The Exploratory Advanced Research Program

EXPLORATORY ADVANCED RESEARCH

Literature Review on Recent International Activity in Cooperative Vehicle–Highway Automation Systems

U.S. Department of Transportation
Federal Highway Administration

Foreword

This literature review supports the main report, *Recent International Activity in Cooperative Vehicle–Highway Automation Systems* (Pub. No. FHWA-HRT-12-033). These publications have been prepared with the support of the Federal Highway Administration's (FHWA's) Exploratory Advanced Research Program under the technical supervision of the FHWA Turner–Fairbank Highway Research Program's Office of Operations Research and Development. This work was initiated to provide the U.S. transportation research community with a better understanding of the current state of research and development and to encourage broader thinking about cooperative vehicle–highway automation systems based on developments in other countries. This topic has received increased attention in the industrialized world, even while interest in the United States has been at a relatively low level in recent years. It is now time that the United States take a fresh look at the technical and institutional issues associated with vehicle automation and its implications for the future of the surface transportation system, particularly when interest in the topic has been growing within the automotive and information technology industries.

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16. Abstract

This literature review supports the report, *Recent International Activity in Cooperative Vehicle–Highway Automation Systems.* It reviews the published literature in English dating from 2007 or later about non-U.S.-based work on cooperative vehicle–highway automation systems. This review covers work performed in Europe and Japan, with application to transit buses, heavy trucks, and passenger cars. In addition to fully automated driving of the vehicles (without human intervention), it also covers partial automation systems, which automate subsets of the total driving process.

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Introduction

This literature review covers recent international activities on development, testing, and deployment of CVHAS. To clarify what this scope means in practice:

- *Recent* means since 2007, so that the focus is on current activities rather than older activities that are likely to have been superseded by now or may already be familiar.
- *International* means that the main focus is on activities outside of the United States, because the United States' activities are already familiar. There will be occasional references to activities in the United States to help set the context for the overseas activities and to offer points of comparison.
- *Cooperative vehicle–highway automation* means that the systems involve some form of vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), or infrastructure-to-vehicle (I2V) cooperation or interactions with the driver in partially automated systems, but this review generally avoids addressing the fully autonomous systems that do not involve active cooperation.
- *Automation* covers multiple degrees of automation of the driving function, ranging from driver warning and control assistance to partial automation and full automation.

To expand on the last bullet item, the full range of levels of cooperation and automation is shown schematically in figure 1. The review here tends to emphasize the upper and right-hand portions of this figure rather than the lower and left–hand portions.

This review focuses on the documentation that exists in the English language reference documents that are publicly available through professional journals, conference proceedings, technical reports, and Web sites. In some cases, documentation of important international activities is not available in these forms. Much information is disseminated through brochures, conference presentations that exist only in PowerPoint®, or in private discussions and visits to other research teams. This richer body of information is not addressed in this report but is covered in the full report, *Recent International Activity in Cooperative Vehicle–Highway Automation Systems* (Pub. No. FHWA-HRT-12-033), which includes meetings with key participants involved in major international projects.

The emphasis of this review is on documentation of broad programmatic issues, such as project goals, concepts of operations, schedules, budgets, and deployment strategies. There is no attempt to report on highly technical details of research projects. This means that there is only limited coverage of publications in the most respected professional journals and in the conferences sponsored by technical societies, such as the Institute of Electrical and Electronics Engineers, which tend to focus on those technical details. There is more emphasis on the papers for the Intelligent Transportation Systems (ITS) World Congresses, which provide the broader programmatic views, and the more general trade press.

