versions deployed. The project is funded with £1.5 million ($2.5 million) from a larger £75 million ($124 million) government program to encourage low-carbon engine technology testing. Current partners include Arup, an engineering firm, as well as Cambridge and Oxford Universities.[426]

UNIVERSITY OF OXFORD AUTOMATED VEHICLE TESTING

The University of Oxford and Nissan collaborated to create and test automated vehicles.[427] The prototype researchers are using is an adapted Nissan Leaf. Earlier testing occurred on a closed test track at Oxford Science Park, but in the summer 2013, the Oxford researchers suggested that they would soon begin testing their vehicle on lightly-used rural and suburban roads. Those tests would require that a driver be present, but the vehicle would be capable of driving independently, without any direction from the driver.

4.13 SWITZERLAND

CITY ALTERNATIVE TRANSPORTATION SYSTEM (CATS)

In June 2014, the Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland was the site of a public experimental phase for the *City Alternative Transportation System* (CATS) project. The demonstration lasted four weeks and involved three Navya shuttles provided by the Induct company. The shuttles provide public transportation around campus and have stops at a nearby hotel and student housing. During the EPFL demonstration, the three vehicles provided transportation to more than 1,500 passengers over four weeks.[428]

Earlier tests occurred in Strasbourg, France, and a second, longer demonstration will begin on the EPFL campus beginning in November 2014. The second demonstration will last for six months and will be related to the

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[426] Westcott 2013.
[427] BBC 2013.
[428] BestMile 2014.

CityMobil2 project. The CATS project began in January 2010 and will continue through 2015. It has been financed by the European Commission (€3 million) and brings together the Lausanne city planning agency, scientific organizations, and institutional partners.[429]

4.14 ISRAEL

COOPERATIVE COMMUNICATION SYSTEM TO REALIZE ENHANCED SAFETY AND EFFICIENCY IN EUROPEAN ROAD TRANSPORT (COM2REACT)

The project *Cooperative Communication System to Realize Enhanced Safety and Efficiency in European Road Transport* (COM2REACT) worked to establish a system using V2V and V2I communication over 2.4 GHz Wi-Fi (802.11b IEEE WLAN standard). This system improved the quality and reliability of information acquired by moving vehicles. An important part of the system was its virtual traffic control sub center (VSC), which controls a moving group of vehicles in close proximity. The VSC creates a network out of vehicles near each other that creates information about local traffic and safety situations. Using V2I communication, the VSC transmits this information to a regional control center which sends back instructions to distribute to the vehicles. This project built upon the *Realize Enhanced Safety and Efficiency in European Road Transport* (REACT) project. REACT involved sensor-equipped vehicles and a regional control center. In addition to the work that was done for the REACT project, COM2REACT developed VSC and integrated it with REACT to obtain a more complex, but more effective system. COM2REACT was a partnership of 13 organizations, including an automaker, road authority, and several high tech enterprises.[430] COM2REACT conducted testing in 2007 and 2008, but little to no information could be gathered on the project's current activities or any follow-up projects.

AUTOMATED VEHICLE ACTIVITIES

The Israeli company Mobileye currently produces some of the camera-based technology used in advanced safety systems currently on the market (both for

[429] BestMile 2014.
[430] C2R 2011.

automakers systems and for the aftermarket). By 2016, it expects to release fully automated vehicle technology.[431]

For several years, Israel has been using automated border-patrol vehicles.[432] The first vehicle was introduced in 2008 and was produced by G-NIUS Unmanned Ground Systems (UGS) LTD, and Israeli company. The vehicle is designed to perform programmed patrols as well as react to unscheduled events.[433]

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[431] Rohde 2013.
[432] Main 2013.
[433] G-NIUS 2013.

5 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. 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. Japan already has deployed a connected vehicle system that uses mobile phone technology, DSRC, and IR and already has a significant user base due to its ubiquitous electronic tolling system.

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 the convergence of connected and automated vehicle technologies.

5.1 FUNDING STRATEGIES

CAR's review of CAV, ITS, and related activities, both domestically and abroad, has revealed at least three distinct, but successful, strategies for funding such activities.

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 other sources. Projects such as PRE-DRIVE C2X, I-WAY, and SMARTFREIGHT were funded in this manner. This approach is not limited to national governments. Domestically, California has committed significant state funding to connected vehicle efforts and is actively pursuing private-sector funding, through incentive programs, to supplement these dollars. It also has strong participation from California-based automotive facilities in its programs, as well as participation from other private-sector entities, such as Nokia.

