The Exploratory Advanced Research Program

EXPLORATORY ADVANCED RESEARCH

Recent International Activity in Cooperative Vehicle–Highway Automation Systems

U.S. Department
of Transportation

**Federal Highway
Administration**

Foreword

This report has 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.

Joseph I. Peters
Director, Office of Operations Research and Development

Debra S. Elston
Director, Office of Corporate Research, Technology, and Innovation Management

Notice

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16. Abstract

This report summarizes the current state of the art in cooperative vehicle–highway automation systems in Europe and Asia based on a series of meetings, demonstrations, and site visits, combined with the results of literature review. This review covers systems that provide drivers with a range of automation capabilities, from driver assistance to fully automated driving, with an emphasis on cooperative systems that involve active exchanges of information between the vehicles and the roadside and among separate vehicles. The trends in development and deployment of these systems are examined by country, and the similarities and differences relative to the U.S. situation are noted, leading toward recommendations for future U.S. action.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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List of Abbreviations

AAC	Advisory acceleration control
ACC	Adaptive cruise control
ADAS	Advanced driver assistance system
AHSRA	Advanced Cruise-Assist Highway Systems Research Association
AIST	Agency for Industrial Science and Technology
BASt	Bundesanstalt für Strassenwesen (Federal Highway Research Institute in Germany)
BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research in Germany)
BMFT	Bundesministerium für Forschung und Technologie (Federal Ministry of Research and Technology in Germany)
CACC	Cooperative adaptive cruise control
CHAUFFEUR	European Commission-funded truck-platooning research project
CVHAS	Cooperative vehicle-highway automation systems
CVS	Computer-controlled vehicle system
DARPA	Defense Advanced Research Projects Agency
DG	Directorate General within the European Commission
DG-CONNECT	Directorate General for Communications Networks, Content and Technology
DG-ENTR	Directorate General for Enterprise and Industry
DG-INFSO	Directorate General for Information Society and Media (obsolete)
DG-MOVE	Directorate General for Mobility and Transport
DG-RTD	Directorate General for Research and Innovation
DLR	Deutschen Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DriveC2X	European project on communication between cars and other cars/infrastructure/nomadic devices
DSRC	Dedicated short-range communication
DVI	Driver-vehicle interface
EC	European Commission
EU	European Union
GM	General Motors
GPS	Global positioning system
HAVEit	Highly Automated Vehicles for Intelligent Transport
HIDO	Highway Industry Development Organization
HMI	Human-machine interface

I2V	Infrastructure–to–vehicle
ICT	Information and Communication Technology
IFSTTAR	Institut Français des Sciences et Technologies des Transports, de l’Aménagement et des Réseaux (French Institute of Science and Technology for Transportation, Development and Networks)
IMTS	Intelligent Multimode Transit System
INRETS	Institut National de Recherche sur les Transports et leurs Sécurité (National Institute for Research on Transportation Systems and Their Safety in France)
INRIA	Institut National de Recherche en Informatique et Automatique (National Institute for Research in Computer Science and Control in France)
ITS	Intelligent transportation systems
LCPC	Laboratoire Centrale des Ponts et Chaussées (Central laboratory of bridges and roads in France)
LIVIC	Laboratoire sur les Interactions Véhicule-Infrastructure- Conducteur (Laboratory on the interactions among vehicles, infrastructure, and drivers in France)
METI	Ministry of Economy, Trade and Industry
MITI	Ministry of International Trade and Industry (obsolete)
MLIT	Ministry of Land, Infrastructure and Transport
NAHSC	National Automated Highway Systems Consortium
NPA	National Police Agency
NSF	National Science Foundation
OEM	Original equipment manufacturer
PARTAGE	French project on driver assistance systems
PATH	Partners for Advanced Transit and Highways
PROMETHEUS	PROgraMme for European Traffic with Highest Efficiency and Unprecedented Safety
PRT	Personal rapid transit
PSA	French auto manufacturer (maker of Peugeot and Citroën)
RCA	Radio Corporation of America
RWTH	Rheinisch–Westfälische Technische Hochschule (Rhine–Westfalian Technical University in Aachen, Germany)
SARTRE	SAfe Road TRains for the Environment
SCORE@F	Système COopératif Routier Expérimental Français (French Experimental Cooperative Road System field operational test)
SPITS	Strategic Platform for Intelligent Traffic Systems
TMC	Transportation management center
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organization for Applied Scientific Research)
TRL	Technology readiness level
V2I	Vehicle–to–infrastructure
V2V	Vehicle–to–vehicle
VITA II	VIsion Technology Application (second generation test vehicle in PROMETHEUS by Daimler–Benz)

Introduction

During the past decade, the level of activity in cooperative vehicle–highway automation systems (CVHAS) has increased significantly in Japan and Europe, whereas it has remained at a relatively low level in the United States. This research project was initiated to create a summary of the current state of CVHAS development and thinking about these systems in other countries and to help inform decisions about future related activities in the United States. This review has identified the following salient points associated with international activities:

- The primary motivation for this work, as with intelligent transportation systems (ITS) in general, is to improve the energy efficiency of road transportation to help countries meet their Kyoto targets for reducing carbon dioxide (CO_2) emissions.
- Most of the development work is supported by public agencies with primary missions in technology development and economic competitiveness rather than in transportation. This means that Japan and Europe see significant export potential in automation technologies, rather than viewing these technologies solely in terms of domestic road transport applications.
- In Europe, there are significantly different perspectives between the organizations that approach CVHAS as automotive products and those that approach it as a means of improving public transportation. The former tend to emphasize partial automation systems operating in mixed traffic, whereas the latter tend to emphasize fully automated (driverless) vehicles in dedicated rights of way.
- Truck platooning and light passenger vehicle platooning have become popular applications for study and development. The former are very much a highway application, whereas the latter could be either highway–oriented or applied to low-speed urban vehicles (e.g., shuttling empty shared vehicles to where they are most needed).
- Automobiles and trucks currently on the market in Japan and Europe tend to be better equipped with advanced technologies than are the vehicles in the United States, and indeed most of the well-equipped vehicles in the U.S. market are imported from Japan or Europe. The sensors used for collision warning and avoidance systems and the electronic actuation systems used for electric and hybrid vehicles are important enabling technologies for the automation systems; thus, the automation system developers are trying to build on the use of the components and subsystems that are already in series production. The relative roles of the automotive original equipment manufacturers (OEMs) and their first–tier system suppliers in developing components and subsystems are sometimes difficult to discern, but

> in general, the automotive industry is becoming more internationalized, with less variation from region to region as both OEMs and major suppliers become truly global corporations.

The following section addresses the current CVHAS highlights by region.

Europe

Two different Directorates General (DGs) of the European Commission (EC) are currently sponsoring the primary automation projects in Europe. Their approaches are quite different, but they held a joint workshop in October 2011 to review current progress and to define the needs for future work with the hope that such automation projects can be better coordinated. DG-CONNECT (Communications Networks, Content and Technology, formerly DG-INFSO (Information Society and Media)) is tightly coupled to the automobile industry; thus, their current projects (i.e., HAVEit and SMART-64) have emphasized partial automation systems that operate in mixed traffic, building on the sensor technologies that are already being used for collision warning and adaptive cruise control (ACC) systems. DG-RTD (Research and Innovation) is more multi-modal in perspective, and its current projects, CityMobil and SARTRE (SAfe Road TRains for the Environment), have emphasized urban transit and trucking applications. CityMobil in particular has considered how to separate automated vehicles from other traffic (including vulnerable road users) to ensure safety.

Germany

Germany sponsored the KONVOI project to investigate the benefits and deployment issues associated with truck platooning, with truck platoons assumed to be operating in mixed traffic on autobahns. More recently, Germany has been studying the legal aspects of vehicle automation systems to determine what legal changes may be needed and how these relate to different levels of vehicle automation (which they defined very carefully and precisely).

The Netherlands

The Netherlands has emphasized cooperative system applications in their national programs, with work on cooperative ACC (CACC) and precursor systems that seek to smooth out traffic dynamics by advising drivers when to accelerate and decelerate. The Netherlands has invested heavily in a testbed environment on a 5-km (3-mi) section of road between Eindhoven and Helmond, where they have already held several high–profile demonstrations and which they are offering as a general European testbed.

France

The automation work in France has been concentrated in its research institutes, which have a substantial heritage of relevant work on both enabling technologies and systems. France is studying partial automation systems, as well as systems for shuttling vehicles among nearby sites at low speeds and without drivers.

Japan

Japan has one of the most ambitious automation projects, with the Energy ITS Project of its Ministry of Economy, Trade and Industry developing and testing an automated platoon of three heavy trucks designed to operate at short enough gaps to produce significant savings in aerodynamic drag. In addition, the Japanese automotive OEMs are experimenting with ACC system interactions and exploring CACC to smooth out traffic disturbances and also to save energy and CO_2 emissions.

Background

This report covers current international activities for developing, testing, and deploying CVHAS, augmenting the literature review that was prepared separately for this project. The focus of this report is on activities outside of the United States, because U.S. CVHAS activities are already familiar. In this report, 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 (and/or interactions with the driver in partially automated systems), but this report generally avoids addressing the fully autonomous systems that do not involve active cooperation. The term *automation* covers multiple degrees of automation of the driving function, ranging from driver warning and control assistance to partial automation and full automation.

The dominant international activities in CVHAS, as indeed in all of ITS, are sponsored by the Japanese government and the EC. Although they have the largest budgets and are most inclined to publicize their work in international technical forums, they are not the only sponsors active in this research area. There are also substantial national programs of research and development (R&D) in individual European countries and in other Asian countries, particularly Korea and China.

There has been considerable heritage of prior work on cooperative automation systems in several countries, although none has previously had as much activity as the United States; however, several of the current international automation activities are substantially larger and more ambitious than any current U.S. activities.

Japan

Japan has the most extensive heritage of relevant prior work. The pioneering work on vehicle automation by Dr. Sadayuki Tsugawa, working for the Ministry of International Trade and Industry beginning in the 1970s, was based on autonomous vehicle concepts.(1) The same ministry, however, also supported the development of one of the earliest and most ambitious automated personal rapid transit (PRT) system concepts—the Computer–Controlled Vehicle System (CVS)—in the 1970s.(2) This included special-purpose passenger and freight vehicles captive to a guideway, as well as "dual mode" vehicles that could operate automatically on the guideway and manually on normal roads. CVS had an extensive test track, with multiple test vehicles, and performed elaborate simulation studies of how large networks of automated vehicles would operate, but it never advanced beyond the test track stage.

When the ITS program became active throughout the world, Japan was one of the most ambitious participants. As soon as the United States formed the National Automated Highway Systems Consortium (NAHSC) in 1994, Japan's Minister of Land, Infrastructure and Transport visited to learn more about it and immediately formed a counterpart government–industry, public–private partnership organization in Japan, known as *AHSRA*. In the first few years, AHSRA concentrated on fully automated vehicle–infrastructure cooperative systems, as the NAHSC had been doing; however, by 1997 it had renamed itself the *Advanced Cruise–Assist Highway Systems Research Association*, and changed its emphasis to much nearer term systems for driver warning and control assistance. AHSRA continued with this emphasis through its dissolution in 2010, when its research mission was declared accomplished and the results of the research were handed off for deployment by the Highway Industry Development Organization (HIDO).

Vehicle automation work shifted in different directions in Japan in the meantime. Toyota concentrated its attention on fully automated driving of passenger cars and small buses by using magnetic guidance based on the Partners for Advanced Transit and Highways (PATH) technology from the United States and very strong infrastructure-based intelligence for controlling vehicles longitudinally (moving block control analogous to rail and automated guideway transit technology). Toyota conducted public demonstrations of its automated cars at its MegaWeb amusement complex in Tokyo and of its three-bus Intelligent Multimode Transit System (IMTS) at several amusement parks and the 2005 Aiichi Expo (World's Fair) near Nagoya, obtaining valuable practical experience with automated vehicle operations.

Japan's Ministry of Economy, Trade and Industry (METI; the new name for the former Ministry of International Trade and Industry) initiated the Energy ITS Program in 2008, with a 5-year plan to develop an automated truck platoon to reduce aerodynamic drag, thereby saving energy and CO_2 emissions. This important project will be described in more depth in the section on Japan in the next chapter of this report.

Germany

Germany's history of cooperative vehicle automation system work is not quite as long and deep as Japan's history, but it is nevertheless substantial. In the 1970s, a German consortium developed an advanced PRT concept called the *Cabinentaxi* under the sponsorship of the Ministry of Research and Technology and tested it extensively on a test track; however, like the Japanese CVS, it never advanced beyond the test track to public deployment.(3)

The German auto industry, with its emphasis on high-end vehicles, has had a significant involvement with advanced technology for automotive vehicles. The emphasis on automated driving has been somewhat muted because of the prevailing ideology about the "fun" of driving oneself, particularly at BMW and Mercedes; however, Mercedes was the founder of the PROMETHEUS project in 1986, the seminal European program that began ITS with a strong theme of automated driving.(4) Mercedes developed an extremely sophisticated and advanced test car, called *VITA II*, under PROMETHEUS, which they demonstrated performing fully automated driving in 1994.(5) The philosophy behind this vehicle development was to make the car fully autonomous, basing its driving decisions entirely on data about the driving environment collected by its sensors (mainly video cameras), without any cooperation with the infrastructure or other vehicles. This was influenced to a considerable extent by the pioneering work of Ernst Dickmanns of the University of the Bundeswehr, who demonstrated a vision-guided car in 1987.(6) German car makers do not trust their infrastructure agencies to be able to provide any cooperative infrastructure, so they have tended to insist that their vehicles be able to operate without infrastructure assistance.

Subsequent to PROMETHEUS, Mercedes was the leader of the CHAUFFEUR projects, in which platoons of two and three trucks were developed and tested. The first truck in the platoon would be driven manually, but the following truck(s) would use automatic steering and speed control to follow the trajectory of the first. This system was highly cooperative: There was close communication between the leading and following trucks and a distinctive pattern of infrared lamps mounted on the rear of the truck trailers that could be recognized by sensors on the trucks that followed behind them.

Volkswagen has been more receptive to vehicle automation than its German competitors have been. It demonstrated an advanced automated platoon system in the late 1980s, in which a heterogeneous platoon of vehicles was driven at short gaps on a test track with no drivers in the vehicles. V2V cooperation and sensing systems supported effective platoon control. More recently, Volkswagen supported the Stanford team's testing of autonomous automated vehicles for the Defense Advanced Research Projects Agency (DARPA) Challenges, and they are now key participants in the HAVEit (Highly Automated Vehicles for Intelligent Transport) project, which is described in more detail in the chapter, "Current European Projects in Cooperative Vehicle–Highway Automation" within this report.

France

In France, the interest in automated vehicles has originated within the research community rather than within the vehicle industry. Following the NAHSC work in the United States, a group of French researchers from several national research institutes developed a plan for an analogous program in France that is based on a very similar operating concept with cooperative automated vehicles driving in protected lanes. These researchers wrote a book about this work *(La Route Automatisée)* and formed a research consortium, LARA, to take it forward. The funding support for this work has been somewhat limited, focused on nearer term applications and narrower developments of enabling technologies.

The two French automobile companies, PSA and Renault, have been relatively negative about vehicle automation until very recently, in large part because of some adverse experiences with early versions of partially automated vehicle control assist systems that were brought to market prematurely; however, as explained in the section on France in the next chapter, this situation is now changing significantly.

The more substantial research activity in France has been in the area of “CyberCars,” small automated vehicles designed for use at low speed in urban areas. Several generations of these vehicles have been developed and tested under a variety of operating conditions, either physically segregated from other vehicles and pedestrians or else operating in locations with a very low density of other vehicles and pedestrians.

Parallel Historical Activities in the United States

In many ways, the United States pioneered the concepts and technologies of cooperative vehicle–highway automation and had the field to itself until the 1970s.(7) The original concepts were defined at General Motors (GM) in the 1930s and were presented to the public in the Futurama exhibits of the 1939–40 and 1964–65 World’s Fairs in New York, NY.(8) GM and RCA pursued development of automated highway technologies throughout the 1950s and into the 1960s.(9) In the mid-1960s, this line of research was picked up at Ohio State University, where it continued until 1980.(10) In the 1970s, there was considerable parallel research on cooperative automation systems for PRT, with heavy funding support from the Urban Mass Transportation Administration, the precursor to today’s Federal Transit Administration.(11) This led to the implementation of the Morgantown, WV, people–mover system and several other urban people movers, as well as many of the airport people movers now in operation around the world. These systems are captive to their specialized guideways, and their longitudinal control is based on moving block point–follower control systems derived from railroad technology, rather than performing active vehicle–following.

There was a hiatus in vehicle automation research in the United States for most of the 1980s,(12) even while this type of research became active in other countries, until the California Department of Transportation (Caltrans) began to sponsor a new generation of this kind of research via the California PATH Program in the late 1980s.(13)

The PATH research on automated highways was State-funded until it started to receive Federal Highway Administration (FHWA) funding in 1993 and was then integrated into the NAHSC research from 1995 onward. Following the demise of the NAHSC in 1998, Caltrans continued to support PATH research on automated trucks and buses through 2003. The Federal Transit Administration provided some support for automatic steering control of buses through its Vehicle Assist and Automation Program, and FHWA's Exploratory Advanced Research Program supported additional research on automated truck platoons and CACC beginning in 2007. For the past decade, these efforts have been funded at much lower levels than the analogous research overseas, which will be described in subsequent sections of this report.

Institutional and Political Environment for Cooperative Vehicle–Highway Automation

Europe in General and European Commission Activities

The institutional environment associated with ITS in Europe is very complicated and substantially different from that of the United States. It is sufficiently complicated that most of the people who work in the field in Europe claim to not understand it themselves, including those who work at the major public and private sector organizations in the field. With the establishment of the European Union (EU), there is some broad analogy to the United States if one thinks of the EU being like the Federal Government and the individual national governments being like the State governments. In this comparison, the EC would be analogous to the executive branch of the Federal Government; however, the analogy between the EU and U.S. Government is imperfect, because the division of responsibilities and the flow of funding between the EU and its member states does not match the division between the Federal and State governments in the United States.

One of the most important contrasts between Europe and the United States is that European countries have ratified the Kyoto Accords on greenhouse gas reductions and take very seriously its mandate to reduce CO_2 emissions from transportation. This means that saving energy and reducing CO_2 emissions has become the most important motivating factor behind ITS as a whole and automation in particular, ahead of both safety and mobility–enhancement goals. The EU's Transport Policy, as defined in a March 2011 White Paper, includes cutting in half the use of conventionally fueled road vehicles by 2030 and eliminating cars from Europe's cities by 2050. National taxation in most European countries has put the price of gasoline in the range of $8 to $9 per gallon in recent times, providing strong incentives for the vehicle industry and consumers to save energy.

At the EC, several different DGs, analogous to cabinet–level Departments in the United States, are involved in ITS:

» DG–MOVE (Mobility and Transport) establishes transport policy for Europe and addresses how to facilitate deployment of ITS technologies in support of that policy. The ITS deployment program EasyMove is centered here, but the only research appears to be policy–oriented rather than technology–related.

» DG–CONNECT (Communications Networks, Content and Technology) is the agency responsible for encouraging more use of information technology throughout Europe and for improving the international competitiveness of Europe's information technology (IT) industry. Its Unit H.5 (Smart Cities and Sustainability, formerly Information and Communication Technology (ICT) for Transport) sponsors the most visible of the EC's ITS research projects, especially on cooperative systems, and is the group that has established a research agreement with RITA's (Research and Innovative Technology Administration's) ITS Joint Program Office.

» DG–RTD (Research and Innovation) sponsors more general enabling technology research and more theoretical research, but it is also the agency that has been supporting most of the CyberCars research and promoting the use of special-purpose automated vehicles for urban transit applications in its Unit H2 on Surface Transport.

» DG–ENTR (Enterprise and Industry) is responsible for strengthening the international competitiveness of European industry and promoting job growth through innovation.

The level of coordination among these DGs is not particularly close, and they are not always aware of the activities in the other DGs. It is also significant that the technical research on ITS is supported in the agencies that are responsible for general research and industrial competitiveness in IT (analogous to National Science Foundation and Department of Commerce in the United States) rather than in transportation.

Each agency has its own processes for project selection and procurement, but in general, their procurements are less prescriptive than in the United States, because their rules are considerably different from the Federal Acquisition Regulations in the United States. There is much more opportunity for the industry and research community to influence the selection of research topics at the start of the process. The EC staff role is more of process facilitation rather than strategic direction setting; thus, the strategic direction comes more from the stakeholder community. In DG–CONNECT in particular, the project development and selection process appears to be much closer to the National Science Foundation process in the United States, with extensive bottom–up input on topics and peer review of proposals, than it is to the U.S. Department of Transportation process. The scope statement for a multi–million dollar project could be defined in one or two pages, leaving significant freedom to the teams competing for the funding to propose different technical approaches.

The EC funding is intended to encourage better integration and cooperation among the member states, so the funding always requires that proposals come from multi-national teams. In recent years, there has also been a strong emphasis on the funding of "integrated projects," which are very large projects composed of multiple subprojects, with teams that can be comprised of 40–50 different organizations and funding levels of tens of millions of dollars. These large projects require their own management structures and decisionmaking processes, which are created by the project partners rather than the EC. This helps keep the EC staff small and its influence over project direction limited.