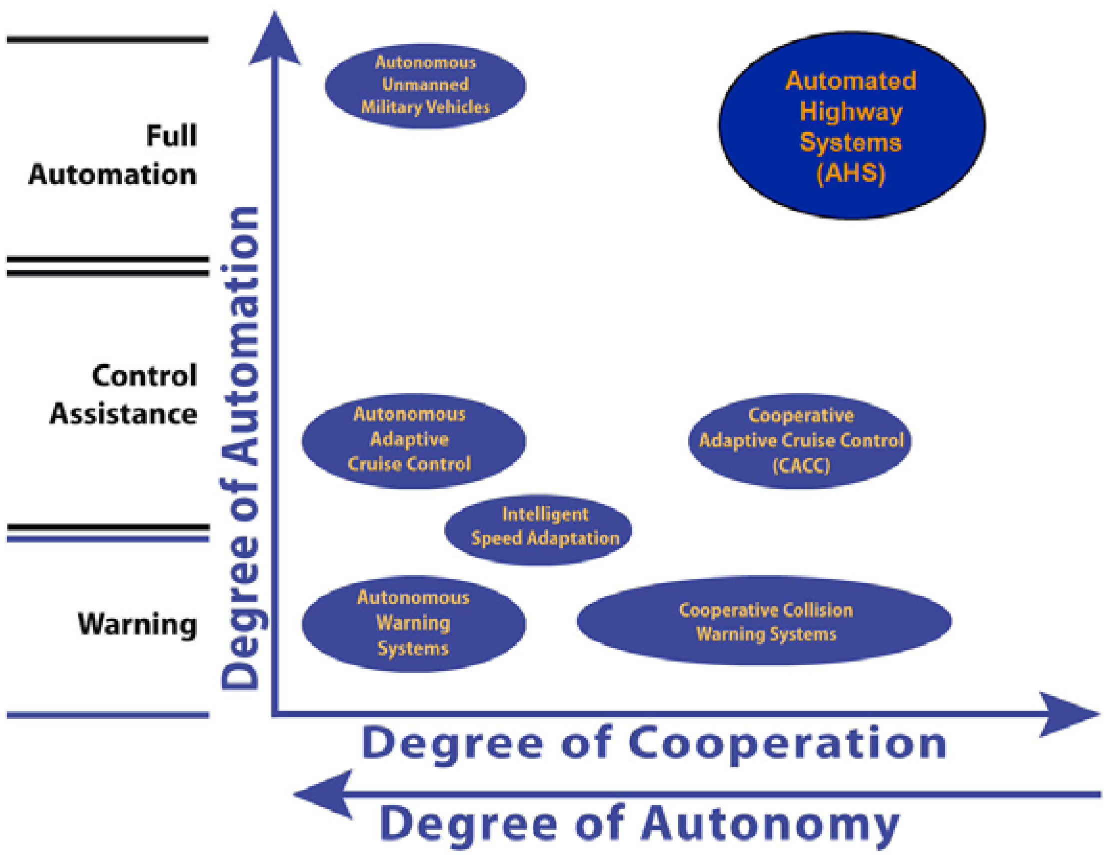

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Figure 1. Chart. Full range of automation and cooperation alternatives.

General Overview of Relevant Current International Activities

The dominant international activities in CVHAS, as indeed in all of ITS, are sponsored by the Japanese government and the European Commission. Although they have the largest budgets and are most inclined to publicize their work in international technical forums, they are not the only ones to be active. There are also substantial national programs of research and development in individual European countries and in other Asian countries, particularly Korea and China. Because those activities are typically lower profile, they will be highlighted in this overview section before getting into specific applications of CVHAS technology.

The current projects related to CVHAS have antecedents in earlier generations of projects, which in some cases have very extensive paper trails of publications that are not reviewed here because they would overwhelm the more current information.

Several general trends are evident in reviewing the recent international literature on CVHAS topics:

- There is very little information based on industry research and development, but virtually everything is associated with public sector projects. Although this may be in part because of industry interests in keeping their information proprietary, there are some other important factors to consider. Particularly because we are focusing on cooperative systems, these require close interaction with the public roadway infrastructure. Industry is reluctant to get too far out in front of the public sector and would not want to invest effort in cooperative systems without assurance that their public sector counterparts are actively engaged and thinking along similar lines. Because deployment horizons for public infrastructure tend to be long, industry is more inclined to focus their own investments in other areas where they can achieve an earlier return on those investments.
- The large majority of available information is about the technical characteristics of the systems that are being developed or considered for development, with relatively limited information about the non-technical issues that could impede deployment, such as costs, legal, and institutional issues.[1,2] This could be because the technologies are not yet ready for deployment or because these issues are too specific to the deployment locales and countries to merit attention in international publications. Regardless of the reasons, it is an unfortunate omission, because it deprives us of the opportunity to learn from others' experience with these issues.
- The European Commission only began to give serious attention to cooperative systems around 2004—after previously keeping its infrastructure and vehicle activities separate—but since that time it has increasingly focused stronger attention on cooperative systems. Within the past 2 years, the European Commission has given considerably more attention to automated driving systems, and some of its senior managers have voiced a strong belief that this is the inevitable future of ITS. This has been manifested in a few new research activities, with the likelihood of more coming in future calls for proposals.
- The activities in Japan are divided by government ministries, which have followed different trends. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) was noted for investing in very ambitious automation initiatives in the early– to mid– 1990s, but by 1997 it had changed its definition of *AHS* from *automated highway systems* to *advanced cruise–assist highway systems*, which mainly provide warnings to drivers rather than control assistance or