PURSUING FUNDING AT THE NATIONAL LEVEL

Beyond the first approach listed, California is also active in pursuing federal dollars, as witnessed by its Urban Partnership grant application, its share of USDOT RITA funding, and its SAFE TRIP-21 award. An even more salient example of this approach is found in Minnesota's efforts to secure funding. Minnesota has both sought and won federal dollars well beyond its normal share of Highway Trust Fund dollars, allowing the state to deploy technologies and other resources beyond what its formula-based share of the federal gas tax would have allowed. In Germany, the state of Hessen has leveraged past experience and actively pursued projects, receiving funding from the Federal Ministry of Economics and Technology to host several CAV projects, including AKTIV, sim^{TD}, Ko-FAS, and KONVOI.

USING TOLLS TO FUND PROGRAMS

Though most of the ITS technologies used in tolling are not technically CAV applications, Florida is a prime example of a state using toll revenues to increase its pool of available funds for deploying innovative solutions. Minnesota also has an active electronic tolling program that supports the market pricing of its high occupancy toll lanes. Transponders placed in vehicles enable automatic fee deduction from an account. The system uses marginal cost pricing by varying fees depending on how busy the HOV lane is. Colorado's tests using DSRC in tolling represent great progress towards integrating electronic tolling with connected vehicle technologies. In Japan, electronic tolling was an early application of the nation's ITS program. Also in Asia, South Korea is working to make electronic toll collection available on its highways and is instituting e-pay on public transit. By integrating tolling into ITS systems, transportation managers have another potential source of revenue for new projects. Similarly, automated vehicle deployments can be designed to function as taxi or personal rapid transit services with fees paid by users.

The widespread use of these three approaches (matching funds, national grants or earmarks, and toll or fee-based systems) 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.

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. The Walbridge Connected Vehicle Research Center, and other efforts to create open public test beds, represents an effort to help facilitate more private deployment testing. In Asia, 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.

5.2 IMPORTANT FACTORS

In CAR's review of CAV and related activities, several important factors arose regarding the research, development, and deployment of these 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 involve national government agencies and manufacturers whereas American partnerships 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.

CREATING 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 including Toyota, Honda, Nissan, Mazda, Mitsubishi, NEC Corporation, Panasonic, Yamaha, Kawasaki, and Suzuki participated in tests for DSSS and ASV and by the end of 2010, systems compatible with *Smartway* infrastructure had been developed by Toyota, Pioneer, Mitsubishi Electric Co., Panasonic, and Mitsubishi Heavy Industries.

DEVELOPING PROGRAMMATIC THEMES AND BOLD GOALS

Internationally, having a strong programmatic theme was particularly useful in moving projects and deployments forward. In Europe, the major theme centered around safety and in particular on using technology to make the vehicle-roadway environment an active participant in assisting drivers. Projects focused largely on decreasing crash risks and reducing the negative consequences of crashes that do occur. In Asia, themes were just as important: South Korea's concept of the "Ubiquitous City" has generated enthusiasm from several cities who want to implement communications technologies. Like Europe, Japan has focused on safety as a central theme. In its *ITS Introduction Guide*, the Ministry of Land, Infrastructure and Transport Japan credits a tragic bus accident as the impetus to improve road safety systems that lead to its ITS program. The international examples have also demonstrated the usefulness of bold goals in motivating achievements, such as Sweden's *Vision Zero*.

GENERATING EXPERTISE

Working on CAV projects has been a boon to several private companies, research institutions, countries, states, and transportation management agencies. This survey of international efforts has stressed the global nature of vehicle electronics, including the advantages of standardization to make it easier for automotive OEMs to offer the same communication technologies globally and the potential competition among suppliers worldwide.

The example of the Industrial Technology Research Institute of Taiwan providing WAVE/DSRC communication units to support a connected vehicle project in the U.S. demonstrates the global nature of automotive research and development. Similarly Cohda Wireless of Australia has developed technology that has been involved in on-road trials in projects such as DRIVE C2X in Europe and, the *Connected Vehicle Safety Pilot* in the United States. 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. Ford, through its *Urban Mobility Initiative*, has shown signs of grasping this concept; GM, too, through its European and Asian operations, is active overseas in CAV-related initiatives.