These aspects of the EC research funding process give it more flexibility to respond to the interests of its industrial and research stakeholders as those interests change, but they also mean that the EC cannot get too far out in front of its stakeholders either. When senior EC staff members make public statements about automation being the inevitable future of road transportation, there can be some confidence that this is more than a personal opinion, rather that it reflects the broader evolution of thinking in Europe.

National Activities in Europe

Despite the presence and influence of the EU, the individual member states maintain their own diverse perspectives on transportation and technology issues. Their differences in geography, economy, and history have produced significant differences in their transportation needs and institutional structures. The major European countries all have their own transportation and technology strategies, as well as different (and competing) industrial interests; thus, Europe cannot be viewed as a monolithic entity.

France

France has a strongly centralized government structure, with heavy national investments in both transportation and research through its government ministries; however, in recent years, the funding for public transit system development and operation has been decentralized to the cities. Economic and political decisions are dominated by Paris, one of Europe's largest urban agglomerations, and all other parts of the country have a different stature (as well as significantly different problems and needs). The intercity high-speed rail network is the most highly developed one on the continent, and the intercity limited–access highways are privately operated toll ways (with high tolls). The highway operating companies have been international leaders in the adoption of ITS services.

France has two major automotive OEMs, Renault and PSA (which produces Peugeot and Citroën cars), neither of which has been exporting to the United States for a long time. They are not as large and do not have as much capability as the major German or Italian carmakers, and they have been relatively cautious about introducing ITS applications. Some years ago, they had a negative experience with the premature introduction of driver assistance systems, which led to a long period in which they were hostile to such systems and more advanced automation systems. Their position is now changing, in large part because of the growing emphasis on reducing energy use and greenhouse gas production. The French carmakers have been supporting new models of car ownership, such as carsharing systems, and have also become more multi–modal in orientation. Because PSA makes bicycles and motor scooters as well as cars, they have been creating integrated mobility solutions that combine these different modes. (Volkswagen has a somewhat different combination of electric bicycles and scooters available in Germany.)

France has a strong and well–funded national research establishment, with many national laboratories of international repute. The two major national research institutes that have been most important in the ITS field, the national institute for research on transportation systems and their safety (INRETS) and the national laboratory for roads and bridges (LCPC) were merged into a single entity, IFSTTAR, at the start of 2011, under the joint sponsorship of the ministries for research and industry and transportation. France had already created a jointly operated research laboratory to explore vehicle automation and interactions with drivers, called *LIVIC*, about 10 years earlier. The French research on CyberCars has been led by France's national research institute for information technology and automation (INRIA), which is more generally oriented toward basic research.

France is also trying to encourage the international industrial competitiveness of its regions through the creation of regional clusters of industry, research laboratories, and academic institutions. The large national technology initiatives are now only accepting proposals from such regional clusters to maximize the likelihood that the research results can be commercialized. The goals of producing a marketable product or a new startup company are now among the specific targets of some of the national projects.

The French research institutes are also networking heavily with researchers in other countries for ITS work. The research and industry ministry sponsors a broad-based cooperative program with the German research and technology ministry called *Deufrako* (based on the contraction of the German words for German–French Cooperation), and there are other active research collaborations with Canada, Australia, and California.

Germany

Germany's government is much more decentralized than France's, with more of the funding and power residing at the state level compared with the federal level. The major intercity highways (autobahns) are free rather than tolled, and the only significant growth in that highway network in recent years has been in the eastern part of the country, where heavy investments were needed to bring the infrastructure up closer to western levels after the reunification 20 years ago.

Germany does not have the kind of national research institutes that France has, but it does have extremely strong research universities and technical universities. Because these universities are considerably more applied in their research than are the French universities and have substantial professional staff, faculty, and students, they are more nearly comparable with the national research institutes in France.

Germany also has three major automotive OEMs (i.e., Daimler–Benz, Volkswagen, and BMW) and tier–one suppliers, Bosch and Continental, which are international leaders in technology and sophistication. Because they all sell high–end cars, they also have the customer base to purchase the latest driver assistance innovations. They have strong corporate research laboratories, which have taken the leadership role in many of the EC projects, giving them a disproportionate influence on the direction of that research.

Germany's research and technology ministry, Bundesministerium für Forschung und Technologie (BMFT), has been sponsoring national research programs in ITS for many years, complementing the EC research projects. These programs have had very strong involvement from the German carmakers and their major suppliers, which has led to a stronger emphasis on vehicle systems than on infrastructure systems. The current program, called *Aktiv*, is ending and will be followed by a new program. Germany's equivalent of FHWA's Turner–Fairbank Highway Research Center, *BASt*, has recently become active in automation issues, sponsoring important research on the legal issues associated with road–vehicle automation.

The Netherlands

The Netherlands is the most densely populated country in Europe and is a transportation crossroads because of its location and its major air and seaports. This means that goods movement is a particularly strong concern here. The Rijkswaterstaat, the agency responsible for the national highway network, has been an international leader in ITS from the start and has been active in many projects. They want to be a leader in implementation of cooperative systems, from traffic management to vehicle-based systems, and have sponsored ambitious field tests of ACC and lane–departure warning systems in the past.

The Netherlands has strong research universities and a national research institute, TNO, which was formerly public but is now a private entity. They have been active participants in European–wide projects and are well networked internationally. The Netherlands does not have a domestic automobile industry, although they have smaller specialty truck and bus manufacturers and many suppliers. The region of North Brabant around Eindhoven is the technology hub for the country and has been investing heavily to establish itself as one of the European centers for automotive technology. The Netherlands is trying to capitalize on its lack of a home–based automotive OEM to market itself as unbiased suppliers to the entire international vehicle industry. Both government and industry have created projects and demonstrations to showcase their interest in V2I and I2V cooperative systems, including various levels of vehicle automation. These have involved the regional development agencies as well as the national ministry for economic development in projects such as the recently completed Strategic Platform for Intelligent Traffic Systems (SPITS), intended to spur deployment of ITS.

Spain

In Spain, the research ministry has been providing support to researchers who are working on several projects that involve vehicle automation at the national scientific research council's automation and robotics center. These projects have mainly been focused on autonomous vehicles but more recently have involved more cooperative systems. The institutional framework, however, continues to focus on basic research rather than transportation applications, and it is not connected to transportation operations or deployment.

Other European Countries

Although there are important activities on automation in other European countries, these activities have been associated with specific industry and research organizations rather than with the national governments in those countries. Both the Volvo car and truck companies in Sweden have been active in several of the prominent EC projects on automation in the hope of continuing to enhance their reputation for leadership on safety issues. Ricardo, an automotive consultancy in the United Kingdom, is leading the SARTRE truck platooning project for the EC. In Italy, the University of Parma and its spinoff company, VisLab, have been international leaders in research on computer vision technology for vehicle automation.

Japan

Japan's government is considerably more centralized than the governments in Europe or the United States; thus, the national government has the authority to make decisions about infrastructure technology and deployment for the entire country. They also have a heavy regulatory hand on the vehicle industry, which they can force to move in a variety of directions. There is also a strong history of cooperation between government and large corporations, with the government promoting the interests of its large corporate citizens. This means that adoption of new cooperative ITS technologies can be pushed faster than in other countries.

Japan has four government ministries with interests in ITS, all with somewhat different areas of focus. The Ministry of Internal Affairs and Communications oversees wireless communication technologies and spectrum allocations. The Ministry of Land, Infrastructure, Transport, and Tourism is responsible for the intercity highway network and for safety regulations on the vehicle industry. The National Police Agency manages traffic within the urban areas (except for the highways), and METI is responsible for the country's economic health and for generating jobs through improving international competitiveness. It has a long–standing role as the protector of the automotive industry and has taken the lead role in the recent Energy ITS Program that is developing an automated truck platoon to save energy and greenhouse gas emissions.

Japan does not generally have the strong national research institutes or universities of the European countries, but its vehicle and electronics industries have very strong technical capabilities in their own research and development laboratories. This is typically from where the major technological advances come. The domestic Japanese consumer market is favorably inclined toward new gadgetry, even before it is mature enough to provide real value. This means that the Japanese companies can generate revenue by selling immature systems to their customers and then gradually improve the systems until they are robust enough for export to other less tolerant markets.

Japan is not a fertile ground for applying automation to transit buses, because the high-priority and high–demand transit services are all on rails rather than on rubber tires, and the buses only provide supporting feeder services or relatively low–volume services. Because the majority of Japan's freight travels by highway, however, the trucking applications look considerably more promising. The automobile applications are more uncertain because of the peculiarities of automobile usage in Japan. Automobiles serve only limited fractions of the trips in the urban areas, because the densities are generally too high for efficient use and parking, and the urban expressways are very narrow (only two lanes each way). On the intercity highways, the congestion problems are associated with grade changes (known as *sags*) and with delays at the access points, where vehicle automation is not a particularly efficient or cost–effective solution compared with other alternatives.

The government and automobile companies are very interested in methods of smoothing out the speed variations at the sags and have consequently created the Smart Traffic Flow Research Consortium to develop strategies for speed harmonization. This consortium, which includes the major automotive OEMs and university researchers, focuses on strategies that are much less ambitious than vehicle automation, including the introduction of pace cars to regularize the traffic speeds, roadside variable message signs to advise drivers to maintain their speeds, V2V communications and in-vehicle displays advising drivers about the speeds they should drive, I2V speed advisories, and V2V speed controls along the lines of cooperative ACC. The consortium is also working on achieving string stability of conventional ACC vehicles, including when vehicles from different makers need to coexist in sequence. These activities were first unveiled to an international audience in Special Session 52 of the ITS World Congress in Orlando, FL, but there were no published papers or other enduring documentation provided in English.

Korea

The institutional structure in Korea is similar to the Japanese model, with a strong central government and strong automotive industry. Because its economy has developed somewhat more slowly than has Japan's, the situation in Korea often gives the impression of being similar to Japan a few decades earlier.

The Korea Highway Corporation is responsible for the extensive toll road system in Korea and is very well–funded as a result. It has initiated a "Smart Highway" project to apply the latest ITS technologies, including cooperative systems, to its highways. After multiple contacts and inquiries, however, it appears that this project is not extending its scope beyond driver assistance systems and into full automation within the foreseeable future, so it is not directly relevant to the current project.

Some Korean universities are participating in projects and contests that involve autonomous automated road vehicles, which are somewhat outside the scope of this review, but it has not been possible to identify any cooperative automation work in Korea.

China

China has a centralized government structure, more so than any of the other countries considered in this report. Inquiries about work on cooperative automation systems have not yielded any leads until now. Multiple universities have been conducting research on autonomous automated vehicles and holding competitions, but there have not yet been any indications of V2V or I2V cooperation in support of automated driving.

Summary of Key Factors Overseas

Several aspects of the environments in other countries are notable, particularly for the ways in which they contrast with the U.S. environment:

» The motivation and funding support for the development of ITS, and vehicle automation systems in particular, generally come from public agencies that are responsible for improving technology and economic competitiveness, rather than transportation.

- The primary public sector goals associated with ITS and vehicle automation in particular have shifted in recent years to energy savings and CO_2 emission reductions, based on the need to meet the targets in the Kyoto Accord (this is now prioritized ahead of safety and mobility issues). Achievement of these goals is already encouraged by high fuel taxation, producing gasoline retail prices at more than twice the U.S. levels.

- The governments of other countries tend to have more centralized decisionmaking and deployment authority than in the United States, making it easier to implement new infrastructure–based systems. At the same time, vehicle manufacturers remain leery of being dependent on deployment of roadway infrastructure elements for their systems to work effectively.

- Vehicle manufacturers and vehicle buyers are willing to pay more for innovative high–technology features in their vehicles.

Current European Projects in Cooperative Vehicle–Highway Automation

The European projects that are currently developing CVHAS, or their subsystems or precursors, are reviewed in this chapter. These reviews are based on in–person visits with the leaders of the projects and, where possible, participation in demonstrations of the target systems. The information reported here augments the information in the literature review that was prepared for this project and developed as a separate report. It also includes more subjective and unofficial information than the more formal published information cited in the literature review.

This review of the current and recent European CVHAS projects begins with the major integrated projects sponsored by the EC and then covers the most important national projects. The section concludes with a discussion of the major workshop that the EC sponsored in October 2011 to synthesize the results of the work performed until that time and to identify the next steps that need to be taken. The following sections in this chapter provide descriptions of the different CVHAS projects reviewed.

SARTRE

The SARTRE project (SAfe Road TRains for the Environment) is the most recent of the major EC–sponsored projects on vehicle automation, and its vision is the most ambitious in the level of automation to be implemented in a public mixed–traffic environment involving automated close–formation vehicle platoons. As the name implies, the main motivations are both environmental and safety–related, but the project is also interested in reducing congestion and enhancing driver convenience. SARTRE is led by the automotive consultants Ricardo from the United Kingdom and the major vehicle industry partners at Volvo, both automobile and trucking companies. The SARTRE project team is developing and testing a concept of a platoon led by a manually driven truck, with a mixture of fully automated trucks and cars following close behind to save fuel and emissions. The SARTRE project team plans to eventually operate these "road trains" on public highways in mixed traffic, with the shortest feasible gaps between vehicles.

SARTRE began in September 2009 and ended in September 2012 with a demonstration in Sweden. It is funded at a total level of €6.4 million ($8.2 million), with the EC funding 60 percent of the total and the seven project partners from four European countries funding the rest as cost share. The project sponsors held a media demonstration in December 2010 and a workshop and demonstration in September 2012, but no demonstrations were scheduled during the information–gathering stage of this international review project; thus, the information reported here was based on meetings with the primary project participants and their presentations at recent international meetings rather than on any direct experience of vehicle demonstrations.

Figure 1 shows the basic SARTRE operating concept in schematic form.(14) A truck driven by a specially trained driver would lead the platoon, and other trucks and cars could then perform fully automated vehicle–following behind the lead truck. The driver of the lead truck would be provided with technologies that would assist him to drive as safely, smoothly, and efficiently as possible. The steering systems of the following vehicles would be designed to follow the same trajectory as the leading truck, but this raises concerns about the safety of the followers if the lead truck runs off the road or is involved in another kind of unsafe scenario. The drivers of the following vehicles would be able to do whatever they want while following in the platoon and would not have any vehicle-control responsibilities, thus freeing up the drivers to perform other duties during their travel time.

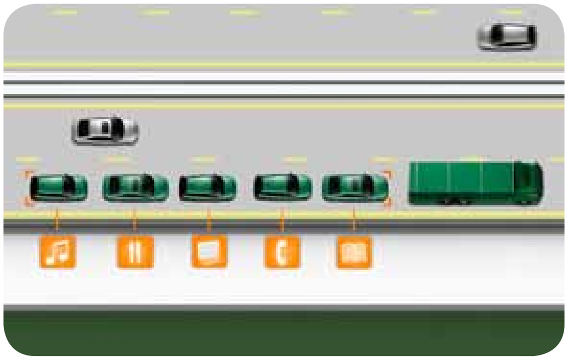
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Figure 1. Diagram. SARTRE operating concept.

The SARTRE project team has been trying to use available sensor technologies as


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Figure 2. Photo. SARTRE demonstration of three automated cars and one automated truck following the lead truck in a platoon (May 2012).

much as possible in their test vehicles, because the Volvo production cars are now equipped with very comprehensive suites of sensors for collision warning and avoidance. SARTRE is using one 5.9 GHz dedicated short-range communication (DSRC) radio per vehicle for the V2V coordination, with 40–Hz updates of the vehicle data on these radios based on the control update cycles of the other elements of the system, but this is a faster update rate than what other DSRC applications have been assuming. The development work has been paying close attention to radio wave propagation challenges in this frequency band, particularly to avoid having cars shadowed by much taller trucks. The first test track experiments were conducted in late 2010, culminating in a high-profile media event that drew considerable attention. A second demonstration on a public motorway in Spain in May 2012 showed three passenger cars and a truck following the lead truck, as illustrated in figure 2.(14) A view from inside a car automatically following behind the lead truck from the first demonstration is shown in figure 3.(14)

SARTRE project members have been considering a variety of use cases for maneuvering, as shown in figure 4,(14) with vehicles of different types entering and leaving the platoon, to make sure that all cases are covered by the technological capabilities of the system. Information from the following vehicles will be communicated to the driver of the lead vehicle so that he can judge, for example, when there is enough space in an adjacent lane to accommodate a lane change by the entire platoon (relying on the blind spot sensor systems on those following vehicles). Vehicles entering and leaving the platoon would be steered manually by their drivers, but their longitudinal control would be automated.


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Figure 3. Photo. Reading a newspaper while being driven automatically in the platoon behind the lead truck (December 2010).

The SARTRE operating concept assumes that no infrastructure cooperation will be needed and that the SARTRE platoons

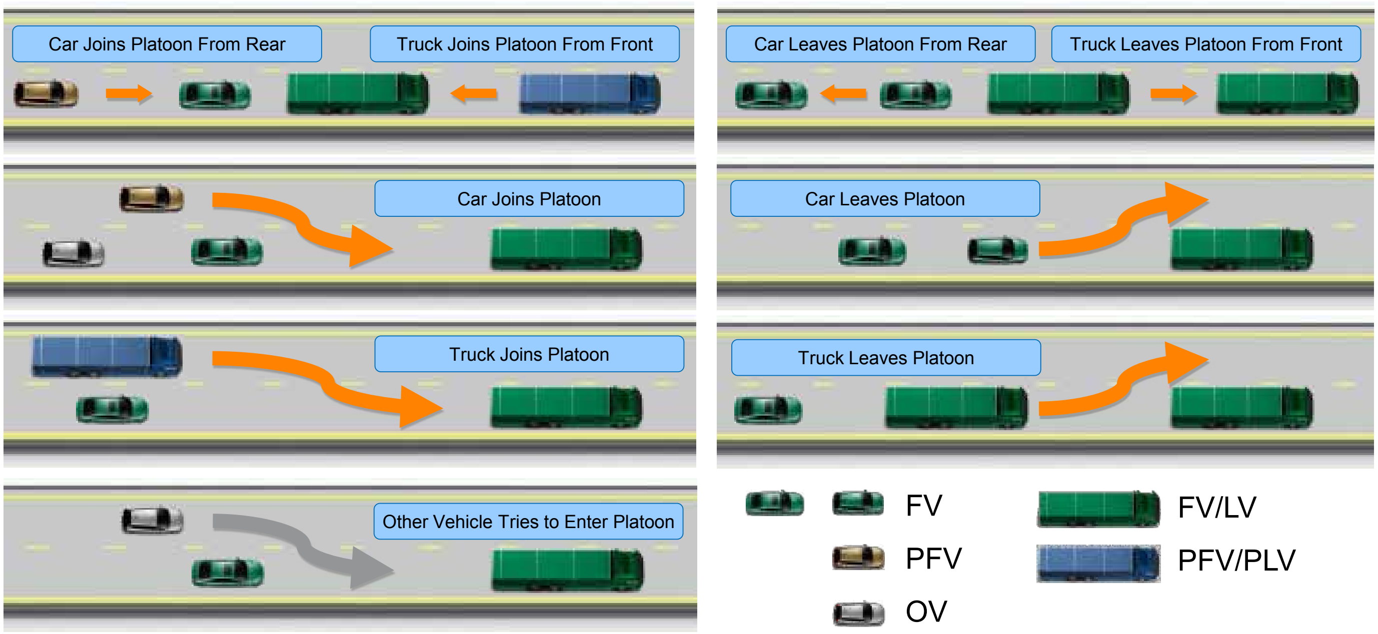

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Figure 4. Diagram. SARTRE vehicle-maneuvering use cases.
NOTE: FV = following vehicle, LV= lead vehicle, PFV/PLV = potential following vehicle/potential lead vehicle, OV = other vehicle (not part of the platoon).

would be able to operate in any highway lane, without segregation from other vehicle traffic. The project team has not worked through the implications of all the hazard scenarios that could arise in this type of mixed traffic automation, but they are aware that there are serious challenges here. One of the project partners, ika Aachen, already had experience with cut-ins within their truck platoon in the KONVOI project several years ago (discussed later in this report), and cut-ins were also tested in SARTRE.

The lateral control of the following vehicles in a SARTRE platoon is performed by following the trajectory of the lead vehicle, more or less like tracking a sequence of "breadcrumbs" from that vehicle, without reference to any roadway markings. This was justified on the basis of avoiding the need to add more sensors to the vehicles, but it increases the risk to all of the followers when the lead vehicle driver does something wrong.

HAVEit

The HAVEit project is another major Integrated Project of the EC, in this case sponsored by DG-CONNECT. The name *HAVEit* stands for Highly Automated Vehicles for Intelligent Transport, but in this context *highly automated* does not mean fully automated. Rather, this project concentrates on partially automated vehicles and has conducted some important experiments and prototype developments to explore how drivers interact with vehicles at different levels of automation, trying to avoid both underloading and overloading of drivers, as illustrated in figure 5.(15)

HAVEit began in February 2008 and ended in June 2011, with a final event held at a Volvo test track in Sweden. It was funded at a level of €27.5 million ($35 million), with €17 million ($22 million) funded by the EC and the rest funded in cost share from the 17 partner organizations led by the automotive supplier company Continental. The primary vehicle industry partners were Volkswagen for cars and Volvo Technology for trucks.

The central principle in the HAVEit project is the provision of four different modes of driver–vehicle interaction, with varying levels of automation, which can be engaged by the driver through a "mode selection and arbitration unit" as follows:

» Driver only—full manual control.