automation. The current MLIT program, Smartway, is focused on deployment of roadside infrastructure to support these cooperative systems on highways, but is no longer doing much research.[3]

» Japan's National Police Agency has long emphasized urban traffic management and control, which is one of its primary responsibilities. Since about 2005, it has invested heavily in cooperative safety-enhancing systems for urban arterials, especially intersections, through its Driving Safety Support Systems (DSSS) research and development program.[4] This involves intensive I2V communications to deliver safety warnings to drivers (but not control assistance or automation).

» Japan's Ministry of Economy, Trade and Industry (METI) has a long history of involvement with vehicle automation technology. Until a few years ago, its projects were strictly based on autonomous vehicles, without any cooperation with other vehicles or with the infrastructure. Since 2008, however, METI has been sponsoring the large Energy ITS project, developing an automated truck platoon based on V2V cooperation.[5] The relationship of these truck platoons to the roadway infrastructure has gone through various political phases since the project began; thus, at different times it was based on dedicated truck lane infrastructure and on mixing the automated truck platoons with conventional non-automated traffic.

» In all countries, the cooperative ITS projects are more heavily focused on traveler information and driver safety–warning applications than on automated driving. Some of these activities are cited in this review to provide the context for future development of automation capabilities.

» The cooperative automated driving applications under current research and development are mainly focused on public transit vehicles and trucks rather than on private passenger cars. This appears to reflect the recognition that deployment opportunities will come earlier for these vehicle types than for passenger cars.

There have been a few prior scans of overseas developments relevant to the scope of this review. The Federal Highway Administration sponsored an international scanning tour of ITS safety applications in 2006.[6] Although most of the topics covered in that scan were related to traffic management systems, it also included adaptive cruise control (ACC) and in-vehicle safety-warning systems. The Federal Transit Administration and the ITS Joint Program Office sponsored a European scan of automated bus guidance systems that the Partners for Advanced Transit and Highways (PATH) led in 2005, exposing transit industry stakeholders to systems that used computer vision, magnetic, and mechanical guidance systems in operation.[7]

Three major European integrated projects on cooperative ITS systems were concluded with a major demonstration in Amsterdam, the Netherlands, in March 2010. Smaller demonstrations were provided at the ITS World Congress in Stockholm, Sweden, in September 2009. The researchers working on these projects—CVIS,[8] COOPERS,[9] and SAFESPOT[10]—developed the communication architecture and technology to use multiple communication media to connect vehicles with the infrastructure and with each other and also demonstrated a wide variety of cooperative applications. These applications included advanced driver assistance systems that provided a limited level of automation of the driving function (providing awareness of the hazards in the driving environment), without taking control of the vehicle motions.

The next generation of European Commission sponsored integrated projects, which are in some sense follow-ons to those just mentioned, are also focusing on collision warning and control assistance—eCoMove and interactIVe.[11,12] As the name implies, eCoMove emphasizes the use of cooperative systems to reduce energy consumption, greenhouse gases, and pollutant emissions. The project interactIVe, however, emphasizes the integration within the vehicle of different warning systems, rather than the V2V or V2I cooperation.

The large majority of the references described here are associated with either European Commission–sponsored projects that involve collaborations among researchers in several countries or Japanese projects; however, these are not the only relevant activities. It is worth noting that there are national programs in a variety of countries, including the European countries that also participate in European-wide projects. There have also been a few papers from private companies that are working on their own and are not associated with national or international programs.