Developing expertise as a way to create future opportunities is also applicable to national and state agencies. For example, the *Test Site Sweden* project was very useful in building up competence in Field Operational Tests and positioned Sweden to take a strong role in proposal phases for a number of important European projects including FESTA, SeMiFOT, and EuroFOT as well as other FOT related projects. Domestically, 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; without legal requirements requiring integration of safety units into vehicles, adoption of DSRC based safety applications will be severely stunted or simply may not occur. Government agencies have the ability and obligation to establish the argument for connected vehicle mandates to ensure adequate coverage necessary to realize safety benefits. 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 U.S. 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.[434]

[434] NHTSA 2013b.

STANDARDIZING GLOBAL/REGIONAL ARCHITECTURES

Global standards and architectures for connected vehicle technologies would strengthen the case for connected vehicle deployment. By using common equipment, the production volumes of in-vehicle and roadside units can be increased, helping to bring down unit costs. 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 connected vehicle system and automakers can use a single system in vehicles, rather than installing different systems for vehicles being purchased in different markets.

DSRC employs spectrum from 5.85 to 5.925 GHz in the United States, from to 5.875 to 5.925 GHz in Europe, and 5.775 to 5.845 GHz in Japan.[435] While various regions of the world have slightly different standards, significant efforts have been completed to harmonize standards. The European Commission, for instance, has funded several projects to create harmonized systems throughout Europe. Australia's strongest argument for securing 5.9 GHz bandwidth for ITS applications was that it would allow an Australian connected vehicle system to be consistent with those in other countries. To some extent, this logic may have already proved to be sound as the *Connected Vehicle Safety Pilot* in Michigan in the U.S. includes DSRC equipment vendors based in Australia (Cohda Wireless) and Taiwan (ITRI). The United States and Europe signed a joint declaration in 2009 pledging to use global standards when possible.[436] The U.S. and Japan signed a similar agreement in 2010.[437]

5.3 CONSIDERATIONS FOR CAV RESEARCH, DEVELOPMENT, AND DEPLOYMENT

INCREASING CONVERGENCE OF CAV TECHNOLOGIES

Several projects documented in this report involve both connected and automated vehicle technologies. For instance, the SARTRE, KONVOI, *CyberCars*, *Grand Cooperative Driving Challenge*, EN-V, and NEDO *Automated Truck Platoon* projects all use a combination of communications

435 PIARC-FISITA 2012.
436 RITA 2009.
437 RITA 2010.

and vehicle-based sensor inputs. Most automated vehicle initiatives, such as Google's self-driving car project, involve some form of on-board connectivity (3G or 4G) 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.[438] Adding communications technology to vehicles equipped with sensor-based ADAS systems can improve performance and in some cases may decrease cost. For instance, adding DSRC to a vehicle system could eliminate the need for some more expensive sensors. On the other hand, convergence could also reduce the required investment in infrastructure for connected vehicle systems. Furthermore, data fusion, which involves combining data from various inputs to produce useful information, enables greater access to both redundant and complementary information, enabling more robust and comprehensive safety systems.[439]

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. While USDOT recently announced it would begin creating regulations to include on-board DSRC equipment in vehicles and many connected vehicle systems are still based on DSRC technology, successful deployment may be based on V2V rather than V2I communications and not ultimately require extensive installation of roadside infrastructure. In addition, many of the V2I applications can be achieved (and indeed are already being achieved to some degree) using cellular networks (e.g., 3G, 4G, or 4G LTE) and nomadic or installed on-board units.

EMERGING REGIONAL COMPETITION FOR AUTOMATED VEHICLE TECHNOLOGY SUPREMACY

With CAV activities increasingly facilitated by private firms and less dependent on government agencies, economic developers might need to play a greater role in attracting projects to specific countries (or states). Initiatives

[438] Silberg and Wallace 2012.
[439] Darms et al. 2010.

that provide a common space to develop, test, and implement CAV technologies, such as Walbridge connected vehicle research center (Michigan), the University of Michigan Mobility Transformation Facility (Michigan), or the TTI Accelerate Texas Center (Texas), 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.

While Michigan has many CAV-related assets, many companies are choosing to develop and test automated technology in other states. While Michigan now has passed legislation clarifying and expanding eligibility for testing automated vehicles on public roads, it may have already missed some of the publicity and opportunities enjoyed by the states of Nevada, Florida, and California, which had passed automated vehicle legislation earlier than Michigan. Although Michigan has done well attracting connected vehicle deployments in the past, the changing CAV environment (move towards convergence, decreased reliance on DSRC-based roadside infrastructure, and focus on automated vehicle technologies) means that Michigan cannot relax its efforts if it intends to maintain its national leadership role among public agencies in CAV development and deployment.