» Driver is assisted by using a single existing driver assistance (warning) system, such as a lane-departure warning or a forward-collision warning.

» Semi-automated, combining warning systems with a longitudinal control

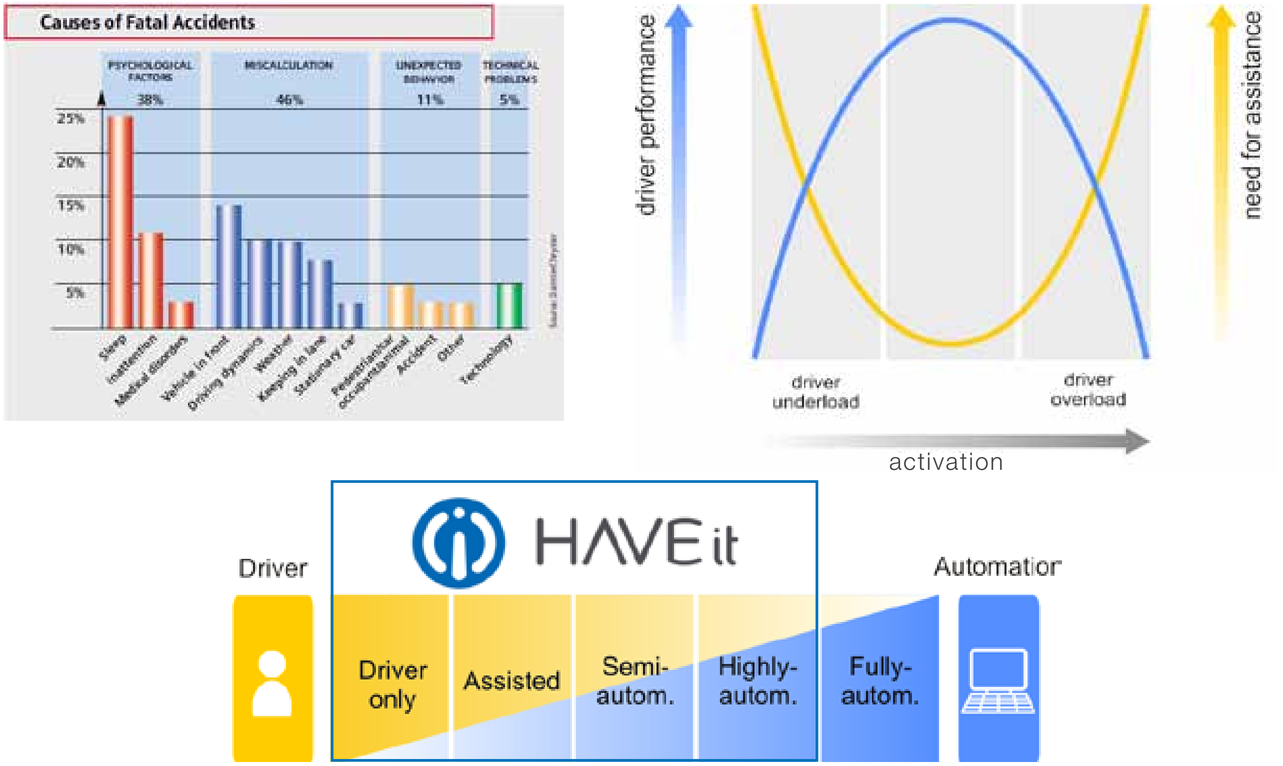

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Figure 5. Diagram. Basic philosophy of multiple levels of driving automation in HAVEit.

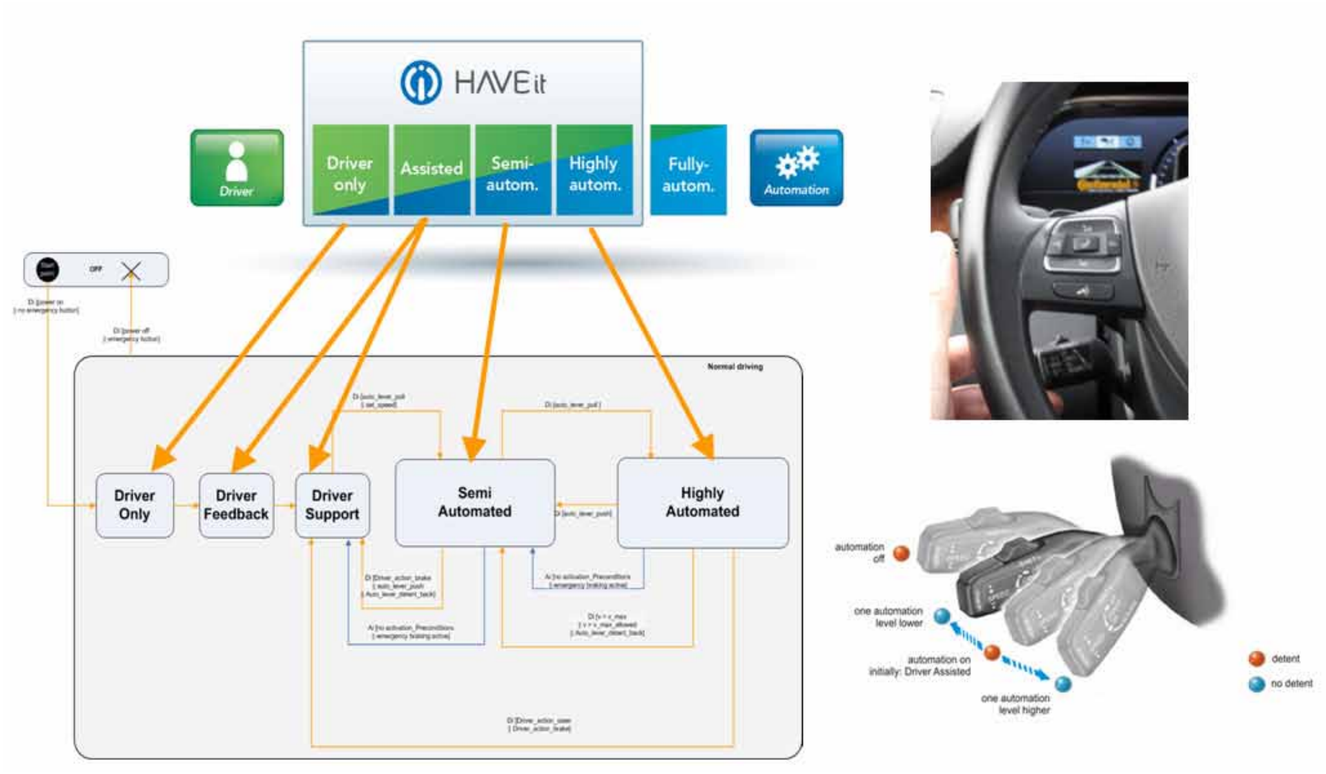

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Figure 6. Diagram. Multiple automation levels through one driver–vehicle interface.

function, such as ACC or full–speed range ACC.

- Highly automated, combining lateral and longitudinal control (ACC plus lane–keeping assistance).

These different modes have been implemented on test vehicles primarily by using existing commercially available sensors and driving assistance systems, minimizing the amount of new purpose–built equipment and associated costs. An integrated driver–vehicle interface (DVI) was developed so that the driver could look in one place to determine which level of driving automation or assistance was being provided and to choose a different level. This concept is indicated schematically in figure 6,(15) and an example implementation on one of the test vehicles is shown in figure 7.(15) Despite the emphasis on re-use of existing sensors and systems, the overall system is still quite complex, as shown in figure 8.(15)

The HAVEit project team is well–supplied with human factors expertise and tools to develop a better understanding of driver limitations and drivers' ability to interact safely with the different levels of automated driving assistance. They used driving simulators in the development, including a "theater technique," in which an expert driver acted as the virtual copilot that the test subjects did not see at a second driving station, by which they could assess which of the copilot's driving strategies


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Figure 7. Photo. Example of a human-machine interface, showing different control mode choices.

worked well with the naive test subjects and which did not so that they could choose which to implement in the system software.

At the HAVEit final event, Dr. Juergen Leohold, the head of research for Volkswagen, confirmed that driving automation had been part of their corporate vision for a long time, motivated primarily by safety considerations. He identified the main challenges to deployment of these partially automated systems to be:

- » Affordable sensors with "high enough" performance capabilities.
- » Sensor fusion to achieve higher reliability and safety.
- » Legal restrictions associated with the Vienna Convention on Road Traffic, liability uncertainties, and the need for consistent regulations.
- » Development of a human-machine interface (HMI) approach to maintain the driver's attention in the control loop without being annoying.

The current prototype vehicle implementation relies on a video camera mounted inside the instrument cluster, observing the driver's face, as explained in figure 9.(15) If the driver's head or eyes are turned away from the forward view of the road, a video image processing system detects this as inattention and issues an increasingly urgent audio alert to the driver. If the driver does not return eyes to the forward

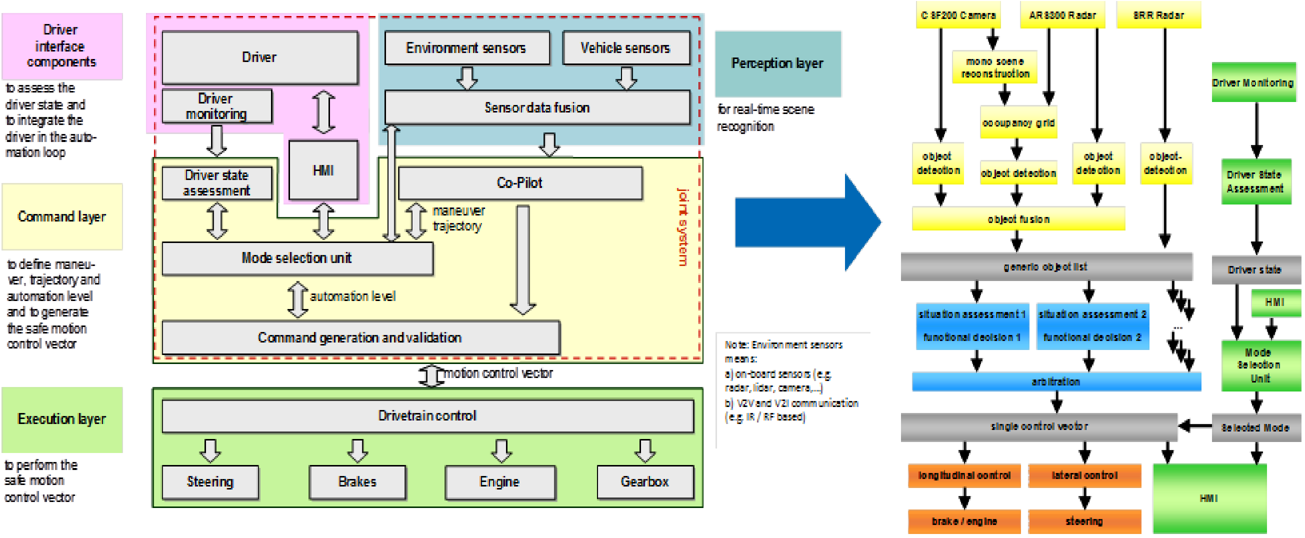

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Figure 8. Diagram. Complexity of HAVEit implementation.

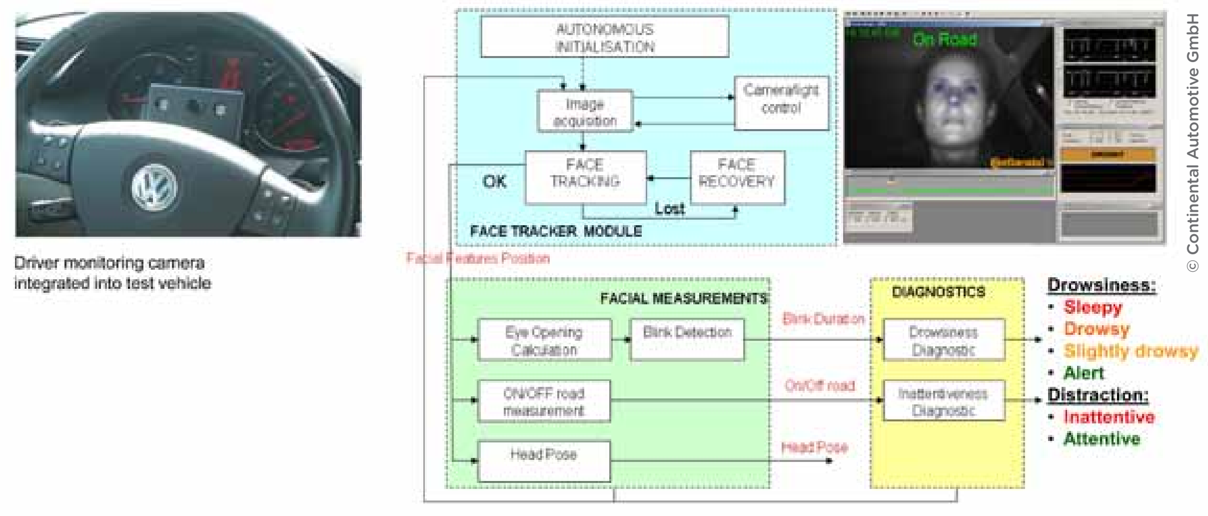
Driver monitoring camera integrated into test vehicle

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Figure 9. Diagram. HAVEit concept of driver monitoring to ensure driver engagement, from Continental Automotive France (CAF).

driving scene, the system then decelerates the vehicle to a stop. This is a very conservative system design approach, intended to deter the driver from non–driving tasks, such as texting, but at the same time it denies the driver one of the primary benefits of automated driving, which is the ability to do other things. Some of the European automotive marketing people believe that this is a lost opportunity, and that the real attraction to the public of automated driving will be the ability to do something else during the driving time. Of course, to be able to do this safely, the performance of the automated system will need to be much more advanced than the current state of the art.

The HAVEit operational concept was described as a "joint system," with the driver assuming supervisory control responsibilities. An analogy was drawn to commercial aircraft automation, in which 95 percent of the time the airliner is flown by the autopilot under the pilot's supervision, but the pilot remains responsible for strategic decisions and must be prepared to take full control at any time. The other metaphor that was used to describe the system was the horse and rider, with "dynamic task repartition" between the elements of a joint cognitive system. In this case, the vehicle system needs to maintain a continuous real–time understanding of both the driver's capabilities (watching the road or not) and its own capabilities (uncertainties or conflicts in its sensors' perceptions of the environment).

The highlights of the HAVEit final event were the demonstrations of the vehicles on the test track, which are discussed in the following sections.

Volkswagen's Temporary AutoPilot

Volkswagen's Temporary AutoPilot received the strongest media attention, because it left the impression of a close approach to truly automated driving, but some of the media coverage overlooked the fundamental requirement for the driver to continue watching the forward driving scene as a prerequisite for the system to continue to operate. The AutoPilot demonstration proceeded through the different levels of driver assistance up to the combination of lateral and longitudinal control. The different control levels were visible on the DVI display, as shown in figure 10.(16)

The vehicle demonstrated the ability to track a slower vehicle in the left adjacent lane and avoid overtaking it on the right, which is illegal in many European countries.

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Figure 10. Photo. Volkswagen's Temporary Auto Pilot display, showing three levels of automation choices in lower right corner.

The vehicle also performed an emergency braking maneuver behind a stopped fake vehicle in its lane (fake for safety, to avoid danger in event of a failure). After engaging the "highly automated" mode with automatic steering and speed control, the driver turned his head to look out the side window for an extended time. That caused the system to beep with increasing urgency to try to draw his attention back to the road. When he failed to respond to the system's beeping, it brought the vehicle to a gradual stop, representing a risk-averse strategy in case the driver was incapacitated or asleep. This strategy also prevented drivers from abusing the system by trying to do something completely different while driving.

Automated Queue Assistance (AQuA)

The Automated Queue Assistance (AQuA) system for trucks by Volvo Technology provided a somewhat different view of highly automated driving aimed specifically at low-speed driving in heavily congested traffic, which could become monotonous for the driver. This system was demonstrated by following a lead car that went through a series of stop-and-go maneuvers, maintaining the truck at an appropriate following distance behind the car. Its driver interface is shown more closely in figures 11(16) and 12,(16) and figure 13(16) shows the view from the visitor seat in the back of the cab during the demonstration. The AQuA function can be engaged only at speeds below 30 km/h (19 mi/h) and when there is a target vehicle within a reasonably short forward range.

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Figure 11. Photo. Steering wheel controls for Volvo Automated Queue Assistance (AQuA) for heavy trucks.


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Figure 12. Photo. Automated Queue Assistance (AQuA) driver interface for heavy trucks.

Automated Assistance in Roadworks and Congestion

Automated Assistance in Roadworks and Congestion was a demonstration intended to address assistance for drivers in a very high–workload–driving environment, in which the automation could help reduce the workload. This demonstration was implemented by the first-tier automotive supplier Continental on a passenger car, which had to drive through a road section where temporary pylons defined a path different from that represented by the normal lane markings. The vehicle had to stay within the pylons while following a lead vehicle that went through a variety of speed changes of the type one would expect when going through a work zone where traffic flow is impeded.

Figure 14(16) shows the additional complication introduced into this scenario, where a truck in the adjacent lane drove very close to the equipped car, actually straying over the lane boundary (this happened toward the right end of the scene in figure 14, after the pylons). In this case, the car's side–mounted laser scanners detected the truck impinging on its lane so that it could adjust its trajectory off the lane center to avoid being hit by the truck. Figure 15(16) shows the DVI on this test vehicle when it was in manual control, using only its collision–warning functions (indicated by the stick figure icon illuminated in white). The touch–screen display could be used to choose the semi-automated mode or the "highly automated" mode, represented by the rectangles that are shown in blue in figure 15,(16) because they were not active when this photo was taken. Although the display in this vehicle and the other cars in the demonstrations


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Figure 13. Photo. Automated Queue Assistance (AQuA) system demonstration for low-speed automation in a truck.

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Figure 14. Photo. An Automated Roadworks Assistant vehicle follows a lead vehicle between pylons and maintains separation from a truck.

were in the center console of the vehicle, it was noted that production systems would be more likely to have their displays located directly in front of the driver, in the primary instrument cluster, where they will be easier to see without diverting the driver's eyes from the forward driving scene.

In figure 15,(16) rain can be seen on the car windshield. The day of the HAVEit demonstration had extremely variable weather, with conditions ranging from bright sun to heavy rain. The vehicle systems worked well under this full range of conditions, and none of the demonstrations had to be aborted because of adverse weather; however, at various times, phantom vehicle icons were observed on the display screens, indicating cases in which sensors were detecting other objects, such as guardrails, and not filtering all of them out.

Although the HAVEit systems that were developed and tested under the current project were entirely sensor-based rather than relying on communication for cooperation, the EC project officer for the project noted that in the follow-on work, cooperative capabilities will be added to provide additional data sources for the vehicle systems.

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Figure 15. Photo. Roadworks Assistant driver-vehicle interface, showing three levels of automation on left side of screen.

CityMobil

The CityMobil project was sponsored by the EC, DG-RTD, from May 2006 through the end of 2011, at a total funding level of €40 million ($52 million), of which €11 million ($14 million) was provided by the EC (29 partner organizations provided the remaining funds, mainly to support their field demonstrations). This is the one project that has emphasized public transit applications of automated vehicles rather than automobile or trucking applications. It is the latest in a sequence of projects that have addressed the "CyberCar" concept, including CyberCars I and II, CyberMove, and City NetMobil.

CityMobil is promoting the development of new forms of public transportation to help reduce automobile usage in cities in support of environmental goals. It is based on the assumption that about one-third of the households in European cities cannot afford a car and one-third of households must have a car based on their housing and workplace situations, but one-third have a choice and can be influenced by the availability of better transit alternatives. CityMobil is targeting diverse niche markets for improved transit services, depending on urban area sizes, patterns of development, and existing transportation infrastructure. CityMobil is considering four classes of vehicles:

- CyberCars—Driverless low-speed vehicles that operate within somewhat restricted environments (low-density pedestrian zones).
- Advanced buses that use guidance and control technologies in busways.
- PRT—Small vehicles that operate between stations on a special dedicated guideway.
- Advanced city vehicles—Cars with driver assistance systems for partial automation and the ability to operate under automatic control under some specialized conditions, such as platooning of empty vehicles without drivers behind a lead vehicle driven by a specially trained person.

The definitions of *CyberCars* and *advanced city vehicles* remain somewhat imprecise at this stage of development, with considerable uncertainty about what levels of automation would be achievable in what kinds of operating environments (how much separation from pedestrians and other vehicular traffic). This is an important issue that became apparent with some of the other CVHAS projects as well and was indeed among the main areas of controversy during the NAHSC research in the United States in the 1990s.

Most of the information to be reported here was obtained during the CityMobil project's final event in La Rochelle, France, in May 2011, which included a small public demonstration of a CyberCar and a 2-day technical conference with over a hundred attendees.