A general overview of cooperative ITS work in China was presented at the 2007 ITS World Congress in Beijing, but this overview does not pay strong attention to automated vehicle applications.[13] The Dutch have been leaders in cooperative ITS, and they have included partially automated systems (speed control) within their program, which hosted an international competition for cooperative system developers.[14,15] Germany has long had a strong national transportation technology research program, the current generation of which is known as *AKTIV*.[16] The German projects tend to be dominated by the automotive original equipment manufacturers, who have not been enthusiastic about fully automated driving. In contrast, the French national projects (under the umbrella program Prédit) are more dominated by the researchers, with a somewhat more theoretical and academic perspective.[17] The Germans and French have even worked together under a program called *Deufrako* (a contraction of the German words meaning German–French cooperation).

Although it does not get as much international attention, Spain also has a national research program—funded as basic research rather than as transportation application research—which has placed a strong emphasis on automated driving.[18,19] Sweden has shown particular interest in the extent to which cooperative systems could be implemented by using cellular communications technology rather than dedicated short-range communication, motivated in large part by the corporate interests of the company Ericsson, which made a major marketing push on this point when the ITS World Congress was in Stockholm.[20,21]

One additional reference worth citing is a Delphi panel study of international experts' attitudes toward the future prospects for a wide range of driver assistance system services, up to full automation, that was conducted by the Technical University of Delft.[22] The panel members' attitudes indicated considerable concern about how long it would take for vehicle automation to become reality.

The results from the Delphi panel study were probably heavily influenced by European concerns about the "Vienna Convention," which always comes up in international discussions about vehicle automation. This is a reference to the Vienna Convention on Road Traffic, a 1968 treaty under the United Nations Economic and Social Council intended to facilitate international road traffic and increase road safety by standardizing traffic rules among countries.[23] Although this treaty has been ratified and signed by most European countries and a few more in other parts of the world, it does not apply in North America or Japan. Article 8.5 of the treaty states, "Every driver shall at all times be able to control his vehicle or to guide his animals." Point 7 of a supplementary European agreement adds the reinforcing language, "Every driver shall have his vehicle under control so as to be able to exercise due and proper care at all times...." Senior European automotive industry officials have pointed out that this language is not unchangeable, and that exceptions could be made when vehicle automation technology is demonstrated to be safe.

Automated Transit Applications

Some of the strongest progress in vehicle automation has already been made in the field of transit. Indeed, one could consider the wide variety of airport people movers and automated urban metros to be examples of existing deployed automated vehicles, but these are mechanically captive to their guideways, so they are generally outside the scope of this review.

The heaviest overseas activity in automated transit applications is in Europe, and some of the European interest has migrated to China. In Japan, Toyota invested considerable effort in its Intermediate Mode Transit System (IMTS) of automated mini–buses, which were used to shuttle 10 million passengers around the grounds of the international Aichi Expo in the summer of 2005. Since this is a bit earlier than the period defined for this review, it is not covered here, but it remains an important development. Other than that, Japan has not been active with automated buses for reasons that are peculiar to national geography and urban transit operations. The large Japanese cities have extremely high population density and very well–developed rail networks (e.g., commuter rail and urban metros). Buses are only used for feeder services or for primary transit service in smaller cities, so they do not have much status, and there is no motivation to invest in upgrading them. If a higher quality of service is needed, a rail line is built to provide it.

The majority of the European automated transit work has been based on the "CyberCars" concept defined and promoted by Michel Parent at INRIA in France. He has succeeded in obtaining European Commission support for a long sequence of projects to develop, demonstrate, and evaluate automated driverless vehicles at low speeds in pedestrian zones, where the automated vehicles have very limited interactions with other vehicles but need to focus on not hitting pedestrians. In some cases the automated driverless vehicles operate on guideways that are mostly segregated from other traffic. The CyberCars work has been documented in many papers, of which only a few of the most recent are cited here.[24,25] The most recent of the projects in the CyberCars sequence is called *CityMobil*, which concluded in May 2011 with a conference and public demonstration. That project, with vehicle demonstrations including an automated bus in Castellon, Spain; smaller people movers in La Rochelle, France, and Rome, Italy; and the Heathrow Airport ULTra PRT (personal rapid transit) system, is documented in several papers and has a substantial Web site.[26,27,28]

Through collaboration between INRIA and researchers in China, there has been an upsurge of interest in CyberCars in China in recent years, evidenced by a variety of technical papers on the subject.[29,30,31] This has even led to an automated vehicle that was claimed to be open to the public in Shanghai since 2007[31] and a demonstration at the 2010 Shanghai World Expo.[30] The technology is mildly cooperative, in that it uses special lane markings in the infrastructure to provide a guidance reference for the vehicle.