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APPENDIX A: LIST OF ABBREVIATIONS

A*STAR – Singapore Agency for Science, Technology, and Research
AAC – Advisory Acceleration Control
ABV – Automatisation Basse Vitesse
AASHTO – American Association of State Highway and Transportation Officials
ACMA – Australian Communications Media Authority
AdaptIVe – Automated Driving Applications & Technologies for Intelligent Vehicles
ADAS – Advanced Driver Assistance Systems
AKTIV – Adaptive and Cooperative Technologies for Intelligent Traffic
AMAS – Autonomus Mobility Applique System
AMTICS – Advanced Mobile Traffic Information and Communication System
ARTC – Automotive Research and Testing Center (Taiwan)
ASU – Arizona State University
ASV – Advanced Safety Vehicle
AUMP – Advanced Urban Mobility Platform (See PAMU)
AVS – Automated Vehicle Systems
BRT – Bus Rapid Transit
C2X – Car to anything (e.g. vehicle, infrastructure, cellular phone, handheld device, etc.)
CACC – Cooperative Adaptive Cruise Control
CACS – Comprehensive Automobile Traffic Control System
CALM – Communications, Air-interface, Long and Medium range (wireless communication protocol)
Caltrans – California Department of Transportation
CAMP – Crash Avoidance Metrics Partnership
CAN – Controller Area Network
CAR – Center for Automotive Research
CAST – Convoy Active Safety Technology
CATS – City Alternative Transportation System
CB – Citizen Band
CCC – Connected Cruise Control
CCTV – Closed Circuit Television
CICAS – Cooperative Intersection Collision Avoidance System
CICAS-SSA – Cooperative Intersection Collision Avoidance System Stop Sign Assist
CICAS-V – Cooperative Intersection Collision Avoidance System for Violations
CITI – Cooperative Intelligent Transport Initiative
CITYLOG Sustainability and Efficiency of City Logistics
CITYNETMOBIL – City Network for Fair Mobility
CoCar – Cooperative Cars

COM2REACT – Cooperative Communication System to Realize Enhanced Safety and Efficiency in European Road Transport
COMeSafety2 – Communications for eSafety (Also, COMeSafety2)
Compass4D – Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment
Coop TS Finland – Cooperative Test Site Finland
COOPERS – Co-operative Systems for Intelligent Road Safety
COSMO – Co-Operative Systems for Sustainable Mobility and Energy Efficiency
COVER – Semantic Driven Cooperative Vehicle Infrastructure Systems for Advanced eSafety Applications
CSS – Cooperative Safety Systems
CTAG – Centro Tecnológico de Automoción de Galicia
CVHAS – Cooperative Vehicle-Highway Automation Systems
CVI-UTC – Connected Vehicle/Infrastructure University Transportation Center
CVII – Commercial Vehicle Infrastructure Integration
CVIS – Cooperative Vehicle Infrastructure Systems
CVTA – Connected Vehicle Trade Association
DARPA – Defense Advanced Research Projects Agency
DAS – Data Acquisition Systems
DGT – Dirección General de Tráfico (Spanish Ministry of Traffic)
DIAMANT – Dynamische Informationen und Anwendungen zur Mobilitätssicherung mit Adaptiven Netzwerken und Telematikanwendungen or Dynamic Information and Applications for assured Mobility with Adaptive Networks and Telematics infrastructure
DITCM – Dutch Integrated Testsite for Cooperative Mobility
DMS – Dynamic Message Signs
DOT – Department of Transportation
DRIVE C2X – DRIVing implementation and Evaluation of C2X communication technology
DSRC – Dedicated Short Range Communication
DSSS – Driving Support Safety Systems
DUAP – Data Use Analysis and Processing (Also DUAP2)
E-VII – Emergency VII
EAR – Exploratory Advanced Research
eCoMove – Cooperative Mobility Systems and Services for Energy Efficiency
EMAS – Expressway Monitoring Advisory System
EMC – Electro-magnetic Compatibility
EN-V – Electric Networked-Vehicle
EPFL – Swiss Federal Institute of Technology in Lausanne
ERTICO – European Road Transport Telematics Implementation Co-ordination Organization
ETC – Electronic Toll Collection
EUCAR – European Council for Automotive R&D