CityMobil La Rochelle Cyber Car Demonstration (May 2011)

The CyberCar demonstration used a single driverless vehicle with space for four passengers to stand while it drove at low speed (approximately a fast walking pace). It was operated in a low-density residential and light commercial area near the harbor in La Rochelle, mainly on a sidewalk adjoining a

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Figure 16. Photo. La Rochelle CyberCar demonstration site features a park sidewalk shared with pedestrians.

park and on an alley beside a row of buildings (figure 16).(16) This is a very low-density area, so interactions with other vehicles and pedestrians were infrequent. An attendant was required for passenger loading and unloading at the stations, and he walked or jogged alongside the vehicle while it was driving (figure 17).(16) When the driverless vehicle approached slower pedestrians, it slowed down behind them and then beeped at them to encourage them to get out of the way (which they generally did); however, if the pedestrians did not move, the vehicle would stop. In the aforementioned alley, the vehicle shared the space with the occasional automobile and had to cross a few other alleys where cars could be operated. In these locations, the driverless vehicle had to wait for the other vehicles to pass before it could proceed.

The demonstration vehicle identified its location based on a Simultaneous Localization and Mapping (SLAM) approach, using laser scanners at both ends of the vehicle to recognize the surrounding built–environment landmarks. The conference attendees were informed that when a large group of

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Figure 17. Photo. A CyberCar at the station in La Rochelle, France, with an attendant who was required for passenger loading and unloading during the demonstration.

reporters and photographers surrounded the vehicle at the time of its media event, they occluded the surrounding buildings from the view of the laser scanners, and as a result, the vehicle lost its bearings (not unlikely in any reasonably dense pedestrian environment). The vehicle was not equipped with a global positioning system (GPS) for positioning because of concerns about interruption of satellite coverage in the alley, which was considered to be an "urban canyon" for GPS coverage. The vehicle was equipped with WiFi communication so that the demonstration operators could keep track of its location and status.

The vehicle demonstration was continued after the end of the CityMobil conference for 10 weeks, during which time it operated 3 hours per day, carrying a total of 900 passengers (an average of about 4.5 passengers per hour). Of these passengers, 200 were surveyed for their opinions about the system.

Even this limited demonstration required considerable political and institutional arrangements. Because the vehicle was driverless, the mayor of the city had to issue a special exemption from normal rules (an *arrêté*), taking on special responsibility for anything that may have gone wrong. The low density of vehicle and pedestrian traffic in the area, as well as the low building density, raised questions about whether the sites that would be technically feasible to use such a vehicle would actually have enough travel demand to produce benefits that exceed the costs. Would these vehicles be able to operate in locations where they are really needed (such as the much more crowded main marina of La Rochelle, only a few hundred meters away from the site that was used)?

CityMobil La Rochelle Conference (May 2011)

The CityMobil conference was considerably more informative than was the vehicle demonstration, with a wide variety of presentations and discussions. Some of the key information brought forward during the conference is discussed below.

Low-Speed Urban CyberCar Plan, Rome, Italy

Although the CyberCar demonstration in La Rochelle was the most visible example of vehicle automation technology, the main field test implementations—where most of the resources were spent in the project—were conducted elsewhere. In the case of low-speed urban CyberCars, the main implementation was planned for Rome, Italy, where the demonstration site would have connected a remote parking lot with a large convention center. The vehicle that was intended to be tested in Rome is shown in figure 18.(16) A close-up view of the soft bumper that is designed to protect pedestrians who could be hit by the vehicle if its sensors did not detect them or if the vehicle did not stop in time is shown in figure 19.(16)

The intended CyberCar implementation in Rome is notable for the difficulties encountered when attempting to obtain the necessary certification for vehicle operation from government authorities. These authorities required that the vehicle only be operated on a right-of-way that was entirely fenced in to preclude interactions with other vehicles or pedestrians (obviating the need for the soft bumper). This obstacle showcased one of the institutional challenges in trying to implement a driverless vehicle in a public environment and raises questions about how it will be possible to put these vehicles into less-protected environments, where they would be easier and cheaper to place into service and would be accessible to more potential users.

Vision-Guided Bus Technology

The advanced bus application in CityMobil is the use of the vision-guided bus technology developed by Siemens (originally Matra) for use on the CiViS BRT bus, in this case applied to a more conventional bus in Castellon, Spain.

This bus-guidance technology has been in commercial use in Rouen, France, for many years but was tested unsuccessfully in Las Vegas, NV, several years ago. It has not been made clear what was sufficiently special about the Castellon application that it should become the subject of study in a major research program.


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Figure 18. Photo. Rome Exhibition Center vehicle.

For example, the Castellon operation has much less automation than does the Phileas bus that was developed in Eindhoven in the Netherlands several years ago. Phileas was a publicly funded project that developed a

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Figure 19. Photo. Soft bumper of the Rome Exhibition Center vehicle.

new automated bus rapid transit system that could be viewed as the equivalent of a rubber-tired tram. Phileas was funded by local and regional governments in the North Brabant region of the Netherlands, with the intention of strengthening the local industrial base and encouraging job growth through export sales of buses to other countries. (See reference 17 for more information about Phileas.)

The Phileas system was tested on a public busway in Eindhoven under fully automatic control (both speed and steering control with driver supervision), but the control system was removed from the buses before regular revenue service began. Although the complete story of the Phileas system has not been documented, unofficial information suggests that the safety certification of the automation system was not included in the planning or budget for the original development of the system. When it came time to obtain the safety certification, there was no budget to pay for it, and thus it was not obtained.

Personal Rapid Transit

The most ambitious project incorporated in CityMobil was the deployment of the ULTra PRT (Personal Rapid Transit) system at Heathrow Airport in London. This system is quite complicated—with extensive infrastructure development—but also has limited passenger capacity in this initial implementation.

The Heathrow PRT has entered public service recently, carrying passengers between Terminal 5 and a remote parking area. Its development and deployment has largely been funded by British Airports Authority, which bought a controlling interest in the company that developed the system and expects to expand it significantly at Heathrow and other airports if the initial experience is favorable. The PRT vehicles are captive to their special guideway, but their driving is automated, with automatic steering control to choose the correct route to follow at diverge points and when entering station loading docks (figures 20 and 21).(18) Their speed control is based on a moving block system comparable with most automated people movers and some advanced rail control systems. This system went through an extensive certification process, analogous to that for railroad control systems, before it could be put into public use.

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Figure 20. Photo. ULTra Personal Rapid Transit (PRT) track at Heathrow Airport.

PRT systems are less like the road vehicles featured in the rest of the project than they are like rail vehicles, even though they do not run on steel wheels. They are confined to a

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Figure 21. Photo. ULTra Personal Rapid Transit (PRT) vehicles and station at Heathrow Airport.

special guideway rather than being able to use the same road space as other vehicles, and they lack a manual driving mode for access to unequipped locations. Their control systems have strong infrastructure involvement and are also much more like moving block railroad signal control systems than like vehicle follower systems.

Advanced City Cars

The final category of vehicles in the CityMobil project, the advanced city cars, are less precisely specified than the other vehicle categories. These could be vehicles equipped with driver assistance systems for partial driving automation or vehicles that could be operated without drivers if they were being led in a platoon by a lead vehicle with a driver (e.g., for repositioning of vehicles in a carsharing operation). Another application that was discussed during the conference was vehicles that could provide enhanced mobility for elderly people who are no longer able to drive themselves. The most ambitious part of the presentation about this element of the project by Gianfranco Burzio of FIAT was the introduction of the FIAT Mio concept vehicle. This concept vehicle, developed for the 2010 Torino motor show, was based on inputs suggested from many online participants around the world. The features that they requested, and that were incorporated in the vehicle, included fully automated driving on dedicated highway lanes and in-motion recharging of the electric vehicle propulsion batteries. The Web site for this concept vehicle includes an elaborately staged video of the vehicle in operation (the video is in Portugese, because it was targeted to a Brazilian audience, but it has English subtitles). The video can be viewed by accessing the following link: http://www.youtube.com/watch?v=aCPrg2TQui0&playnext=1&list=PL5FED4D80C03D0EA0.

Automated Vehicle Certification

One of the most challenging issues that CityMobil encountered was the certification process for obtaining approval for operation of the automated vehicles in a public environment. The CityMobil team is concerned that it will be necessary to have a common legal and certification framework for gaining approvals for deployment throughout Europe in order for the automated vehicle market to pose acceptable business risks to suppliers. As previously mentioned, certification issues forced the application planned for Rome to be changed significantly to eliminate all possible interactions between the automated vehicle and other vehicles and pedestrians. If these types of restrictions were to be encountered everywhere, the CyberCar concept would not be deployable. At the other end of the spectrum, the Heathrow PRT went through a railroad-level certification process, which is a well-established process but also extremely conservative in its assumptions and expensive to satisfy. TNO, the prime contractor for CityMobil, has a lot of experience with safety certification, and they use a rather traditional risk-based approach, in which the stakeholders determine what level of hazard they can accept, by analogy with comparable existing systems, and then design to that level.

For CityMobil, they assumed that the safety numbers for automated vehicles should be twice as high as that of existing road traffic based on road traffic safety statistics. In the TNO process, the severity of outcomes and their frequency of occurrence were treated as two dimensions of a matrix, and hazard level values were assigned to each cell of that matrix. The combinations of severity and frequency that exceeded an acceptable threshold level of hazard were highlighted as unacceptable.

Questions were raised at the conference about how the TNO process can account for the complexity of software–intensive control systems for automated vehicles, with their multitude of possible outcomes. The answers to these questions were not satisfying, because they were based on assuming a process of documenting each stage of the development process, with failure mode effects and criticality analyses. Offline discussions with automotive industry participants who were attending the conference indicated that they recognized that this process is inadequate for addressing the safety of software systems, which remains an important unresolved problem.

Non-Technical Risks

Public agencies perceive significant non–technical risks associated with automated vehicle deployment, in addition to the technical risks. For example, the PRT systems have uniquely designed vehicles that must operate on uniquely designed guideways, so that once a locality commits to deploying a specific system, they are locked into a proprietary technology with only one supplier. This leaves the locality vulnerable to monopoly pricing for future expansions, as well as to the risk of premature obsolescence if that supplier goes out of business. Because the developers of most of the systems (not just the special guideway systems) are small companies, the risk of a supplier going out of business and not being able to provide future maintenance and support is very real.

Operating Costs

A discussion of operating costs of driverless vehicles revealed that the existing, relatively small fleets of driverless vehicles (e.g., the Rivium people-mover near Rotterdam) have operating costs comparable with those of conventional bus systems. This seemed surprising, because the dominant element of conventional bus operating costs is the driver labor, and no drivers are needed for driverless vehicles. The answer was that the maintenance labor costs compensated for the lack of driver labor costs. A certain minimum number of maintenance people are needed full time to handle any problems that may arise, and with a complicated system, one person cannot be expected to know how to fix all possible problems. When the number of vehicles is small, this fixed labor cost per vehicle can be high, but the cost will be reduced when it can be spread across a larger fleet of vehicles.

Challenges

There was considerable discussion of the challenges to widespread deployment of automated urban transit vehicles, and there seemed to be general agreement that there are multiple challenges, as follows:

- No established legal framework for allocating risks and responsibilities.
- Lack of an EC directive to define which regulatory framework should be applied, thus leaving each country on its own to establish its own framework (leading to unmanageable complexity for system developers and suppliers who need to deal with inconsistent requirements).
- Diverse safety certification approaches and requirements, which lead to the conclusion that this is likely to be a slow and expensive process.
- Larger up–front capital costs when compared with the cost of other alternatives, without a convincing way to demonstrate net life–cycle cost–benefit advantages.
- Risk to system deployers and operators that small company suppliers of new systems may not survive to provide needed product support for the full life of the product.
- Challenges in physically retrofitting a new system into an existing built environment.
- Need for a well thought–out concept of operations of how driverless vehicles should interact with pedestrians and other vehicles.
- Need to overcome public anxieties about witnessing driverless vehicles operating in people's immediate vicinity.
- Opposition by labor unions who fear loss of bus driver jobs if driverless vehicles are used instead of conventional buses.
- Limitations of system capabilities that restrict their application to low–density or fully controlled environments to provide acceptable safety levels.
- Perceived to be high–risk alternatives by risk–averse public authorities.

These problems were identified, and strategies were suggested for finding solutions for some of them, but solutions do not appear to be imminent.

Public Attitudes

On the positive side, many people attending the conference thought that public attitudes in Europe were shifting in favor of innovative transit services and away from automobile use. The impression is that the public values mobility rather than car ownership. Marketing approaches were suggested to make transit options emotionally appealing to people. One person even noted that a recent opinion poll found that young people were more inclined to perceive cars as "Viagra™ in chrome."

Public Operational Test

The EC is preparing to sponsor a public operational test of an automated transit system, representing a follow–on project to CityMobil. Several cities that would like to compete for the operational test made their pitches at the conference.

eLanes

One of the most important concepts developed in CityMobil is the "eLane," which signifies a special subset of the roadway infrastructure in which the vehicle automation functions can be used. The publications on the subject of eLanes have been somewhat vague about the definition, leaving considerable uncertainty about how much physical separation would be needed between eLanes and other traffic. This uncertainty is real and continues to persist: Participants in this research confirmed in offline discussions that substantially more research is needed to determine what levels of vehicle automation can be applied with what degrees of physical protection from intrusion. This corresponds to the situation that the NAHSC researchers encountered in the United States in the 1990s, in which the question of dedicated and protected lanes was one of the most controversial issues. Despite more than a decade of effort since then, the issue remains unresolved, but there at least appears to be general agreement within CityMobil on the principle that fully automated vehicles cannot mix entirely with conventional traffic unless they are operated at very low (i.e., walking) speeds. Some degree of separation and protection is required.

2010 SMART-64

The EC, through DG–CONNECT, sponsored a small study in 2011 to investigate the impediments to deployment of vehicle automation systems and to determine what steps need to be taken to overcome them. This project, labeled SMART–64, was intended to define the framework for the next generation of EC work on automation. The project team was led by TNO from the Netherlands, with major subcontracts with the University of Southampton in the United Kingdom (UK), DLR (German Aerospace Research Laboratory), Frost and Sullivan and Tecnalia. Their final report summarizes the findings from their study, including stakeholder interactions in a European workshop.(19) The emphasis in this study was very heavily focused on private automobile applications, with limited attention paid to trucking and virtually no attention paid to public transport systems, reflecting the focus of the larger DG–CONNECT projects.

Figure 22(20) depicts the types of automation concepts that were considered in each of three different road environments in the SMART-64 study, and figure 23(20) shows estimates of the deployment time frames for applications clustered in functional groups. The blocks in gray in figure 22(20) were considered to be "pre automation" systems that could support automation rather than automation systems that take on vehicle control responsibilities. The applications that were assumed for the highway environment were largely partial automation rather than full automation, with the exception of a "safety pull over," which is a system that would automatically take over full control of the vehicle and move it to the highway shoulder, where it would be automatically stopped if the driver were to become disabled. This appears to be an exceptionally challenging application. The applications selected for the

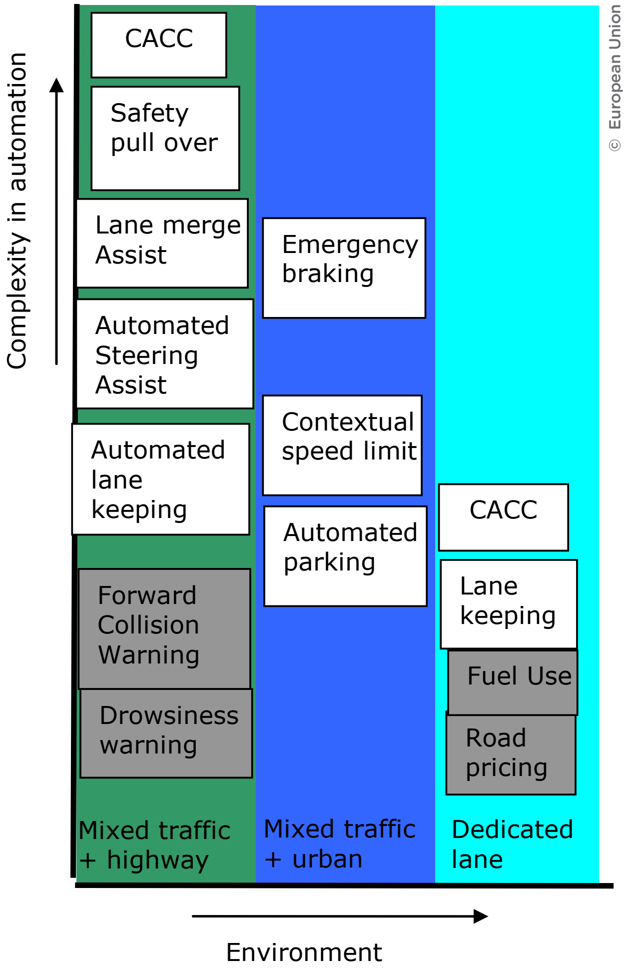

Figure 22. Chart. Automation concepts considered in the SMART-64 project. NOTE: CACC = cooperative adaptive cruise control.

urban environment were generally providing low levels of driver assistance, comparable with systems that are already commercially available on some cars. The applications defined for the dedicated lane environment are closer to an automated highway system, but in this scenario there is no reference to providing any physical protection against intrusion of debris or unauthorized vehicles, only a legal prohibition against use of the lane by unauthorized vehicles.

The SMART-64 project report created its own definitions of automated driving, cooperative driving, and autonomous driving, but these definitions are rather awkward and misleading. The project defined *automated driving* as a driver assistance system with partial automation of the driving functions and the driver being either in control or able to quickly resume manual control. The project defined *cooperative driving* as the use of ICT in conjunction with automated or non-automated driving vehicles, overlooking the fact that any level of automation or driving assistance will of course have to depend on ICT (e.g., sensors, computers, software, and communications). The definition then mentioned V2V and V2I communications, with the implication that somehow these represent the totality of ICT, even though there are many other elements of ICT. SMART-64 defined *autonomous driving* as fully automated driving, with no human intervention in the driving process, and

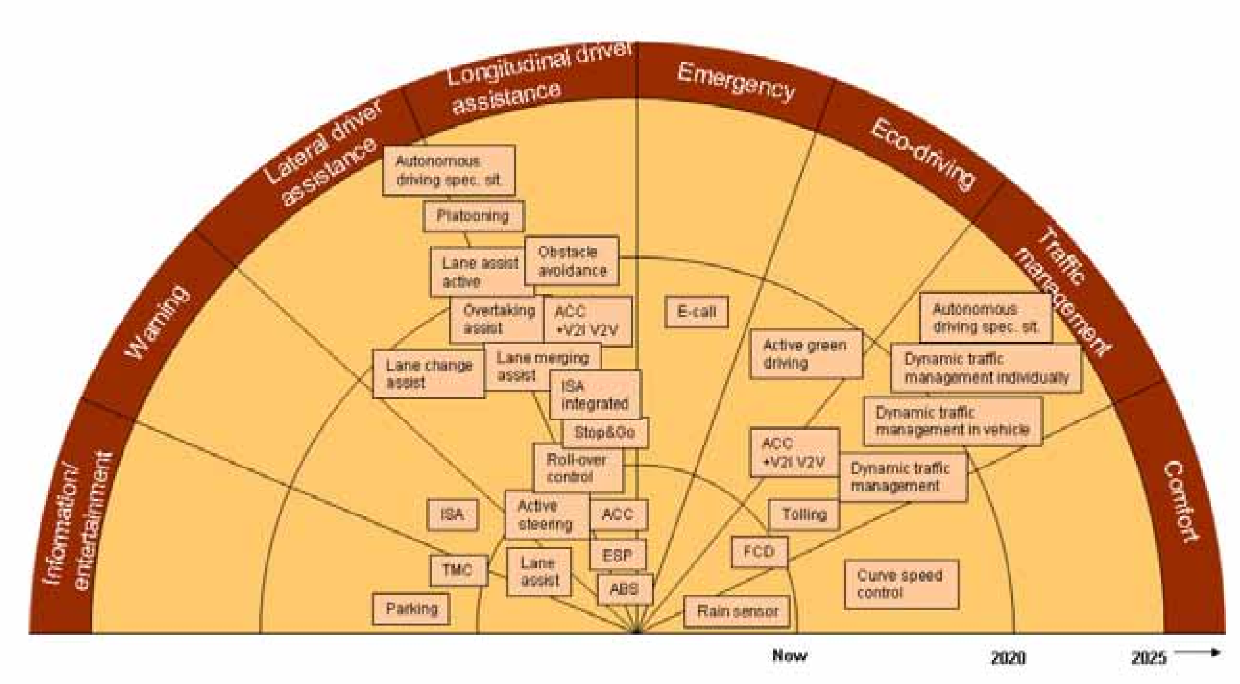

Figure 23. Chart. Automation applications and their deployment timescales assumed in SMART-64 project.

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declared this to be outside the scope of the project, which addresses a time horizon up to the year 2025 for private automotive vehicles.

SMART-64 also defined three institutional scenarios for the stimulation of automated driving, one led by government, one led by industry, and one based on "disruptive developments." It is curious to note that there was no scenario involving coordination of government and industry activities, which would probably be the most likely to succeed. Subsequent discussion with one of the project leaders revealed that the absence of this scenario was intended to steer readers to draw that conclusion themselves by seeing the limitations of the strictly government–centered and industry–centered scenarios.

The focus of the government–led scenario was on gaining societal benefits, stimulated by infrastructure investments. Suggested government actions included:

- Funding (e.g., direct investment or tax incentives).
- Facilitation (e.g., addressing liability, legal, and political challenges, promoting user acceptance, and developing evidence of benefits).
- Technical involvement (e.g., providing test facilities and a deployment roadmap and stimulating standards).
- Roadside infrastructure enhancements.