One of the most important European automated vehicle projects was the Phileas bus, developed by an industrial consortium in the Eindhoven region of the Netherlands.[32] This bus had many advanced features, including a magnetic guidance system that enabled it to operate under fully automated control on a busway, where it was partially segregated from other traffic and pedestrians. It was put into public service for a brief time in Eindhoven but was then withdrawn from service, although it is still operating in Douai, France, where it is known as *Le Tram*. It has not been clear whether the termination of Phileas service was because of problems with the guidance system or with other innovative systems that it also contains. The Korea Railroad Research Institute under the Ministry of Land, Transport and Maritime Affairs, has licensed the FROG guidance system used in the Phileas bus to use in its BiModal Tram guided bus, but it is not clear how close to deployment that is based on the brochure that was distributed at the ITS World Congress in Busan, South Korea, in October 2010.

The broader challenges associated with deployment strategies for automated short-distance transit vehicles have been studied by Southampton University in the United Kingdom.[33,34] They considered the initial applications to be at low speeds in pedestrian zones, with later applications becoming essentially dual-mode guideway operations. They found transit operators concerned about the economic risks of these new systems. Their study found the most promising applications to be:[34]

» Public transport where conventional transport is restricted, such as in historic city centers.

» Public transport in low–demand (e.g., rural) areas or at low–demand times (e.g., night).

- Feeder services to park and ride or transit terminals.
- Systems to cover the "last mile" not served by conventional transit.
- Special purpose transportation for theme parks, campuses, or exhibition centers.

The main barriers to deployment were found to be:[34]

- End-user familiarity with conventional public transport systems.
- General negative perception of public transport in the "private car society."
- Organizational issues for coordination with existing transit systems.
- Operators and decisionmakers perceiving high risk because of their unfamiliarity with automated transport systems.
- Skepticism toward automated systems operating in environments shared with other traffic.
- Legal and certification issues.
- Securing funding for implementation and operation.

As the CityMobil project has been drawing to a close, it has published a large collection of reports on issues associated with deployment of automated transit systems on its Web site.[35]

Automated Trucking Applications

From 1996 to 2004, the two CHAUFFEUR projects sponsored by the European Commission were among the most prominent ITS research projects. In these projects, automated truck platoons were developed and tested, producing some dramatic results, including very favorable indications about the potential for fuel savings by reducing aerodynamic drag. The CHAUFFEUR system used V2V communication for close coordination of truck movements, but it had no cooperation with the roadside. By the end of the second CHAUFFEUR project, the project team was convinced that they would have to proceed in either one of two different directions—(1) a fully automated platoon of three or more trucks that would have to operate only in a dedicated lane segregated from other traffic or (2) driver assistance systems, such as ACC and lane-keeping assistance, with the driver remaining fully engaged in the driving process. Because they saw no real prospects for getting dedicated truck lanes built in Europe, they stopped work on the fully automated platoon option. Subsequent European Commission projects (e.g., SPARC and PEIT) focused on improved drive-by-wire drivetrains for trucks and truck automation at low speeds in terminals rather than on highways.

Automated truck platoons returned to attention in the KONVOI project sponsored by the German government (under economics and technology rather than transportation) from 2005–2009. The German government funded KONVOI approximately €4 million ($5.1 million), with industry cost share bringing the total budget to about €5.5 million ($7 million). This project focused on determining impacts of automated vehicles on traffic and the environment, rather than on developing technology, but the researchers implemented their experimental system from scratch themselves rather than building on the prior work developed under CHAUFFEUR, SPARC, or PEIT (which had a different industry partner). The concept of operations that the researchers tested, with a lead vehicle driven manually and police escorts following them on public autobahns, was dictated by government agency constraints rather than representing what they would actually have expected to deploy. The KONVOI researchers do not expect to be able to add dedicated truck lanes, so they believe that they are compelled to coexist with other traffic.