EV – Electronic Vehicle
FDOT – Florida Department of Transportation
FESTA – Field Operational Test Support Action
FHWA – Federal Highway Administration
FIRST – Freeway Incident Response Safety Team
FM – Frequency Modulation
FOT – Field Operational Test
FOT-Net – Field Operational Test Network
FOTsis – European Field Operational Test on Safe, Intelligent and Sustainable Road Operation
FTE – Florida Turnpike Enterprise
GHz – Gigahertz
GLIDE – Green Link Determining System
GNSS – Global Navigation Satellite System
GPRS – General Packet Radio Service
GPS – Global Positioning System or Global Position Satellite
HAR – Highway Advisory Radio
HAVEit – Highly Automated Vehicles for Intelligent Transport
HeERO – Harmonized eCall European Pilot
HLSV – Hessian State Office of Road and Traffic Affairs
HMI – Human-Machine Interface
HOT – High Occupancy Toll (traffic lane)
HOV – High Occupancy Vehicle (traffic lane)
HSPA – High-Speed Packet Access
HTAS – High Tech Automotive Systems (Dutch innovation program)
I^2R – Institute for Infocomm Research
IAP – Intelligent Access Program
ICM – Integrated Corridor Management
ICT – Information and Communication Technologies
ICT 4 EVEU – Information and Communication Technologies for Electric Vehicles European Union
ICT PSP – Information and Communication Technologies Policy Support Program
INRIA – French National Institute for Research in Computer Science and Control
IR – Infrared
ISM – Industrial, Scientific, and Medical (radio band, 2.4 GHz)
ISMUF – *IntelliDrive*^{SM} for Safety, Mobility, and User Fee Project
ITRI – Industrial Technology Research Institute of Taiwan
ITS – Intelligent Transportation Systems
I-WAY – Intelligent Co-Operative System in Cars for Road Safety
IWCU – ITRI WAVE/DSRC Communication Unit

KLiEn – Klima- und Energiefond (Austrian Climate and Energy Fund)
Ko-FAS – Cooperative Perception Systems for Preventive Road Safety
Ko-KOMP – Cooperative Components
KONVOI – Development and Analysis of Electronically Coupled Truck Platoons
Ko-PER – Cooperative Perception
Ko-TAG – Cooperative Transponders
LAN – Local Area Network
LIT – Lighting and Infrastructure Technology
LTE –Long Term Evolution
M5 – CALM microwave medium at 5 GHz
MCNU – Multiband Configurable Networking Unit
MDOT – Michigan Department of Transportation
MEDC – Michigan Economic Development Corporation
MLFF – Multi Lane Free Flow
MnDOT – Minnesota Department of Transportation
MOBI.Europe – Integrated and Interoperable ICT Applications for Electro-Mobility in Europe
MOBiNET - Europe-Wide Platform for Connected Mobility Services
MOLECULES – Mobility based on eLEctric Connected vehicles in Urban and interurban smart, cLean, EnvironmentS
mph – miles-per-hour
MSU – Montana State University
MTC – Metropolitan Transportation Commission (California) or Mobility Transformation Center (Michigan)
MTF – Mobility Transformation Facility
MTO – Ontario Ministry of Transportation
NCAR – National Center for Atmospheric Research
NDS – Naturalistic Driving Studies
NEDO – New Energy and Industrial Technology Development Organization
NextGenITS – Next Generation Intelligent Transportation Systems
NHTSA – National Highway Transportation Safety Administration
NRI – Notice of Regulatory Intent
NSW – New South Wales (Australia)
NTRC – National Transportation Research Center
NTRCI – National Transportation Research Center, Inc.
NUS – National University of Singapore
OBE – On Board Equipment
OBU– On Board Unit
OEM – Original Equipment Manufacturer
OPIM – Open Platform for Intelligent Mobility