The authors of the SMART-64 project report then concluded that public benefits would be limited compared with the benefits of cooperative systems, creating an artificial dichotomy between automation and cooperation.

The private–sector–focused scenario assumed that the vehicle industry would build on current products, with government playing only a passive role (although the report acknowledged in passing that ideally both public and private sectors would take active roles). The private sector was assumed to be involved in:

- Defining and adapting to new legislation (including standardization).
- Aligning with societal and political needs.
- Quantifying economic benefits from diverse stakeholder perspectives.
- Accelerating technological developments.

The main focus of the private-sector–focused scenario would be on making automated driving systems both reliable and affordable. The authors expressed their doubts that the private sector would develop automated driving systems that depend on road infrastructure changes.

The disruptive developments scenario was based on the dream that artificial intelligence technology would somehow provide the ability to drive fully automated vehicles in mixed traffic, most likely motivated by the publicity generated from Google's "self-driving" car.

SMART-64 included a summary of driver assistance products that are already on the market, categorized as warning systems, assisting systems, and "toward CACC," which is a rather odd classification scheme because this third category contains both warning and assisting systems. The review of the current state of the art made optimistic assumptions about the capabilities of these current systems relative to automated driving, which colored some of the conclusions and recommendations in the study. The review tabulated these in terms of the well-known "technology readiness level" (TRL) measure of technology maturity, without accounting for the higher levels of maturity and robustness that are needed when the driver's role is reduced. The authors even claimed that "current technology is ready for autonomous (sic) driving on separate segregated lanes in a controlled environment," citing the examples of automated people movers and the first generation PRT systems that are already in use, without recognizing the differences in costs and complexity when trying to apply this on a wider scale. They also assumed, erroneously, that these exclusive guideway systems use the same obstacle detection and sensor systems as advanced driver assistance systems for cars.

The authors of the SMART-64 report contended that dedicated lanes are not feasible on cost grounds and that "automated vehicles will have to be mixed with manually driven vehicles, at least in the early days." They then introduced the eLanes concept from the CityMobil project but interpreted it to involve coexistence of fully automated and manually driven vehicles rather than the separation envisioned by the creators of the concept. This perspective appears to ignore the extreme technical challenges that would have to be solved to enable safe coexistence of fully automated and manually driven vehicles.

The authors of the SMART-64 project report explored several aspects of automated driving in more detail, as presented in the following sections.

Vienna Convention on Road Traffic

This set of rules, adopted by most European countries, includes several provisions regarding drivers' control of vehicles that weigh against full automation of driving, unless the driver can maintain control by overriding the automation system. The researchers for the study noted that there are loopholes and opportunities to amend the Vienna Convention rules so that they need not serve as a permanent obstacle to automation. The authors of the report concluded that there is no need to adopt a strategy for handling the Vienna Convention rules on road traffic until there is an agreed-upon deployment staging strategy for road vehicle automation.

Liability

It was noted that different countries in Europe still have substantially different legal systems; thus, there is no consistency in how liability is handled across the continent. A substantial in-depth study will be needed to sort out these differences in legal systems and the diverse operational concepts of vehicle automation systems to determine how such liability would be handled. This is an important issue for vehicle manufacturers because they need to be able to market their vehicles throughout the continent and would be reluctant to proceed with market introduction until they knew that there would be a consistent and predictable legal environment for handling liability. This might require European legislation.

Some additional issues to consider in terms of liability are as follows:

- It was suggested in the report that the easiest way to develop strategies for providing liability insurance for automated vehicles would be to start with fleet vehicle operations, in which there would be a business–to–business relationship between the vehicle owner and insurer. There was also a suggestion of a government-supported insurance pool to encourage initial adoption of automation technologies before there is a substantial body of actuarial data about the safety of the systems.
- Once automated systems are demonstrated to improve safety, vehicle OEMs could eventually be found liable for not implementing automation.
- Experiences from rail and aviation systems are not expected to be especially applicable because of the large differences in training of vehicle operators and constraints on the operating environments.
- Standards and New Car Assessment Program ratings could be used to ensure minimum performance and quality levels so that unsafe systems are not introduced.

Reliability

Automated system reliability was explored in the context of the ability of the driver to recover control quickly enough to avoid a crash. This will require clear definition of the responsibilities of the driver versus the vehicle provider. It was also recognized that additional work will be needed on developing fail-safe mechanisms, in-vehicle and I2V health checks, HMI systems to alert drivers about problems and to manage the control transitions, and infrastructure features to augment system safety.

Recommendations in the report for EC actions included:

- Technology R&D (e.g., fail-safe technologies, sensor fusion, and redundancy).
- Legislation.
- Driver interactions—how to keep the driver in the loop and transfer control.
- Stimulate standards and certification.

Controller Development

The report recognized the important challenges in software complexity and cost reduction before automation systems can be widely deployed, but it made unrealistically severe assumptions about the computational update rate that would be needed (assuming 1 millisecond).

Drive-by-Wire Technology

The authors of the report devoted disproportionate attention to the technical issues associated with "by wire" actuation, without recognizing that the required actuation for vehicle automation can be accomplished by using less risky technologies that are already widely used on electric and hybrid vehicles.

Sensor Systems

The authors of the report enumerated the types of sensor technologies that would be required in vehicles and the infrastructure to implement automated driving; wireless communication was included as one of the sensor technologies. The authors adopted an optimistic view of the maturity of the current sensor technologies, without considering the challenges associated with adverse environmental conditions.

Positioning Technology

The authors of the report also reviewed the types of positioning system performance that might be needed for automated driving but underestimated the update rates that would be needed for good vehicle control performance.

Cross–Border Driving

Because European countries have so many borders that road vehicles would be expected to cross frequently, a section of the report was devoted to the issues that need to be resolved to ensure smooth and safe cross–border operations of automated vehicles. These issues include the need to establish well–defined standards to ensure interoperability of vehicles and the cooperating infrastructure where that is needed.

Interactions with Human Drivers

The authors of the SMART-64 project report focused on scenarios with partial automation—rather than full automation of driving—and included the statement, "The driver is and must stay in control; responsibility remains with the driver." Yet parts of the report also addressed issues that arise with fully automated vehicles. The driver interaction research questions were identified as:

» What effect does higher automation in the vehicle have on the driver?

» How can the driver interface be improved without overloading the driver with information?

» How can standardization for automated vehicle control and interface design be achieved without legislation?

» How can driver training for automated systems be improved?

» Should a gradual migration of skill be allowed or should some form of universal training be introduced?

» How should automated vehicles be integrated with other road users?

» Will other road users also require training about how to interact with automated vehicles?

Dutch Programs

The Netherlands has several relevant current activities that address partial vehicle automation and some potential precursors, all with a very strong emphasis on cooperative systems. These activities were all showcased during the "automotive week" activities in Eindhoven in mid–May 2011. It is notable that these activities are most strongly driven by regional economic development interests centered in the North Brabant province around Eindhoven, which sees itself as the "Brain Port" for the country and the center of automotive industry activity. The multitude of projects in the Netherlands is confusing to sort out, particularly because some of the names are quite similar even when the projects and their participants are different.

Strategic Platform for Intelligent Transport Systems

The Strategic Platform for Intelligent Transport Systems (SPITS) was a consortium of 13 companies and universities funded by the Dutch Ministry of Economic Affairs, from July 2009 to June 2011, to position the Netherlands for a strong role in future European projects and to encourage commercialization of the results of prior projects. The work of SPITS includes the development of a unique test site along the A270 highway between Eindhoven and Helmond. Along a 5-km (3-mi) stretch of this highway, 48 video cameras were mounted on poles, providing continuous and overlapping coverage of all vehicle movements. The real-time video images were fed back to a control center where image processing software produced continuous traces of the trajectories of all the vehicles traversing the section of roadway. This site provides an outstanding data recording capability that can be used in experiments that investigate traffic flow stability and countermeasures for improving stability. This same stretch has continuous coverage by 5.9 GHz DSRC, based on 11 DSRC transceivers installed along the roadside, providing an environment for testing V2I and I2V cooperative strategies.

Advisory Acceleration Control Field Test

The Advisory Acceleration Control (AAC) field test was an innovative experiment conducted by TNO under SPITS auspices in which drivers of 48 vehicles were provided with a display (implemented using TomTom hand–held navigators reprogrammed for the purpose) to advise them whether to accelerate, decelerate, or maintain their current speed, based on use of an algorithm designed to dampen traffic shock waves.

During a weekend period in February 2010 when the A270 highway was closed to the public, these drivers were lined up in one lane of the highway, while another 48 vehicles in an adjacent lane were unequipped with driving aids. The vehicles at the head of the two streams of vehicles followed a prescribed speed profile, with speed variations intended to promote shock waves among the followers. The dynamics of the two traffic streams were compared by using the trajectory data extracted from the roadside video systems, and the advisory display was shown to reduce the severity of the shock wave. An example of these results is shown in the distance–versus–time plots of figure 24.(21) in which the lighter color and higher slope of the plots on

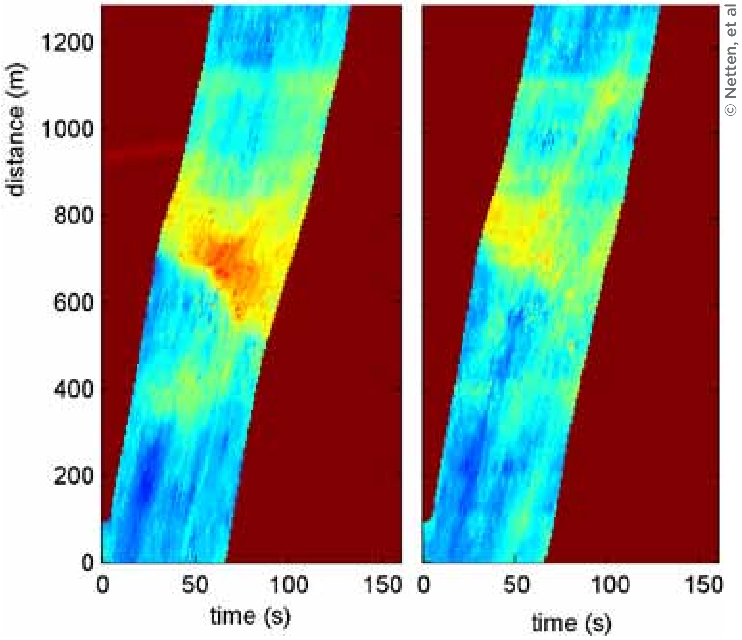

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Figure 24. Photo. Distance–versus–time plot comparing a stream of 48 Advisory Acceleration Control vehicles (right photo) with 48 unequipped vehicles (left photo).

the right (representing higher traffic speeds) indicate how the shock wave was attenuated by use of the AAC guidance system. This was meant to demonstrate a potentially near-term application that could smooth out traffic flow in the same way that CACC would, but without requiring that vehicles be equipped with the relatively expensive ACC control system.

Dutch Integrated Testsite for Cooperative Mobility

The Dutch Integrated Testsite for Cooperative Mobility is a new initiative, created in May 2011, to bring together diverse Dutch interests as a successor to SPITS, with a particular emphasis on becoming the European test site of choice for all future cooperative ITS services. It will, of course, need to compete with other sites for specific project opportunities.

Connected Cruise Control

Connected Cruise Control is a project of the Ministry of Economic Affairs for providing individualized speed, lane selection, and gap advice to drivers to deter the formation of shock waves in traffic by smoothing out speed variations. This project is under development by a consortium of universities and companies, beginning in 2010 and aiming for commercialization of a product by 2013.

Connect and Drive

This project of TNO Mobility and Transport and the Technical Universities of Eindhoven and Twente has developed and tested a prototype cooperative ACC system, aimed at longer term implementation when there is a high market penetration of cooperative vehicles. Although it is expected that the first practical application will be for heavy truck platoons, Toyota Prius vehicles served as the demonstration platforms (figure 25)(22)

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Figure 25. Photo. Cooperative adaptive cruise control platoon of Toyota Prius vehicles developed as part of the Connect and Drive Project.

and showed very good performance in the low-speed demonstration of four vehicles that was performed for visitors in May 2011. The parameters of the CACC system could be adjusted by using the vehicle's touch-screen display, which was reprogrammed for this purpose (figure 26).(16) These vehicles accomplished their cooperation by using WiFi communication, because DSRC radios were not available to the project team at the time they integrated the vehicle systems, but they recognized the need to migrate to DSRC and did so in subsequent work, using IEEE 802.11p and the ETSI (European Telecommunications Standards Institute) protocol stack.

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Figure 26. Photo. Touch-screen control panel for adjusting parameters of a cooperative adaptive cruise control (CACC) test vehicle. NOTE: RSU = roadside units, CC = cruise control, ACC = adaptive cruise control.

Grand Cooperative Driving Challenge

The Grand Cooperative Driving Challenge was an international competition that was inspired by the DARPA Challenges and organized by TNO and the High-Tech Automotive Systems program, with sponsorship from the local and regional governments around the competition site in Helmond, a suburb of Eindhoven. In contrast to the DARPA Challenges, this challenge depended heavily on V2V and I2V cooperation, requiring that the competing teams not only control their own vehicles well but also communicate good information to the vehicles from the other teams. This significantly raised the awareness of the competing research teams—11 university groups from throughout Europe—to the importance of cooperative systems and their advantages over autonomous systems.

The vehicles were staged through two scenarios, one representing urban traffic conditions (figure 27)(23) and the other representing highway traffic (figure 28).(23) The final competition was held in May 2011, in combination with several other cooperative system events, and was won by a team from the Karlsruhe Institute of Technology in Germany.

Shock Wave Mitigation with Mixed Equipped and Unequipped Vehicles

During the same period as the Grand Cooperative Driving Challenge, the SPITS A270 test site was used for another experiment, attempting to mitigate congestion shock waves by two alternative means: (a) giving some drivers detailed real-time in-vehicle advisories about their driving speeds; and (b) providing the same drivers with CACC speed control, with the set speeds commanded from the roadside. The advisory speeds for both of these strategies were determined in the same way, making use of the detailed real-time traffic data from the video monitoring of the 5-km (3-mi) test section of highway to identify potential shock waves being formed and then instructing the equipped vehicles what speed to travel for breaking up the shock waves. The people working on this project recognized that the intensive video monitoring infrastructure of this highway test section would not be replicable on normal roads, however this was being used to emulate the kind of data that could be available with widespread market penetration of probe vehicle monitoring.

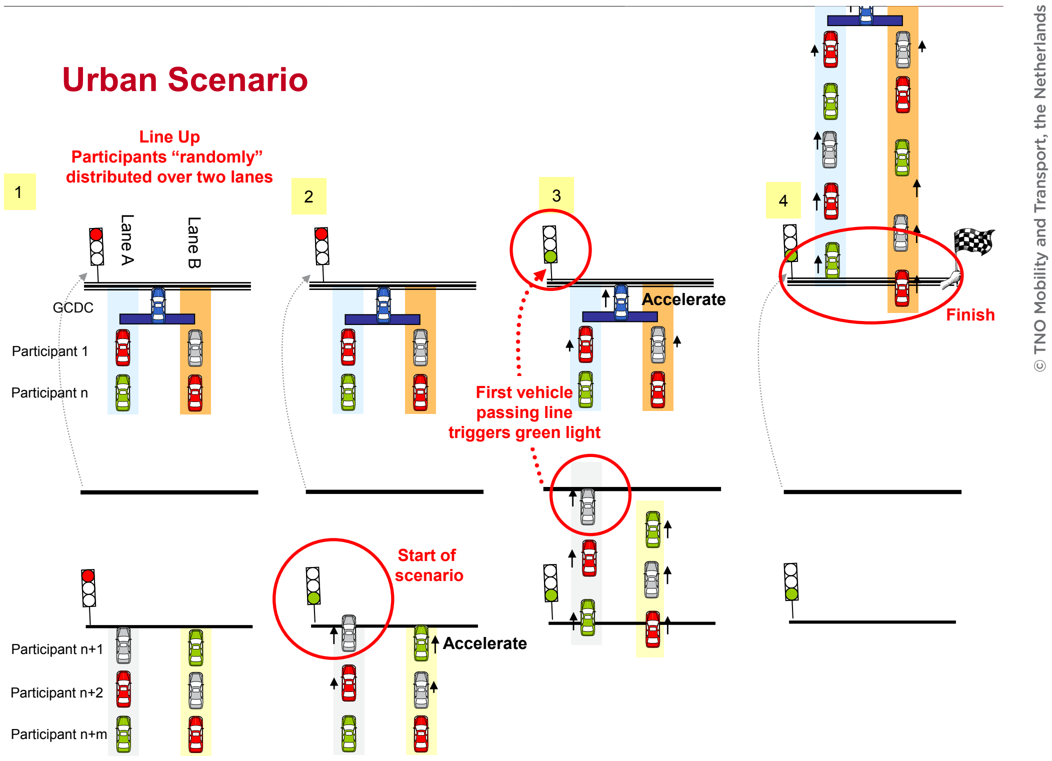

Figure 27. Diagram. Urban scenario of the Grand Cooperative Driving Challenge.

The experiment was performed with a string of 70 vehicles, 8 of which were equipped for infrastructure-cooperative ACC and 12 of which had driver advisory displays, scattered at fairly uniform intervals along the string of vehicles. The shock waves were deliberately induced by the lead vehicle in the string, which slowed down so that the driver could look at a roadside incident (which also made it more likely that the other drivers would be tempted to slow down to take a look). The trajectories of all the vehicles were recorded to see what effects could be achieved with the advisory system (with specially trained drivers instructed about following the advice so that they would be more likely to follow

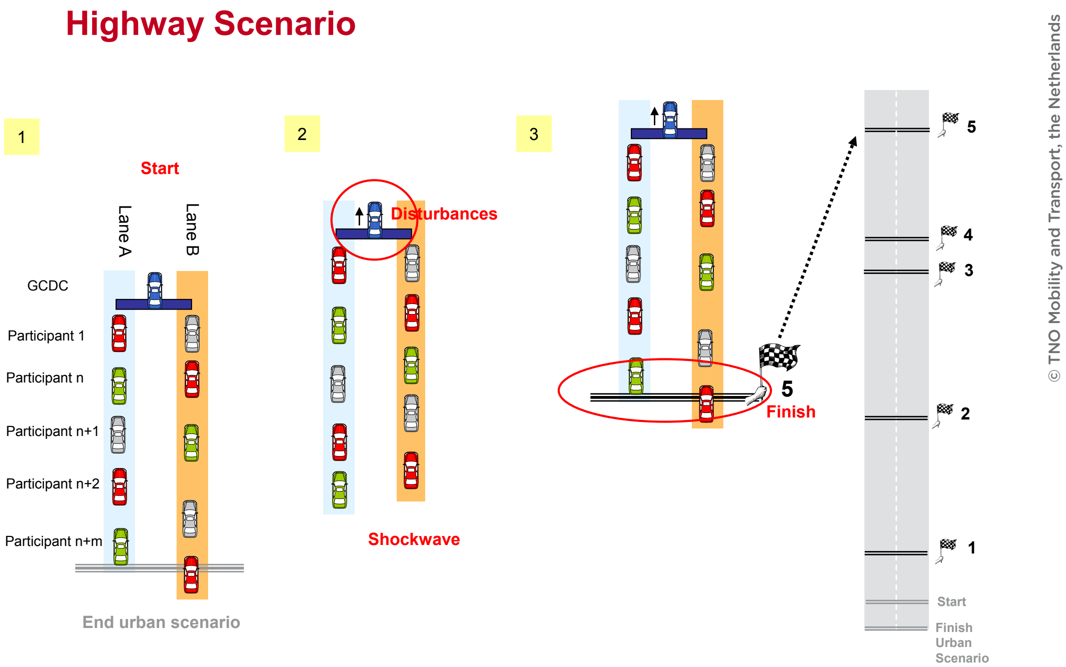

Figure 28. Diagram. Highway scenario of the Grand Cooperative Driving Challenge.

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Figure 29. Photo. Aerial view of A270 test site with vehicle locations superimposed.

it than would be drivers from the general public) and with the CACC system. The locations and trajectories of the vehicles were observed from a traffic management center.

Figure 29[24] shows one of the displays from the TMC, with the locations of the vehicles superimposed on an aerial photograph of the roadway, with red marks signifying equipped vehicles and green marks signifying unequipped vehicles. Note that a long sequence of unequipped vehicles was deliberately grouped at the start to get the shock wave triggered, and the increased density of the vehicles there is evident in the photo. The red marks and the green marks following them represent the mixture of equipped and unequipped vehicles, attenuating the shock wave by requiring the red vehicles to maintain appropriate gaps relative to their predecessors, which the drivers are not able to determine on their own without assistance. The blue camera icons along the side of the roadway in figure 29[24] show the locations of the video cameras that are used to monitor the trajectories of all the vehicles.