KONVOI has not been very visible on the international scene, but it is notable for having conducted a set of tests of a four-truck platoon on public highways in Germany. The platoon drove over 3,000 km (1,864 mi), with the first truck manually driven and the other three following under automatic control, with a police escort vehicle behind them to alert drivers of other vehicles that would be passing them. During these test drives, the platoon encountered 15 instances of cut-ins by drivers of private cars squeezing in between their trucks, requiring the platoon to separate automatically. Six of these cut-ins occurred when the trucks were only 10–15 m (33–49 ft) apart. Although the KONVOI experiments on a test track showed substantial fuel savings, the savings while driving in public traffic were significantly reduced because of speed variations imposed by interference from other traffic and the disruptions to the platoon from cut–ins. There have been a few English language papers about KONVOI, mostly very technical, but one that provides a more general and informative overview of the project, as well as reporting on a driving simulator study of driver responses to driving in truck platoons, can be found via reference 36.

The research team that led the KONVOI project at the technical university RWTH Aachen is one of the partners in the European Commission-sponsored SARTRE project (SAfe Road TRains for the Environment). (See references, 37, 38, 39, and 40.) SARTRE is led by the automotive consultants Ricardo from the United Kingdom, and the major vehicle industry partners are at Volvo, both automobile and trucking companies. SARTRE has developed and tested a concept of an automated platoon led by a truck driven manually, with a mixture of trucks and cars following close behind in order to save fuel and emissions. Like KONVOI, the researchers of SARTRE operated these "road trains" on public highways in mixed traffic. Although their original concept definition contemplated gaps between vehicles as short as 2 m (6.6 ft), the tests were conducted at gaps of 4 m (13.2 ft). They addressed some of the human factors issues in a driving simulator experiment[39] and gave test track demonstrations in late 2010 and at the project conclusion in September 2012, in addition to a demonstration on a public highway in Spain in the spring of 2012.[40]

In addition to the major integrated projects, there have been some smaller research projects that have addressed truck platooning in Europe. Scania simulated the fuel saving potential of automated truck platoons and then conducted a limited field experiment with two trucks coupled at unspecified vehicle-following gaps using an ACC system.[41] A research group at RWTH Aachen developed three 1/14-scale model trucks in support of a cooperative platooning experiment, but there are serious questions about whether this test will be able to produce realistic estimates of performance or fuel savings.[42]

By far the most ambitious current activity on truck automation is the Energy ITS project, funded by Japan's METI. This is a 5-year project, funded at $12 million per year: Ninety percent of the funding is supporting the truck-platooning work, and the rest of the funding is being devoted to developing methods of evaluating the greenhouse gas savings that can be achieved from other ITS applications. The main focus of this project is on saving energy, and hence, greenhouse gas emissions, from truck operations.[43] The work is being conducted by a variety of university researchers, led by the Japan Automobile Research Institute, but it does not have active participation by the truck manufacturers in Japan.

The operational concepts for the Energy ITS project have shifted over time based on political pressures from sponsors, so the project researchers have gone back and forth over the issue of whether the truck platoons would be operating on dedicated truck lanes or in mixed traffic. There has been some work on modeling and simulation to evaluate the impacts that deployment would have on transportation and environmental issues, but the majority of the effort has been devoted to development and testing of the technology on a platoon of three trucks.[44,45,46] There has also been some attention devoted to the issue of how to communicate information about the status of the automated platoon to the drivers, but this issue is sure to need a lot more work.[47]

Automated Driving of Cars

There is very little current activity that addresses fully automated driving of passenger cars (other than the autonomous vehicle research that is outside the scope of this review). In recent literature, there appears to be only one significant project that points entirely in this direction, which is Toyota's research on a tightly coupled platoon of automated cars.[48,49] In this research, Toyota has concentrated on fuel saving; thus, they have designed their car–following control to maximize smoothness while also maintaining a small gap among cars and have, as a result, shown better fuel–saving results than in earlier work. Toyota in Europe has produced an animation that showcases their future vision of fully automated driving, which is posted on YouTube®.[50]

BMW presented a paper that mentioned vehicle automation for special purposes, such as remotely controlled parking of vehicles in a garage and training race car drivers to make an optimal drive around a race track, but these are not mainstream driving applications.[51]