ORNL – Oak Ridge National Laboratory
ORT – Open Road Tolling
PAMU – Plateforme Avancée de Mobilité Urbaine (See AUMP)
PATH – Partnership for Advanced Transit and Highways
PGS – Parking Guidance System
PhD – Doctor of Philosophy
PRE-DRIVE C2X – PREparation for DRIVing implementation and Evaluation of C2X communication technology
PRESERVE – Preparing Secure Vehicle-to-X Communication Systems
PROMETHEUS – PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety
PVIS – Traffic Information Platform (For COOPERS Project)
RACS – Road Automobile Communication System
REACT – Realize Enhanced Safety and Efficiency in European Road Transport
RFID – Radio Frequency Identification
RHODES^{NG} – Real-Time Hierarchical Optimized Distributed Effective System Next Generation
RISC – Rapid Incident Scene Clearance
RITA – Research and Innovative Technology Administration
RSE – Roadside Equipment
RSU – Roadside Unit
RTMC – Regional Transportation Management Center
RWIS – Road Weather Information System
SAE J2735 – Society of Automotive Engineers standard for DSRC message sets
SAFE TRIP-21 – Safe and Efficient Travel through Innovation and Partnerships in the 21st Century, a USDOT program managed by the Volpe Center
SAFER – Vehicle and Traffic Safety Center at Chalmers University (Sweden)
SAFESPOT – Smart Vehicles on Smart Roads
SAFETEA-LU – Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SAIC – Science Applications International Corporation
SAIC – Shanghai Automotive Industry Corporation
SARTRE – Safe Road Trains for the Environment
SATIE – Support Action for a Transport ICT European large scale action
SCORE@F – System Coopératif Routier Expérimental Français
SCOT – Shared Computer Operated Transport
SeMiFOT – Sweden-Michigan Naturalistic Field Operational Test
Sevecom – Secure Vehicular Communication
sim^{TD} – Safe and Intelligent Mobility Test Germany
SISCOGA – Sistemas Cooperativos Galicia

SKY – Start ITS from Kanagawa, Yokohama
SMART – Singapore-MIT Alliance for Research and Technology
smartCEM – Smart Connected Electro Mobility
SMARTFREIGHT – Smart Freight Transport in Urban Areas
SPAT – Signal Phase and Timing
SPITS – Strategic Platform for Intelligent Traffic Systems
SRIS – Slippery Road Information System [in Sweden]
TeleFOT – Field Operational Tests of Aftermarket and No-madic Devices in Vehicles
TMC – Traffic Management Center or Transportation Management Center
TNO – Netherlands Organization for Applied Research
TOCC – Transportation and Operations Communication Center
TPIMS – Truck Parking Information and Management System
TRB – Transportation Research Board [of the National Academies of Science and Engineering]
TSS – Test Site Sweden
TTI – Texas A&M Transportation Institute
U-City – Ubiquitous City
UA – University of Arizona
UGS – Unmanned Ground Systems
UMTRI – University of Michigan Transportation Research Institute
UMTS – Universal Mobile Telecommunications System or Universal Traffic Management Society of Japan
UNSW – University of New South Wales
USDOT – United States Department of Transportation
UTC – University Transportation Center
UTMS – Universal Traffic Management Society of Japan
V2D, V2X – Vehicle to Device Communications
V2I – Vehicle-to-Infrastructure
V2V – Vehicle-to-Vehicle
VAD – Vehicle Awareness Device
VDOT – Virginia Department of Transportation
VERTIS – Vehicle, Road and Traffic Intelligence Society
VICS – Vehicle Information and Communication System
VIDAS – Vehicle-Based Information and Data Acquisition System
VII – Vehicle-Infrastructure Integration
VII-C – Vehicle-Infrastructure Integration Consortium
VSC – Virtual Traffic Control Sub-Center
VTTI – Virginia Tech Transportation Institute
WAVE – Wireless Access in Vehicular Environment
WDT – Weather Data Translator

WiMAX – Worldwide Interoperability for Microwave Access, a telecommunications technology providing wireless data, voice and video over long distances
WLAN – Wireless Local Area Network
WTI – Western Transportation Institute

APPENDIX B: CONNECTED AND AUTOMATED VEHICLE PROJECTS BY GEOGRAPHIC REGION

By Continent

Continent	Projects
Asia	90
Europe	172
North America	176
Oceania	10
Grand Total	**448**

By Country

Country	Projects
China	10
India	1
Israel	6
Japan	45
Singapore	4
South Korea	17
Taiwan	6
Turkey	1
Austria	2
Belgium	10
Finland	2
France	15
Germany	46
Greece	2
Italy	12
Netherlands	21
Norway	2
Portugal	1
Romania	1
Spain	6
Sweden	16
Switzerland	1
United Kingdom	10
Europe-Wide	25
Canada	6
USA	170
Australia	8
New Zealand	2
Grand Total	**448**

By U.S. State

State	Projects
Arizona	3
California	31
Colorado	2
District of Columbia	4
Florida	7
Georgia	1
Idaho	1
Illinois	2
Indiana	1
Maryland	3
Massachusetts	2
Michigan	45
Minnesota	9
Missouri	1
Montana	10
Nevada	1
New Jersey	2
New York	6
North Carolina	1
North Dakota	1
Ohio	1
South Carolina	1
Texas	7
Virginia	9
US-Wide	19
Grand Total	**170**