Figure 30[16] shows the monitors at the TMC, which display the distance–versus–time plots in real time during the experiment. To the right side of the right monitor in figure 30,[16] the white gaps represent the extra gaps in the traffic stream created by the equipped vehicles following the speed guidance, thereby breaking up the shock wave. The preliminary indications are that the CACC vehicles were somewhat more effective at dissipating the shock wave than were the vehicles with the guidance displays, which

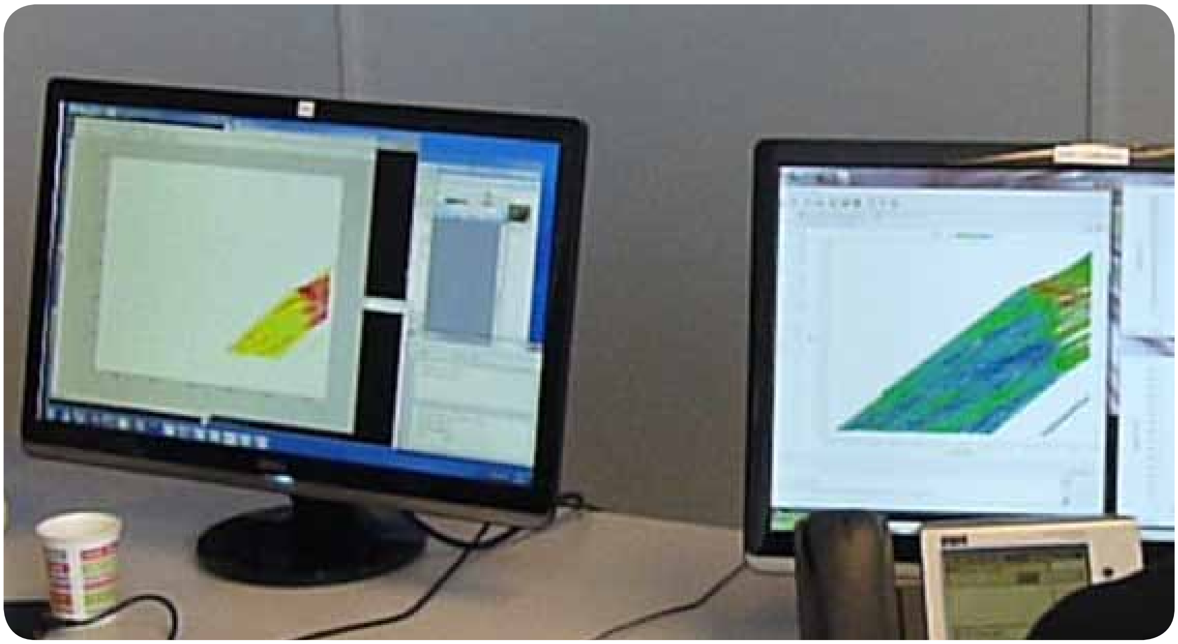

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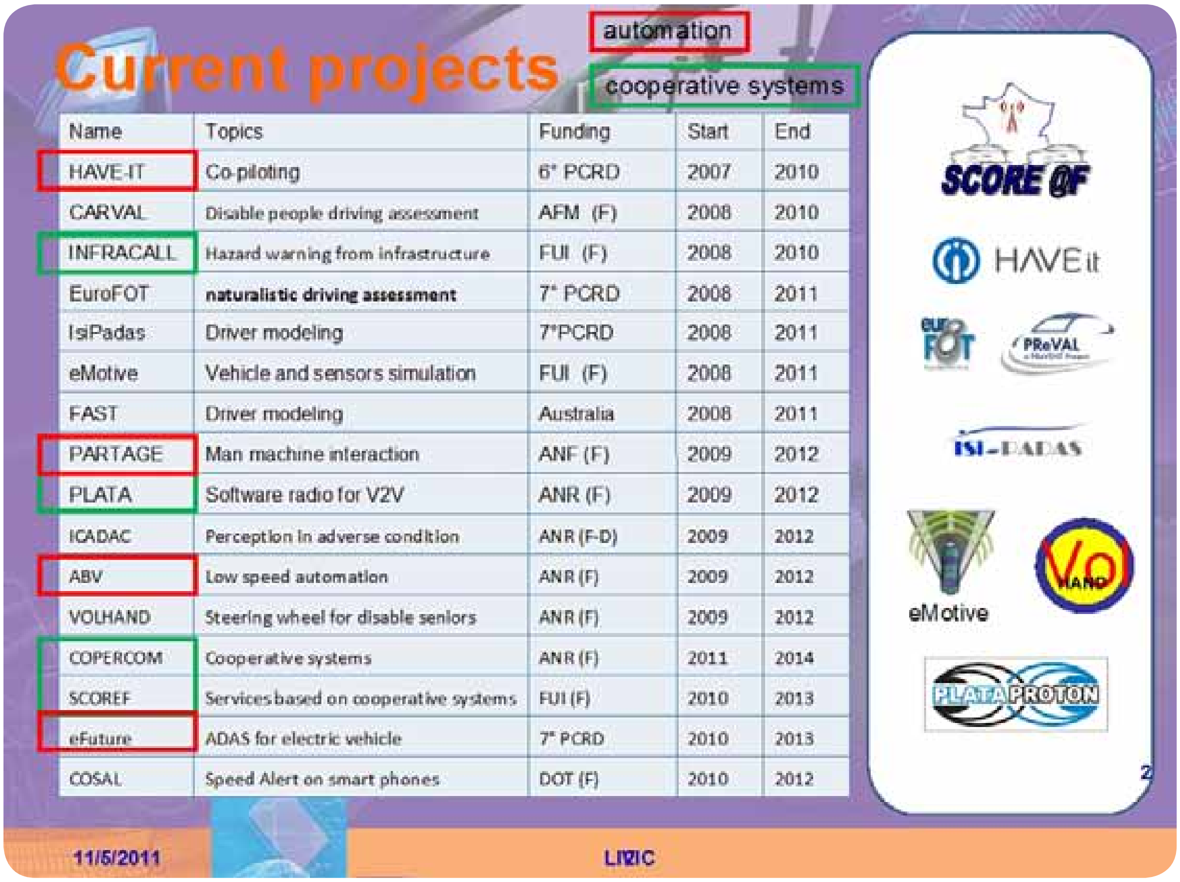
Figure 30. Photo. Real-time plots of distance–versus–time diagrams during an attempt to mitigate congestion shock waves.



Current projects

automation

cooperative systems

Name	Topics	Funding	Start	End
HAVE-IT	Co-piloting	6° PCRD	2007	2010
CARVAL	Disable people driving assessment	AFM (F)	2008	2010
INFRACALL	Hazard warning from infrastructure	FUI (F)	2008	2010
EuroFOT	**naturalistic driving assessment**	7° PCRD	2008	2011
IsiPadas	Driver modeling	7°PCRD	2008	2011
eMotive	Vehicle and sensors simulation	FUI (F)	2008	2011
FAST	Driver modeling	Australia	2008	2011
PARTAGE	Man machine interaction	ANF (F)	2009	2012
PLATA	Software radio for V2V	ANR (F)	2009	2012
ICADAC	Perception in adverse condition	ANR (F-D)	2009	2012
ABV	Low speed automation	ANR (F)	2009	2012
VOLHAND	Steering wheel for disable seniors	ANR (F)	2009	2012
COPERCOM	Cooperative systems	ANR (F)	2011	2014
SCOREF	Services based on cooperative systems	FUI (F)	2010	2013
eFuture	ADAS for electric vehicle	7° PCRD	2010	2013
COSAL	Speed Alert on smart phones	DOT (F)	2010	2012

11/5/2011

LIVIC

© IFSTTAR

Figure 31. Chart. Relevant current projects at France's LIVIC laboratory. NOTE: ABV = Automatisation Basse Vitesse.

were more subject to the uncertainties of driver responses (even with specially trained drivers instructed to follow the guidance as well as they could).

French Programs

Although the French Transport and Research ministries have been supporting research on ITS topics for many years, relatively little of that research within the past decade has been directed toward the longer term issues of vehicle automation. Interest in automation is being revived within the vehicle industry, and it has remained strong among researchers all along. Recent increased research activity related to vehicle automation has been evident within economic competition channels rather than within more traditional transportation or research channels. The increased research activity has been motivated by concerns about energy saving, mobility, and preserving accessibility for senior and disabled citizens.

The central group for research on automated driving of road vehicles is the LIVIC laboratory in Versailles, France, now a part of IFSTTAR. LIVIC developed a useful chart that lists their active projects on automation and cooperative systems, as can be seen in figure 31.(25) The project names that are highlighted in red boxes are the most relevant to this review. The LIVIC researchers have been influenced by working with researchers from other countries on European projects, such as HAVEit, and have adopted the concept of protected eLanes, for example. They are in the process of forming a larger vehicle automation research cluster with other leading French research labs, including INRIA and the research groups of the Ecole des Mines.

One unique national project listed in figure 31(25) is Automatisation Basse Vitesse, a €5.5 million ($7.2 million) project that is focused on low-speed vehicle automation (the meaning of the French words that are abbreviated in its acronym). This project intends to improve fuel economy for vehicles driving in congested traffic on urban and suburban freeways. The project was developed based on the concept of a "secured road," meaning that there should be communication and cooperation between vehicles and roadway infrastructure. This could include sensing technology and special markings on the infrastructure to facilitate vehicle automation, but the infrastructure should still be capable of being shared to some extent with conventional traffic.

PARTAGE is a related project that is focused on sharing responsibilities between the driver and the automation system. This builds on the "co-pilot" concept in HAVEit, with a "decision unit" that shares responsibilities with the driver and could indeed override the driver's decisions in some cases after warning him or her. The research is extending beyond the technical issues in sensor fusion, communication, and control in an effort to also deal with legal and standards compliance issues and assessments of impacts on traffic congestion and fuel consumption.

The French research institutes and automotive companies are also working on the development of vehicle automation capabilities that can be used in support of carsharing services, especially for electric vehicles with limited range. Within an office park or research campus, the shared vehicles could be deposited at locations that do not match well with the upcoming demand patterns. One employee manually driving a lead vehicle would collect the vehicles and act as their platoon leader, while the following vehicles would follow through electronic coupling with nobody onboard. This kind of operation could be performed on a special-purpose dedicated roadway infrastructure that minimizes the complexity of the driving environment and the interactions with pedestrians and other vehicles.

France is an active participant in European field operational tests, and in addition to the EC-funded projects, they have also established their own field operational test project for cooperative systems, called *SCORE@F*, in collaboration with the European Drive C2X initiative. This will include eco–driving at traffic signals and driver assistance systems for safety but will not include fully automated driving, because that is still viewed as being too futuristic to be ready for use by naive drivers.

German Programs

KONVOI Project

The KONVOI project was sponsored by Germany's Federal Ministry of Economics and Technology (not transport) as an examination of the impacts that a truck–platooning system could have on traffic flow, fuel consumption, and the environment. Because researchers for the CHAUFFEUR project had already performed extensive truck-platoon technology development and testing between 1996 and 2004, KONVOI began with the assumption that any technological problems were close to being solved.

In this case, a research team from the RWTH Aachen University, the heavy vehicle and vehicle supply industry, and major trucking firms developed the project to evaluate how a truck platoon system could operate in practice on public roads. This project had about €4 million ($5.2 million) of government funding, plus industry contributions, which raised the total budget to approximately €5.5 million ($7 million; similar in scale to the newer SARTRE project). KONVOI was active from mid-2005 to mid-2009, and the work is now complete. There is no direct follow-on project.

The technical implementation of the KONVOI platooning system was based on the integration of components and subsystems that were already commercially available or getting close to commercial availability and did not depend on any exotic technologies because the project partners believed that the technology was already relatively mature and close to deployable. The control design approach is conceptually very similar to the approach that PATH has adopted in the United States but with some differences in specific sensing technology. KONVOI's concept of operations for application of the truck platoons in public mixed traffic, coexisting with other vehicles and drivers, was constrained by the need to acquire authorization from government agencies and safety certification authorities before they could conduct their tests.

The target concept for KONVOI is of a platoon of up to four trucks that would drive in mixed traffic on the highway, with the driver of the first truck making the strategic maneuvering decisions for the platoon, using his own eyes combined with assistance systems to give warnings about potential hazards in the driving environment. The drivers of the following trucks would be in a passive mode, monitoring their trucks for problems and being prepared to intervene if necessary by taking over control in case of a failure or emergency. The goals of this truck platoon are to increase the capacity of the highway lane by enabling the trucks to use less space (running at shorter gaps) and reduce fuel consumption and greenhouse gas production by running them close enough together that they could save aerodynamic drag.

The minimum allowable gap between trucks was set at 10 m (33 ft) based on analyses of the effects of cut–ins at highway entrance ramps, where hard braking of the following truck could be required. For the constant distance separation policy used here to support energy savings at all speeds, it is essential to have V2V communication to achieve string stability of the platoon. The researchers actually tested emergency braking maneuvers with two trucks on the test track, with the first truck decelerating at 0.7 g (7 m/s^2 or 22.5 ft/s^2) and the second truck responding to that. During this braking maneuver, the gap between the trucks was reduced from 10 m (33 ft) to 5 m (16 ft) before they stopped because of the finite delay time before the second truck could apply its brakes, but they were still able to avoid a crash. This test was one of project's more important accomplishments.

The lateral control of the KONVOI trucks was based on use of a wide-angle, multi-beam laser sensor at the front of each truck, which detects the lane striping, measures the distance to the forward truck, and detects cut-in vehicles. With the wide field of view, the sensor can see the lane markings even at the shortest permitted gap between trucks of 10 m (33 ft; but that would not have been possible at the significantly shorter gaps of 3–5 m (10–16 ft) used by Energy ITS in Japan or PATH to achieve their drag reductions). In this way, each truck follows the lane markings

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Figure 32. Photo. Four-truck KONVOI platoon driving at 10-m (33-ft) gaps between trucks on a German autobahn.

directly rather than performing an "electronic towbar," that is, following the lateral motions of the preceding truck as the CHAUFFEUR project was doing.

To change lanes, the planned operational concept was for the driver of the lead truck to look for a long enough gap in the adjacent lane for the entire platoon to make the lane change, to then activate his turn signal to alert all other drivers, and then for each driver to verify a safe gap next to his truck and press a button to confirm it. Although this was performed on the test track, the researchers were not authorized to test it on the public highway (and it does seem cumbersome and difficult to implement in practice). The drivers of the following trucks expressed a strong interest in having a live video feed of the forward view from the front truck so that they would know what was happening up ahead. It was not clear whether this would be useful in practice, but it would at least help the drivers feel more comfortable about their ability to make decisions. This concept would, however, impose a significant wireless communication burden.

After they performed an extensive set of tests on test tracks, the researchers tested the KONVOI trucks on public highways for 9 days, acquiring about 3,300 km (2,000 mi) of driving data. Of this, 2,100 km (1,250 mi) of driving data were collected by using the full four–truck platoon, as shown in figure 32.(26) During these tests, the platoons were followed by a police escort vehicle that had flashing lights and a sign that warned drivers approaching from behind that these trucks were special test vehicles. This police escort interfered with the testing goal of obtaining completely naturalistic driving data about the way drivers of other vehicles would interact with the truck platoon. The police escorts believed that drivers did not pay any special attention to them and that they behaved largely as they would have under normal conditions. With this caveat, there were still 13 cut–ins into the truck platoon by other drivers during the highway tests (an average of once per 250 km (155 mi) or once in approximately every 3 hours of driving), six of which occurred when the gaps between the trucks were only 10–15 m (33–49 ft). The platoon control system was designed to split the platoon as soon as a cut-in was detected by the wide–angle laser sensors on each truck, and these splits were performed correctly each time they were required.

Researchers claimed that the trucks on the test track achieved some fuel-consumption savings even when they were driving at the 10-m (33-ft) gap between trucks; however, there was no fuel-consumption savings in the tests on the public highway because the trucks had to vary their speeds to respond to traffic conditions and other vehicles on the road. The trucks' control systems were designed to emphasize accuracy of gap control in vehicle-following (which is important for safety reasons, among other things). To achieve this accuracy, it was necessary to design the systems with a high bandwidth, which means that it makes frequent corrections and tends to be "busy," which increases fuel consumption. This is a fundamental trade–off in the design of such systems and indicates the difficulty of saving energy and greenhouse gas emissions when the equipped vehicles have to share the road with unequipped vehicles that do unpredictable things.

There are only limited technical papers in English about KONVOI, and because the project was funded by the German government, the final reports are written in German.(27) As a result, there are few good reference documents available to cite; however, based on detailed discussions with several key people who worked on the project at RWTH Aachen, the following main observations are worth considering:

- Researchers concluded from the start of the project that it would be essential to operate the truck platoons in a mixed traffic environment, because there have been no prospects for constructing new dedicated truck lanes or other new infrastructure in Germany. This imposed significant technical constraints on the system design and operational concept.
- Although KONVOI researchers say that the technology is relatively mature and close to deployment, when considering what roles the drivers could play in practice and how reliable the system would actually need to be, it is clear that there is a disconnect between desire and reality. The researchers understand that none of the systems are close to the level of reliability needed to permit a KONVOI platoon to drive with full automation of the following trucks for an extended period of time. The safety of the system is based on the drivers being able to constantly monitor the truck's operations to detect any anomalies, but the researchers recognize that it is not possible for drivers to take on such a responsibility for an extended driving period in the real world because of basic human factors limitations. Furthermore, during the tests, the only drivers who were authorized to drive the trucks on the public highways were the ones who were directly involved in developing the system and who knew its peculiarities intimately. Professional truck drivers from trucking fleets did not drive the trucks on the public highways.
- The need to mix the trucks with the rest of the traffic was a political imperative and goal for the project, but at some level, the KONVOI research team also recognized that it was an impediment to achieving the hoped-for efficiency benefits. The traffic dynamics generated by all the other vehicles imposed disturbances on the truck platoon that prevented it from smoothing out its driving profile enough to actually save significant fuel. The cut–ins required expanding and contracting the gaps within the platoon, by decelerating and then accelerating, subsequently interrupting constant-speed cruising.
- There were additional political and regulatory impediments specific to Germany and Europe that would have to be changed before a KONVOI type of system could be integrated into public operation. The short gaps between trucks were below what is legally permitted for vehicle-following, so those rules would have to be changed (these rules are more rigid and stricter than in the United States), and the Vienna Convention on road traffic in Europe

also requires that the driver always be in complete control of his or her vehicle. Although these issues do not apply so directly in the United States, they do indicate some of the challenges to implementation that will have to be considered.

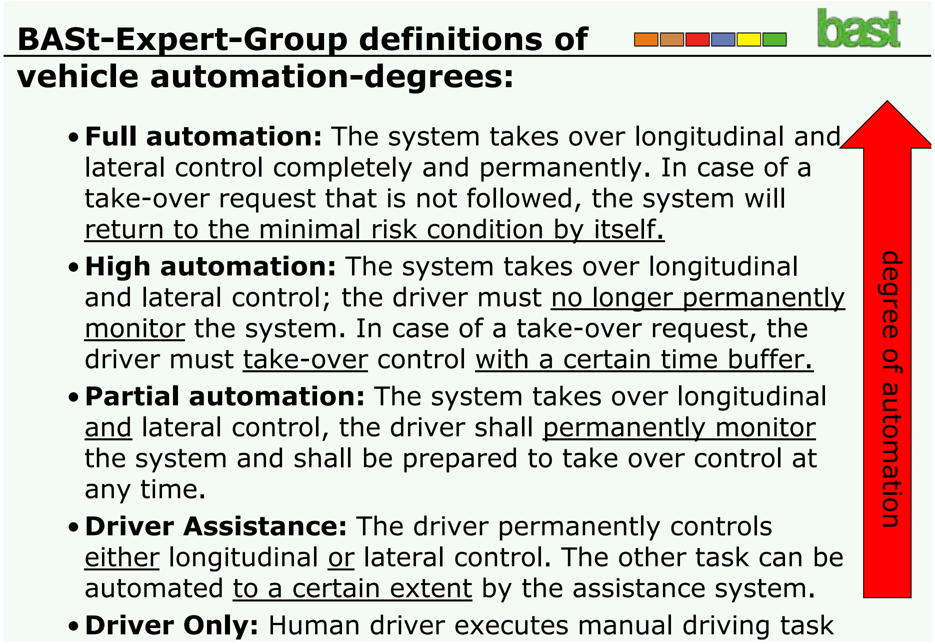
- In sum, there are doubts as to whether the technical and non-technical issues facing the KONVOI system can be resolved successfully, because they are pulling the system design and operational concept in opposite directions (regarding the mixing of the truck platoons with general traffic). The same conflicts might be found during U.S. attempts at automated truck platooning, and U.S. researchers will need to find ways of resolving these conflicts within their own environments.

German Study on Legal Aspects of Road Transport Automation

The German Federal Highway Research Institute, BASt (equivalent to FHWA's Turner–Fairbank Highway Research Center), has been leading a study of the legal implications of road transport automation under German law, in collaboration with representatives of the German automotive industry. A BASt report (in German) was published early in 2012, and some informal presentations of its findings have been given in English at international meetings during the final quarter of 2011 and have attracted strong interest in Europe. This study is very significant because it combines technical factors, human factors, and legal expertise to make explicit determinations about what aspects of automation systems are clearly legal, clearly illegal, or in the gray area in between. For those aspects that fall within the gray area, BASt is currently identifying what research is required to resolve the ambiguities. The study is focused on automation in mixed traffic operations rather than in segregated or dedicated infrastructure, because this is where the issues are most complicated and where they are expected to first arise.