FIAT created a concept car called the Mio in late 2010, based on ideas submitted from members of the general public throughout the world. This car, which was presented at the 2010 auto show in Torino, Italy, included not only fully automated driving on a dedicated lane, but also inductive recharging of the batteries that were used by its electric powertrain, representing a very advanced vision for future mobility.[52]

Some European researchers have also started studying the concept of a fully automated intersection, in parallel with similar activities in the United States. In these studies, there would be no traffic signal controller, but the vehicles would communicate with each other and with the intersection to reserve slots that they could track through the intersection to avoid conflicts with vehicles crossing at right angles.[53] Spanish researchers have also studied (in simulation) an intersection control strategy that could involve a mixture of automated and manually driven vehicles.[54]

Partially Automated Car Applications (Control Assistance)

Driving assistance is currently more popular than automated driving in the automotive world, so there is more work in this area. There are, of course, commercially available products already on the market that provide lane–keeping assistance and ACC in high–end cars in Europe and Japan. The one notable study of drivers' use of ACC that was conducted outside of the United States was in the Netherlands, and the results can be found via reference 55.

Nearly all control assistance systems that have been developed and tested have been autonomous and are therefore outside the scope of this review; however, the Technical University of Eindhoven and TNO in the Netherlands have started developing a cooperative ACC (CACC) system similar to what has already been tested by the Partners for Advanced Transit and Highways (PATH) in the United States.[56,57] This CACC system was demonstrated at a conference coinciding with the Grand Cooperative Driving Challenge in Eindhoven, the Netherlands, in May 2011.

Under the SPITS project, Dutch researchers have also developed a few cooperative systems. These systems rely on partial automation and driver assistance to encourage transitions toward deployment before a fully automated system can be implemented and even before CACC can achieve large market penetration. These systems were tested and demonstrated on a stretch of heavily instrumented roadway between Eindhoven and Helmond in the Netherlands, where a 5 km (3 mi) stretch of highway is equipped with 48 video cameras and 11 dedicated short-range communication transceivers, providing continuous surveillance and communication with the vehicles.[58] These systems, recently named *advisory acceleration control* (AAC), provide the driver with an in-vehicle display that continually advises him or her whether to accelerate or decelerate, or gives a recommended target speed.[59] These systems have been implemented in two different ways: (a) Using V2V communication within the vehicle stream to generate the accelerate or decelerate recommendations or (b) using I2V communication based on data collected from the highly instrumented highway segment. The latter approach is seen as a way of providing benefits to the early adopters on critical highway stretches before large portions of the vehicle fleet are equipped and has been tested successfully with 8 equipped vehicles scattered along a string of 68 vehicles.[60]

van Arem, Driel, and Visser used the MIXIC microscopic simulation to investigate the traffic throughput and stability impacts of CACC, incorporating good vehicle dynamics and driver behavior models.[61] They studied a freeway lane drop as the disturbance to induce a shockwave to limit capacity and found that the shockwave effect could be mitigated and the average speed increased with higher market penetrations of CACC. Schakel, van Arem, and Netten used a different simulation model to explore the traffic flow stability implications of CACC and the AAC, which advises the driver when to accelerate and decelerate rather than doing so automatically.[62] The researchers included results of a field experiment that used 50 vehicles equipped with the AAC, showing reductions in variability of speeds and gaps between vehicles.

Driver Guidance and Cooperative Collision Warning Applications

Driver guidance and collision warning systems are more popular than control assistance systems, so there is more work on these applications. Although most such systems have been autonomous, there is growing attention to cooperative applications. These have been important elements of the three major European cooperative system integrated projects, CVIS, SAFESPOT, and COOPERS, for the past several years and have actually been the primary focus of SAFESPOT. Related work has also been conducted in the supporting projects on the communication-enabling technologies, such as COMeSafety and the work of the Car2Car Communications Consortium. The current generation of European research projects was reviewed in the "General Overview of Relevant Current International Activities" section of this literature review, but it is also worth noting that field operational tests of a variety of cooperative systems are planned within the Drive C2X Project (C2X refers to *car to car or car to infrastructure or car to nomadic device*). Some of the very complicated linkages among the European cooperative system projects were explained in a briefing by Ertico's Maxime Flament focused on the Drive C2X project.[63]

Most of the documentation of the work within the individual projects that is reported in the literature is highly technical and therefore not appropriate for inclusion here; however, a good introduction to the general approach to V2V cooperative collision warning in Europe is provided via reference 64.