The most important initial contribution of this study appears to be a carefully developed definition of five different levels of vehicle automation, which was an essential prerequisite to addressing legal issues (figure 33).(28) These levels are:

1. No automation—Driver is in complete control of the vehicle.
2. Driver assistance—Partial automation of either longitudinal control (e.g., ACC) or lateral control (e.g., lane-keeping) while the driver controls the other functions and remains fully engaged in the driving task.
3. Partial automation—Both longitudinal and lateral control are automated, but the level of automation is sufficiently limited in capability that the driver needs to continuously monitor its behavior and be prepared to take over control at any time.
4. High automation—Both longitudinal and lateral control are automated but at a higher level such that the driver no longer needs to continuously monitor its behavior and only needs to be prepared to take over control within a "certain" (currently unspecified) time interval.
5. Full automation—The system has a sufficiently high level of automation



BASt-Expert-Group definitions of vehicle automation-degrees:

- **Full automation:** The system takes over longitudinal and lateral control completely and permanently. In case of a take-over request that is not followed, the system will return to the minimal risk condition by itself.
- **High automation:** The system takes over longitudinal and lateral control; the driver must no longer permanently monitor the system. In case of a take-over request, the driver must take-over control with a certain time buffer.
- **Partial automation:** The system takes over longitudinal and lateral control, the driver shall permanently monitor the system and shall be prepared to take over control at any time.
- **Driver Assistance:** The driver permanently controls either longitudinal or lateral control. The other task can be automated to a certain extent by the assistance system.
- **Driver Only:** Human driver executes manual driving task

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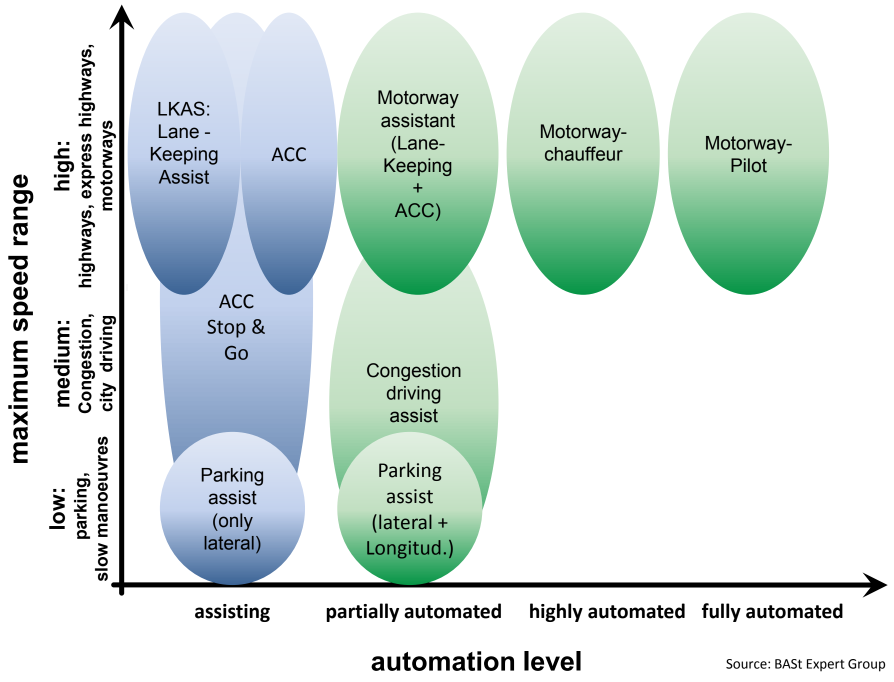
Figure 33. Chart. BASt definitions of levels of automation.

that when it requests the driver to regain control (because of a condition it cannot handle), and the driver fails to respond, it can return to a minimum-risk condition (such as stopping the vehicle) by itself. (Fortunately, BASt avoided the common misuse of the term *autonomous* to represent this level of automation.)

Researchers for the BASt study found the first three levels of vehicle automation to be within the current legal requirements of the German road traffic codes, based on the driver's duty to drive safely, to monitor the traffic and vehicle status, and to be prepared to override the vehicle automation in case of inappropriate system behavior. The two higher levels are not consistent with the current legal requirements because of the reduced driver role. It was also unclear whether a lane-keeping system that permits "hands–off" operation would be permissible, with more human factors research needed to determine whether this would adversely affect driver vigilance.

The BASt study group also thought that it would be important to conduct more research on both human factors and technical issues to determine the ability of drivers to recover control quickly enough to ensure safety at different driving speeds, as indicated in figure 34.(29) In this case, it would be important to compare the driver recovery times with the length of time during which the automation system could remain safe following a failure in each speed range.

The BASt group produced an effective set of Venn diagram graphs to illustrate the potential safety benefits and disbenefits of automation systems. The diagrams use a blue circle to represent present-day crashes associated with manual driving hazards, and a red circle to represent the changes in crashes that occur when the automation system is doing the driving. The BASt group's general approach is illustrated schematically in figure 35,(16) where the overlaps between the circles represent the crashes that could potentially be eliminated by automation. The crescents outside the overlap area represent the crashes that would still occur after the introduction of automation. The relative sizes of the areas in the Venn diagram illustrate the net safety effects of automation in a way that can help facilitate outreach to the general public. Outreach to the general public was another important theme in the BASt study, because this was identified as the necessary mechanism for fostering the legal changes needed to authorize vehicle automation through the legislative process.



Source: BASt Expert Group

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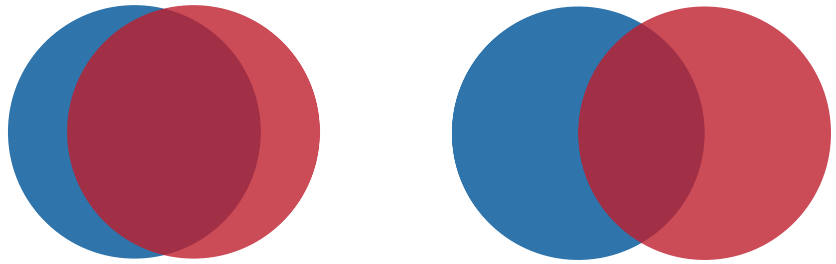
Figure 34. Chart. BASt mapping of automation levels into operating speeds for safety. (NOTE: Assist = assistance, ACC = adaptive cruise control.)

The BASt study also addressed the liability issues, identified separately as *product liability* and *road traffic liability*. In the product liability category, *defectiveness* was identified as the key concept, which depends on the instructions that are provided to the user to condition his or her expectations about system performance. These could be conveyed through the owner's manual and by other means as well. This concept was used to distinguish *reasonably foreseeable misuse* from *abuse* by the driver. The manufacturer of the system would be responsible for



Automation avoiding most current crashes, but generating some new ones, producing a net decrease in crashes

Automation avoiding some current crashes, but creating enough new ones to produce a net increase in crashes

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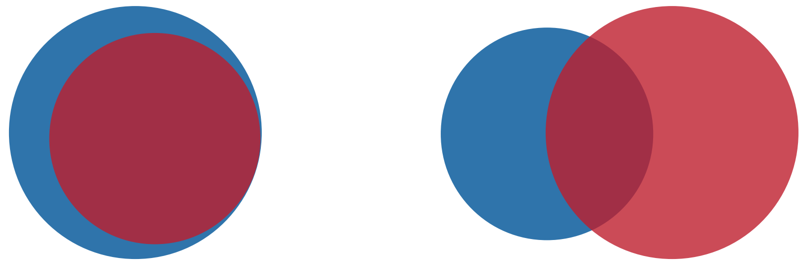


Automation avoiding most current crashes, but generating no new crashes

Automation avoiding some current crashes, but creating many more new crashes

Figure 35. Diagram. Venn diagram of automation safety benefits and non-benefits, inspired by the BASt study. NOTE: Existing crashes are represented by the blue circle and changes in crashes associated with automation are represented by the red circle. Existing crashes that could be avoided by use of automation are thus represented by the overlap areas.

consequences from the former but not the latter. Under current German law, the manufacturer would be liable for crashes that occur at the two higher levels of automation unless the crash could be determined to be solely the fault of the other vehicle or driver. The road traffic liability issue was identified to be particularly associated with platooned operations, in which each vehicle is no longer entirely self–sufficient, but its safety depends to some extent on the actions of the other vehicles in the platoon.

The identified research needs included:

» Determine human ability to interact with automation systems in real road traffic.

» Determine performance and reliability of driver–state–monitoring systems that may be needed to determine driver condition in real time.

» Define functional safety of automation systems at two higher levels.

» Determine human capabilities to take control over automation under fault or emergency conditions.

» Determine driver skill loss from use of automation.

» Identify any new driver skills or training that would be needed to use automation systems safely.

» Review national road traffic codes to determine what changes are needed to produce sufficient harmonization to sell the same vehicles throughout Europe.

» Identify demands of automated systems on road infrastructure (e.g., quality of road markings).

Private Automotive Industry Activities

The automotive industry in Europe has shown more interest in automated driving within the past few years than at any time since the completion of the PROMETHEUS program in 1994. Because the industry does not trust the infrastructure providers to be reliable providers of cooperative infrastructure, this interest has been shown unofficially rather than officially, through publicity demonstrations of autonomous partially automated driving. However, companies have been gaining practical experience with the operation of automated vehicles in specialized applications, such as robots driving test cars on test tracks or training race car drivers in “optimal” strategies for driving specific race tracks. BMW even staged media demonstrations of automated driving for a test course in September 2011. Mercedes has presented videos at several public meetings of their test vehicles being driven by strap-on robotic vehicle controllers in precisely controlled close encounters, which would be unsafe and insufficiently repeatable if the vehicles were driven by humans.

European Commission Workshop on Automation in Road Transport

The EC organized a workshop in Brussels, Belgium, on October 26, 2011, to present and discuss the current state of the art and future needs in road transport automation. This was a rare opportunity to bring together the key people interested in the topic area throughout Europe, representing the vehicle industry and research institutions, as well as sponsors and participants in the projects associated with both DG–CONNECT and DG–RTD. The workshop was heavy on presentations, leaving very little time for question-and-answer sessions and interactive discussion, but it still revealed some contrasts that will have to be harmonized. At the most basic level, the DG–CONNECT work is strongly oriented toward the private automobile industry, whereas the DG–RTD work is multi-modal in its orientation, with an emphasis on public transit and trucking applications. This difference in perspectives colored the attitudes that were expressed about some of the key automation attributes, such as full versus partial automation and operations in dedicated lanes versus in mixed traffic. There were about a hundred attendees, who represented a broad cross-section of European ITS interests.

Juhani Jääskeläinen of DG-CONNECT (then still known as DG-INFSO) opened the workshop with a strong statement in support of the notion that "the time has come" for automation to be considered seriously as a means for improving Europe's road traffic safety, mobility, and environmental impacts. The other options short of automation have been exhausted by now, but more gains are needed. Because there has already been a substantial amount of research on automation issues, Jääskeläinen is eager to find automation options that can be tested and deployed relatively soon. He wants to do what is good for the competitiveness of Europe's automobile industry and for the health of its cities.

The bulk of the workshop contained a series of presentations about current European projects related to automation and cross-cutting issues associated with automation, with time for only a few questions after each presentation. The presentation slides are posted online at
http://ec.europa.eu/information_society/activities/esafety/2011/automation_workshop/index_en.htm.

Rather than reciting the details of all the presentations, which tended to cover many of the topics already reported in the preceding sections of this report, some of the highlights from the workshop and new insights are summarized as follows:

- The SMART-64 project was only one of the topics under discussion, not the centerpiece of the meeting. It used the term *smart lanes* to represent what appears to be the same concept as the eLanes defined in the CityMobil project (sponsored under a different DG). In these lanes, the level of automation could be increased, but the degree of automation increase and the degree of separation from the rest of traffic were still not completely defined.

- The main hurdles to overcome in pursuit of automated vehicle deployment were recognized to be (a) human factors (e.g., driver interactions with the automation systems and driver ability to remain sufficiently alert to intervene); (b) liability; and (c) the need to enhance technical performance (e.g., sensors, driver interfaces, driver status monitoring, data communication, fail-safe systems).

- There was considerable discussion about the need to clearly define and demonstrate automation technology benefits to the driver (or to those purchasing a vehicle) in an effort to motivate the purchase of the system. Increasing the level of enthusiasm by the general public will also be important in obtaining political support for some of the legal changes that are likely to be needed in Europe. The benefits also need to be demonstrated to the infrastructure owners and insurance industry so that they will be amenable to playing a role in the deployment of automation systems. The automotive people generally saw the opportunity for drivers to safely perform non-driving tasks while driving (e.g., texting, Web surfing, etc.) as the major selling point, but at the same time this is in conflict with the need to keep the driver engaged to handle adverse conditions that the state-of-the-art systems cannot handle.

» There was considerable discussion about driver training needs and driver skill loss. The training issue was particularly important because of concerns about the difficulty of making the driver interfaces so completely intuitive (especially regarding the different possible modes of operations and the transitions among those modes) that no training would be needed, versus the practical challenges of implementing a training regimen. This is one aspect in which introduction in systems used by professional drivers could help pave the way for applications to be used by the general driving public.

» The HAVEit project leader made the important observation that the automation systems that keep the driver in the control loop have less stringent redundancy requirements and can make use of less expensive technology, which would have to be traded off against the reduction of comfort and convenience benefits. He also noted that the systems implemented in the demonstrator vehicles for HAVEit, which do not permit the driver to disengage from attention to the road for more than 2 seconds, would not be marketable to the public; rather, it will be necessary to have systems that can tolerate longer periods of driver disengagement without becoming unsafe in case of failures.

» A multi–dimensional conflict in goals and practicality became evident, considering the expressed needs for systems to be affordable (in both vehicle and infrastructure elements), to provide attractive comfort and convenience to users, and to be safe. One of the main reasons that additional R&D work is needed is to determine whether acceptable combinations of these attributes can be achieved, given that improvements in one of these dimensions lead to losses in one or more of the other dimensions. For example, the automobile industry representatives believe that systems must be able to operate in mixed traffic, because they do not expect protected lanes to be made available (for reasons of construction cost and right–of–way limitations), but at the same time, none of their technologies are yet able to operate in a sufficiently safe manner in a mixed–traffic environment.

» One suggested approach to get around the mixed–traffic challenge is to provide time-dependent segregation of automated traffic from the rest of the traffic. The context for this suggestion was nighttime operation of trucks on toll roads, where the road operator would be responsible for verifying that any vehicles admitted to the road are qualified and would take on the liability for any untoward events. The driver or vehicle operator would pay a premium for the privilege of a guaranteed arrival time.

- Early developments in the automotive systems are expected to focus on low–speed automation for congested traffic scenarios, where the consequences of failures are less severe than at higher speeds, and it may be possible to allow more time for the driver to intervene when a problem arises.

- In contrast to the automotive industry representatives, the public transit industry representatives were strongly in favor of dedicated, protected rights–of–way for operation of automated vehicles. The most extreme example of this is PRT on dedicated special–purpose guideways, but they also suggested separated rights-of-way for CyberCars. Because of the high density and well-developed mass transit systems in the large European cities, public transit representatives see the most promising applications for automated transit systems to be in the small–to–medium cities or on the outskirts of the larger cities, where the automated systems could provide feeder service to the high–capacity mass transit systems.

- An important economic incentive for truck automation would be the potential to relax hours of service restrictions if drivers were not responsible for the continuous control of their vehicles while their vehicles operated in the automated mode. This could increase the drivers' productivity and earning power.

- One of the main impediments to the deployment of transit automation systems is the lack of common European standards for certification of these systems. The certification requirements and approaches differ dramatically from place to place, which places a severe burden on the developers of systems, who have to meet incompatible requirements.

- Anna Schieben from the German aerospace research center DLR, one of the main human factors experts from HAVEit, presented an excellent summary of the human factors considerations and design challenges associated with partial automation of road vehicles. She emphasized the importance of focusing on the transitions between automation levels and ensuring that these transitions be designed to reinforce drivers' correct mental models of the relative responsibilities that they and the system have. She also raised the issue of the challenges faced by other road users (especially pedestrians and bicyclists), who are accustomed to communicating with vehicle drivers based on eye contact but who would not be able to do that with automated vehicles. There is not yet any well-established knowledge about how well and how quickly drivers will be able to regain control of their vehicles in emergencies if they are significantly distracted by other activities (such as texting or Web surfing). Surveys of drivers who participated in the HAVEit driving simulator experiments were very favorable about almost all aspects of the automated driving experience with the exception of a concern that it could be "sleep inducing."

- The BASt study of the legal aspects of vehicle automation under German law drew strong interest from the conference attendees, including requests that it be translated into English. This study appears to be the most comprehensive current treatment of a topic that has induced anxiety in most people who think about vehicle automation.

At the end of the workshop, there was a proposal to establish a European working group on automation, which would include representatives of the different parts of the EC, for developing a roadmap to define future work that will be needed under the next calls for proposals for EC research programs. There were no definitive answers to the various questions posed during the workshop, but a substantial number of topic areas were discussed and recorded.

The Working Group on Automation in Road Transport was established in response to this need for defining future work. The group began meeting in the spring of 2012 under the general structure of the European "iMobility Forum," the stakeholder group that promotes deployment of ITS technologies. It is one of five parallel working groups that address specific ITS topics (the others being Clean and Efficient Mobility, Digital Maps, Vulnerable Road Users, and Nomadic Devices). The Working Group on Automation in Road Transport is considering a variety of automation functions that would be needed in four different operating environments for automated vehicles and identifying the cross-cutting issues that need to be resolved.

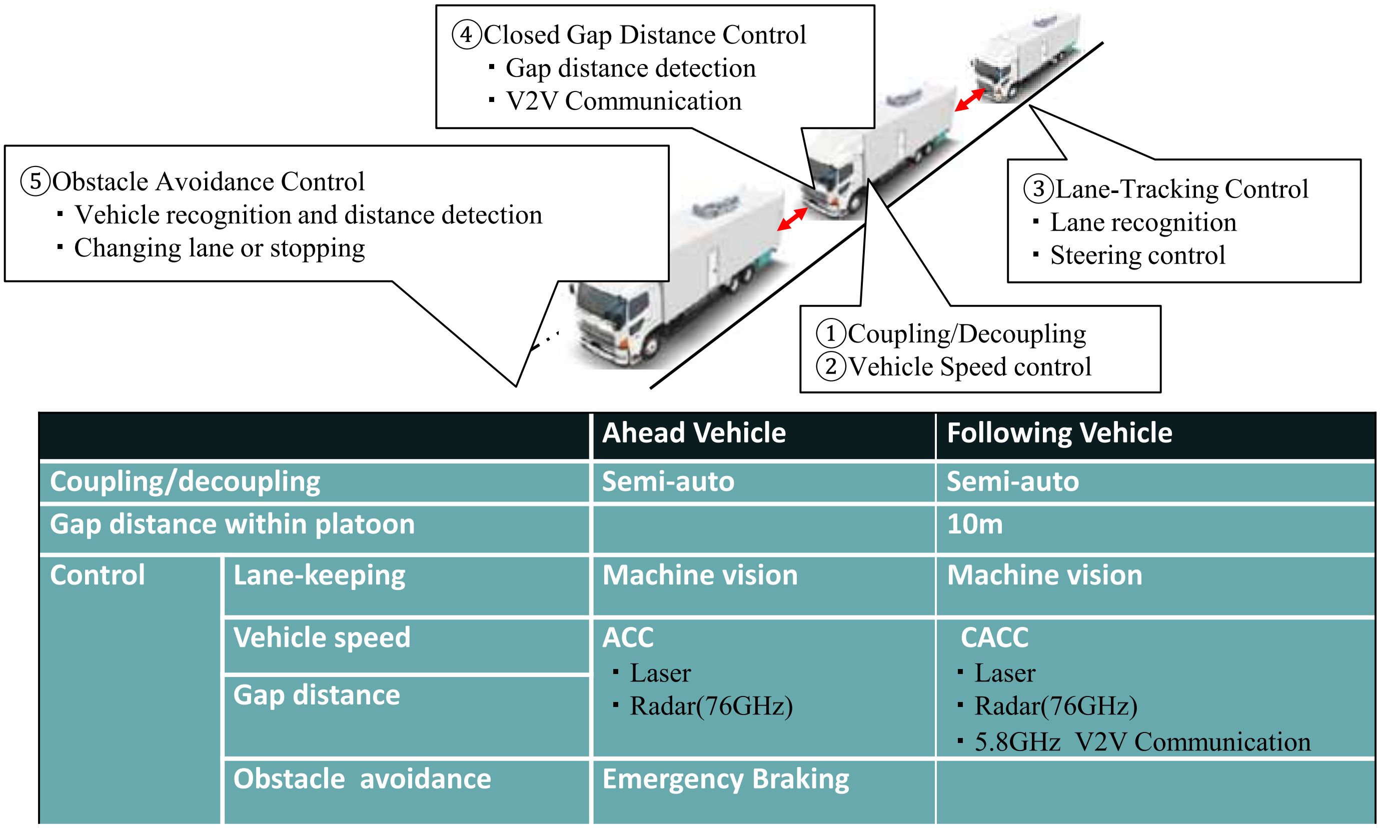
Current Asian Activities in Cooperative Vehicle–Highway Automation

Japan's Energy ITS Project

The most ambitious fully automated driving activity appears to be occurring in Japan's Energy ITS project, which has been developing and testing a platoon of three fully automated trucks for close to 5 years. This project, under the sponsorship of METI through its New Energy Technology Development Organization (NEDO), has been funded at the equivalent of about $12 million per year for 5 years. The work is being conducted by researchers at multiple universities, with coordination and management by the Japan Automobile Research Institute (JARI) but with little direct involvement by the truck manufacturers. The primary goal is to attain energy savings (CO_2 reductions) through the reduction of aerodynamic drag by operating trucks in an electronically coupled platoon at shorter-than-normal gaps, with additional objectives of improving highway traffic flow and safety. Because of Japan's rapidly aging population, its truck fleet operators are concerned about future shortages of truck drivers, which could be alleviated if the following trucks in the platoon could indeed be driverless.