The Intersafe-2 project on intersection collision avoidance technology has been working on both V2V and I2V cooperation to exchange information about vehicle movements approaching intersections.[65] SAFESPOT also addressed V2V cooperation for intersection safety.[66]

The national research programs in Europe have also started to work on cooperative driver assistance systems. The Dutch work on "Connected Cruise Control," which gives real-time advice to drivers about their car following to reduce shock waves in traffic, was already cited earlier in the section, "Partially Automated Car Applications (Control Assistance)" in this literature review, because it also includes partial driving automation elements. The French research programs ARCOS (2002–2004) and SARI (2005–2010) produced some relevant work on improving traffic safety, but their documentation is rarely provided in English.

Japan has placed more emphasis on cooperative safety systems than has any other country and has published many papers about their work at the ITS World Congresses. Because of the boundaries in responsibility among their government ministries, there are separate activities aimed at highway safety and safety of driving on urban streets and arterials.

The highway–oriented cooperative ITS research programs, under the sponsorship of the MLIT, were coordinated by the public–private partnership organization AHSRA until it was disbanded last year. The program was transitioned toward a more mainstream deployment orientation as the Smartway project, under the Highway Industry Development Organization. The program defines the acronym *AHS* as *advanced cruise–assist highway system* rather than *automated highway system* in the description of their projects. The main concerns on the Japanese highway system are congestion associated with traffic merging from on–ramps[68,69] and with grade changes in rural areas, referred to as *sags*,[70,71] so these have been primary topics for attention in the Smartway/AHS program.

The National Police Agency of Japan created the DSSS program to develop infrastructure–vehicle cooperative safety systems that rely on the infrared beacon systems that they have already deployed in many arterial locations in Japan. The industry partners in this program have presented many papers at recent ITS World Congresses about their test systems. (See references 72, 73, 74, 75, 76, 77, 78, 79, and 80.) There are four major test sites in Japan, each in the home city of a different major automotive original equipment manufacturer that leads a different project. These systems are so tightly integrated with the specific technical characteristics of their communication system that it is difficult to see how transferable many of their results will be to other countries.

General Driver–Vehicle Interaction Issues

There is some limited international literature that addresses the interactions between drivers and vehicles in automated and partially automated systems. All of this literature is from two of the major European research projects.

The CityMobil project addressed driver–vehicle interaction issues by using driving simulator experiments, with drivers supported by different driving assistance systems. The researchers tested 43 drivers who used full speed range ACC or a combination of lateral and longitudinal control to see how this would affect their responses to unexpected events.[81] The researchers then considered the transitions between automated and manual control in the simulator when drivers were driving on what they termed *open eLanes* and *closed eLanes*.[82] The open eLanes would support varying levels of automated driving in coexistence with mixed traffic, whereas the closed eLanes would support fully automated platoon driving. In a separate study, the driver was treated as the third element of the cooperative system, in parallel with the vehicle and infrastructure, and a driving simulator was used to test the driver's ability to regain control of a vehicle after being given an alarm to indicate the need to intervene.[83] When the driving was automated, drivers needed significantly more time to respond than when the driving was manual.

HAVEit (i.e., Highly Automated Vehicles for Intelligent Transport) was the European Commission's flagship project for studying human interaction with partially automated vehicles, until its completion in June 2011. In this project, *highly automated* meant partially automated but not fully automated. This project studied different levels of partial automation in driving simulation and with full-scale test vehicles on test tracks to determine how well drivers can remain engaged and alert when their vehicles are driven with different types and levels of automation.[84,85,86] HAVEit staged demonstrations of their test vehicles at their final event in June 2011 in Sweden.

Both the CityMobil and HAVEit projects have documented their work on human factors in reports that are available as project deliverables on their Web sites,[87,88] and both have made extensive direct references to the relevant research performed in the United States in the 1990s under the AHS program. HAVEit has gone into greater depth in developing and testing designs of driver interfaces and operating concepts for partial automation, including means for detecting driver engagement and insisting that the driver remain engaged (looking at the traffic scene ahead) in order to maintain automatic speed and steering control.

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