The operational concept for this system has gone through some changes, motivated by political pressures from the sponsoring agency. Originally the project was planned to evaluate both a mixed–traffic and a dedicated–lane approach for truck platooning. After some evaluation, the researchers decided to focus on the dedicated-lane scenario based on technical feasibility considerations, but then the sponsors directed them to switch their attention to the mixed–traffic scenario. After several years of development activities, the project manager saw problems with the feasibility of the mixed–traffic scenario, based on its mixed treatment of driver roles and responsibilities (unable to control but still in the control loop in an ambiguous way). At present, the project manager does not see a clear way past this challenge, because operation of fully automated platoons without drivers in the following trucks on dedicated lanes will not be possible until the future and would involve significant complications in assembling and disassembling the platoons in special staging areas.

The target trucks for this work are 25–ton single–unit trucks, which are the typical type of heavy truck used for over-the-road freight hauling in Japan. The trucks have been retrofitted with an extensive suite of sensors, actuators, computers, and displays, and their cargo compartments have been equipped as mobile office space, with computer racks, desktops, displays, and seats for visitors to receive demonstration rides. Researchers tested the trucks on a section of the New Tomei Expressway before it was opened to public traffic, but most testing and demonstrations have been performed at the test track of the Agency for Industrial Science and Technology, part of METI, near Tsukuba City. The researchers provided a demonstration of these trucks to attendees



④Closed Gap Distance Control
- Gap distance detection
- V2V Communication

⑤Obstacle Avoidance Control
- Vehicle recognition and distance detection
- Changing lane or stopping

③Lane-Tracking Control
- Lane recognition
- Steering control

①Coupling/Decoupling
②Vehicle Speed control

		Ahead Vehicle	Following Vehicle
Coupling/decoupling		Semi-auto	Semi-auto
Gap distance within platoon			10m
Control	Lane-keeping	Machine vision	Machine vision
	Vehicle speed	ACC ▪ Laser ▪ Radar(76GHz)	CACC ▪ Laser ▪ Radar(76GHz) ▪ 5.8GHz V2V Communication
	Gap distance		
	Obstacle avoidance	Emergency Braking	

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Figure 36. Presentation slide. Energy ITS truck platoon definition of capabilities. NOTE: V2V = vehicle-to-vehicle communication, ACC = adaptive cruise control, CACC = cooperative adaptive cruise control.

of the active safety conference, FAST-Zero, in September 2011.

The intended operations of the Energy ITS project truck platoon system are summarized in figure 36,(30) indicating that all of the trucks are expected to be driven automatically while in the platoon, although the drivers would be responsible for the lane-changing maneuvers associated with entering and leaving the platoon.

The components and subsystems that were added to the trucks to implement the automated platoon functions are summarized schematically in figure 37.(30) Note that two different sensor technologies are used for forward ranging, both laser and millimeter wave radars. The laser radar has a very wide field of regard so that it can be used to detect cut-in maneuvers by cars or other trucks (as was demonstrated successfully). When an unauthorized vehicle (a private car) cuts

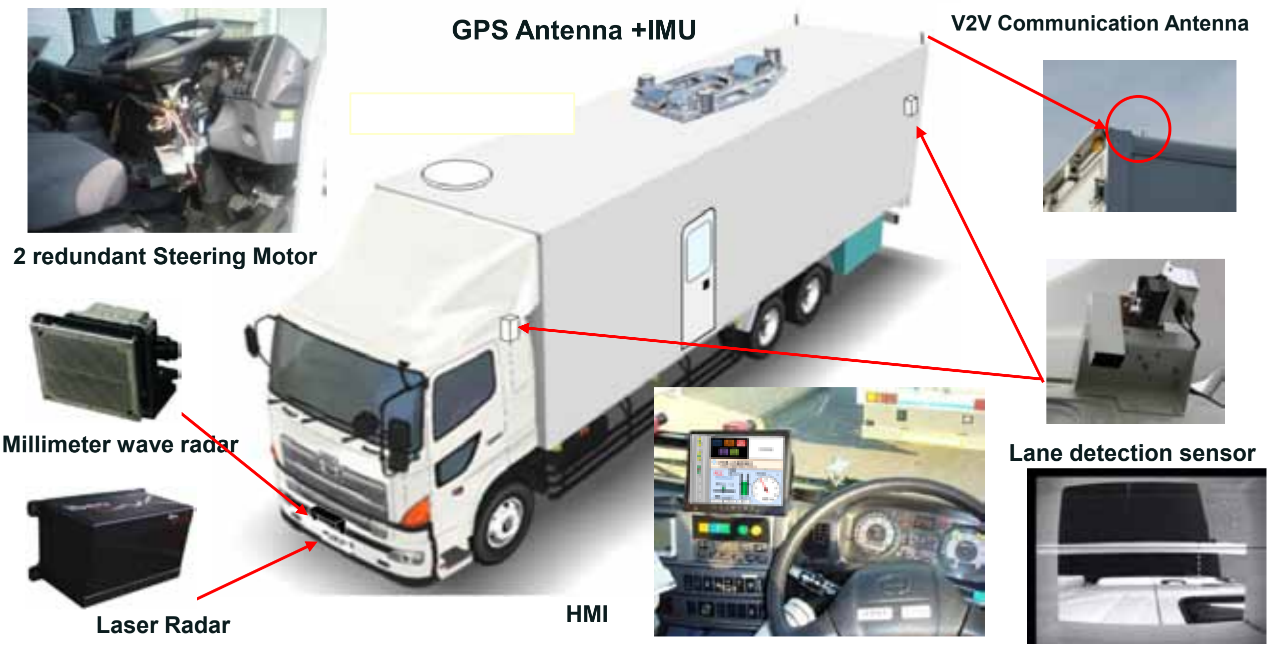

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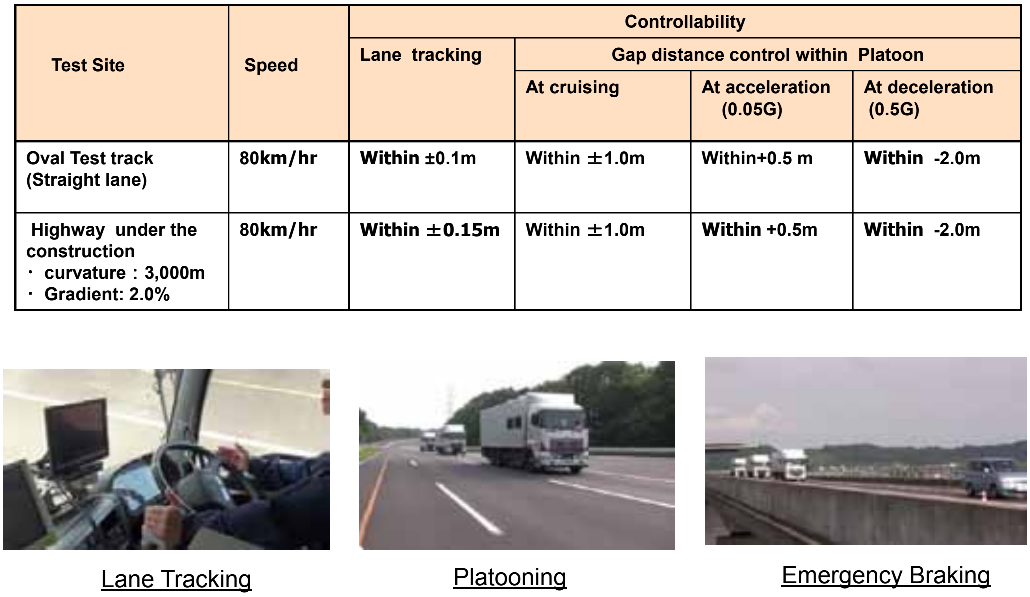
Figure 37. Diagram. Automation equipment installed on Energy ITS trucks. NOTE: GPS = global positioning system, IMU = inertial measurement unit, V2V = vehicle-to-vehicle communication, HMI = human–machine interface.

into the platoon, the truck behind it breaks away from the platoon and follows the cut–in vehicle at a much larger gap, using a basic ACC strategy. When the intruding vehicle departs, the following truck can re-connect to the platoon. The steering actuators and V2V communication systems are redundant for safety purposes. The lane-position detection is performed by using video cameras that face down at the front and rear of the truck so that the two separate measurements can be used to identify both lateral displacement and yaw angle relative to the solid lane marking on the left side of the truck. A laser scanner system for lane–marker detection has also been tested and will be added as a redundant source of lane position information. For safety considerations, the braking rate of the first truck is limited to substantially less than the braking capabilities of the following trucks. The control computers have also been designed for safety considerations, with each



Test Site	Speed	Controllability			
		Lane tracking	Gap distance control within Platoon		
			At cruising	At acceleration (0.05G)	At deceleration (0.5G)
Oval Test track (Straight lane)	80km/hr	Within ±0.1m	Within ±1.0m	Within+0.5 m	Within -2.0m
Highway under the construction ・ curvature : 3,000m ・ Gradient: 2.0%	80km/hr	Within ±0.15m	Within ±1.0m	Within +0.5m	Within -2.0m

Lane Tracking

Platooning

Emergency Braking

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Figure 38. Presentation slide. Performance requirements for Energy ITS truck platoon system.

truck equipped with two dual-processor computers provided by a railway signal maker. This increases cost and complexity but greatly reduces the likelihood of a catastrophic system failure.

The performance requirements for the truck platoon system are summarized in figure 38.(30) Emergency braking at 0.4 g (4 m/s^2 or 12.9 ft/s^2) was demonstrated for visitors in September 2011, and the higher braking rate of 0.5 g (5 m/s^2 or 16.1 ft/s^2) is planned for later stages of the project. The 0.4 g (4 m/s^2 or 12.9 ft/s^2) braking rate is hard enough that passengers feel significant pressure as their bodies press against their shoulder belt restraints.

The Energy ITS team has developed a variety of scenarios to prove the feasibility of the maneuvers needed to form and break a platoon, as shown in figure 39,(30) and they demonstrated those scenarios in September 2011. In the first scenario, a third truck joined a two-truck platoon in the middle. To accommodate this, the

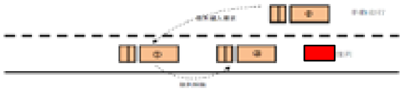
Test	Demonstration Scenario	Outline of Control Process
1	Coupling of three vehicles from two vehicles. 	◆ Split of two vehicles with the engagement. ◆ Enlargement of gap distance up to 35m. ◆ Cut in front of second vehicle. 
2	Platoon with three vehicles at a speed of 80 km/h.	◆ Gap distance of 15 m at speed of 80 km/h. 
3		◆ Detection of the cut-in vehicle. ◆ Decoupling of vehicles. ◆ Deceleration and maintaining safe gap distance. 
4	Emergency braking for collision avoidance.	◆ Maintaining gap distance under large deceleration.

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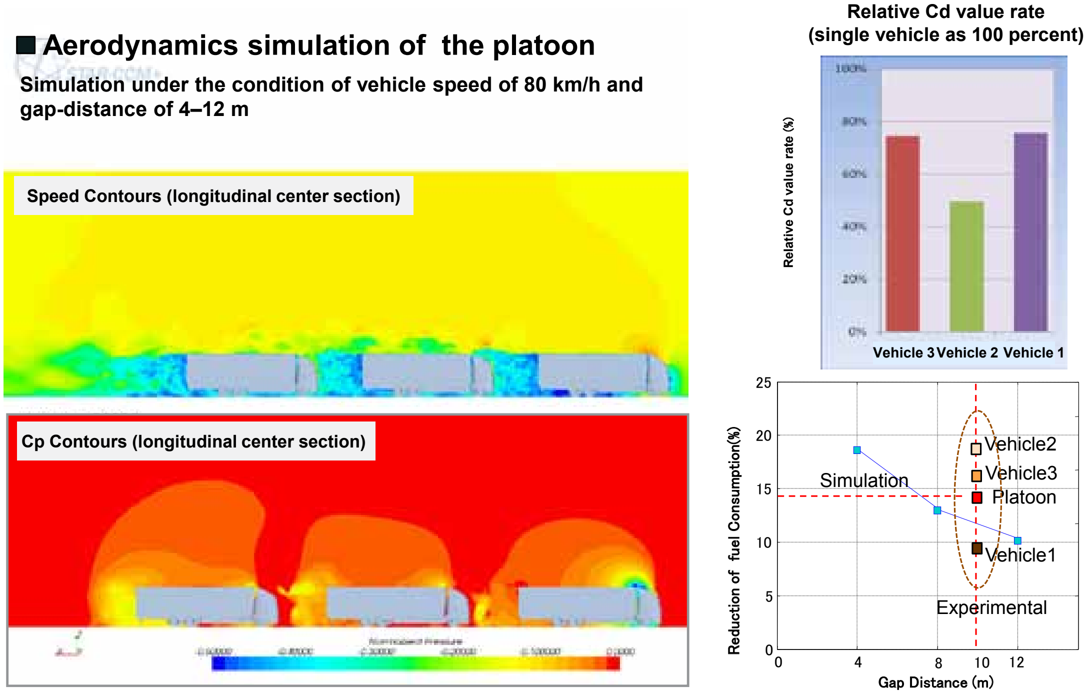
Figure 39. Diagram. Maneuver scenarios for Energy ITS project truck platoon. NOTE: 80 km/h = 50 mi/h.

following truck in the platoon increased its following distance to 35 m (115 ft) to leave enough space for the new truck to enter, and they then formed a new platoon. The steady cruising of the second scenario was performed at a 15-m (49-ft) gap, although the target gap for the end of the program is 10 m (33 ft). In the third scenario, an unauthorized non-equipped vehicle cut into the gap between the second and third trucks, but this was detected by the wide-angle laser radar on the third truck, which proceeded to increase its gap so that it followed the intruder vehicle at a safe gap by using ACC car following. The final scenario was the emergency braking already mentioned. An additional scenario that was not demonstrated to visitors was a coordinated lane change by the entire platoon to avoid a vehicle stopped in its lane.

The goal of the Energy ITS project is, of course, drag reduction to reduce CO_2 emissions. In support of this goal, researchers conducted computational fluid dynamics simulations to predict the extent of the drag reduction before full-scale tests could be performed under all conditions of interest. Some of the results of these simulations are shown in figure 40,(30) together with some early results from test–track tests of the full-size trucks. The colored plots on the left of figure 40(30) show visualizations of air speeds and pressures around the truck platoon. The plot on the upper right of the figure shows the estimated reductions in the drag coefficients of each truck at the minimum gap of 4 m (13 ft). Because the aerodynamic drag accounts for only about half of the truck energy use at highway speeds, these percentage reductions are much larger than the reductions in energy use. The plot in the



■ **Aerodynamics simulation of the platoon**

Simulation under the condition of vehicle speed of 80 km/h and gap-distance of 4–12 m

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Figure 40. Presentation slide. First predictions of aerodynamic drag effects of Energy ITS project truck platooning, compared with experimental results on full–scale trucks. NOTE: 80 km/h = 50 mi/h, 4 m–12 m = 13 ft–40 ft, Cd = drag coefficient, Cp = pressure coefficient.

ⓘ Available to request platoon

Figure 41. Photo. In-vehicle display screen of a following truck in the Energy ITS platoon.

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lower right corner of figure 40[30] converts these results to estimates of fuel consumption savings as a function of vehicle–following gap. The results of test-track experiments with the full–scale truck platoon at a 10-m (33-ft) gap are plotted for comparison with the predictions. The second truck had the largest fuel savings, whereas the third truck saved slightly less fuel. The 14–percent average fuel saving for the entire platoon shown here was somewhat higher than the trend of what was predicted from the simulation. Note that even the first truck saved about 10 percent of its fuel consumption by being coupled in the platoon at a 10-m (33-ft) gap.

One aspect of the Energy ITS truck platoon system that is not yet well developed is the driver interface. There is a complex display screen in each truck, which includes much technical information of interest to the researchers developing the system, but it is likely to be overwhelming for a truck driver in real–world operations. At the request of the truck drivers, it includes live video of the first driver's forward view, which is transmitted to the drivers of the two following trucks. This display screen is shown in figure 41[16] as a picture that was taken before the trucks started to move. In addition to the display screen in the truck, the driver is also expected to monitor three types of information displays on the back of the preceding trailer, as shown in figure 42.[16] The three colored lights at the lower center of the trailer have been coded to represent a large number of different operating conditions, based on different patterns of colors for the center and outer lights and whether they are illuminated steadily or flashing.

The Energy ITS program has not yet succeeded in stimulating strong interest in the Japanese trucking fleets, who would be the end users of the system. Although Japanese trucking fleets are intrigued by the potential energy savings and reductions in driver labor costs, they are concerned about the complications of forming a platoon among trucks from different fleets, especially when the energy-saving benefits depend on their position within the platoon.

Toyota's Platooning Development Work

Toyota Motor Company has developed and tested a platoon of three Lexus LS-460 passenger cars that follow each other closely to reduce fuel consumption. Toyota has described this work in a few conference papers but has not provided any demonstrations of the system to visitors. This system uses frequent V2V communication to coordinate longitudinal motions of the vehicles and includes both forward- and rear-facing millimeter-wave radars on each vehicle to provide redundant information about the range and range rate between successive vehicles. Toyota reported string stability of vehicle-following control, with 10-m (33-ft) gaps and spacing errors of 1 m (3.3 ft) or less, including decelerations up to 0.4 g (4 m/s^2 or 12.9 ft/s^2). These vehicles did not include automation of lateral control.

Published results show impressive fuel savings from this system, which was optimized for fuel economy.(31) The aerodynamic drag reductions were reported in the 40 percent range for the following vehicles and in the 8–9 percent range for

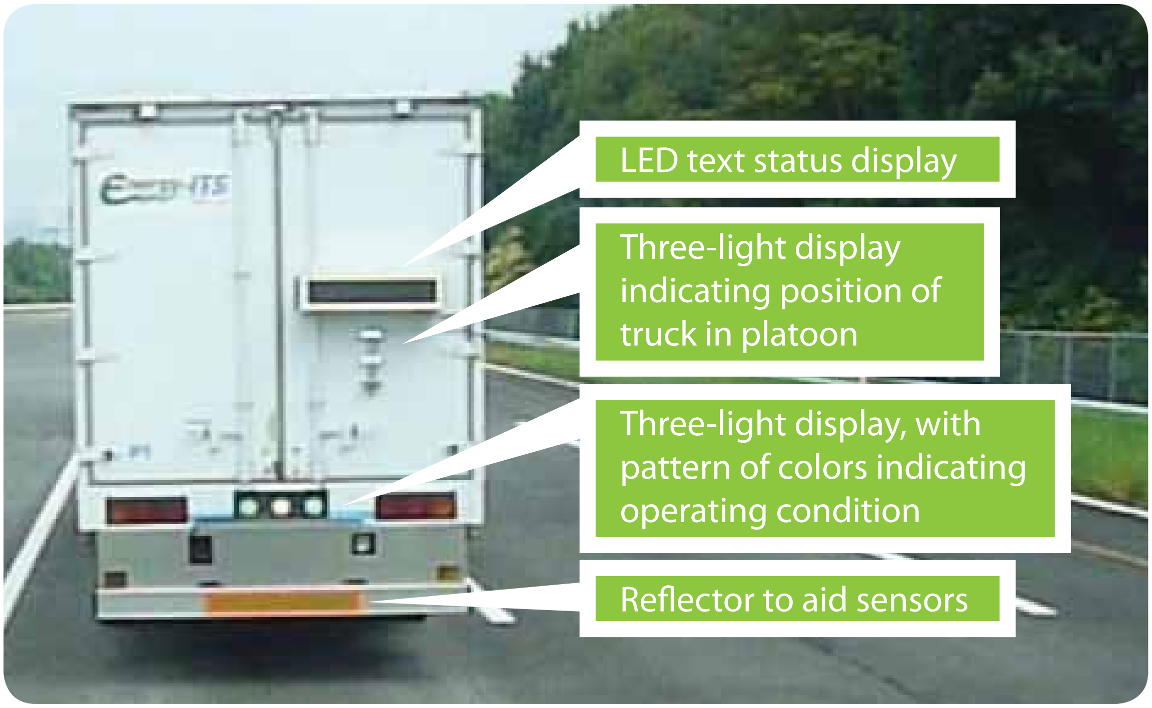

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Figure 42. Photo. Rear view of Energy ITS truck with three information displays.

the leading vehicle at a 10-m (33-ft) gap. Even at a 20-m (66-ft) gap they were still reporting 25 percent drag reductions for the following vehicles. The second vehicle saved somewhat more than did the third vehicle when direct fuel consumption measurements were recorded, in the 8–10 percent range (compared with 1–2 percent for the leading vehicle) at 10-m (33-ft) gaps, with gradual declines in savings as the gaps were increased in 5-m (16-ft) increments to 30 m (98 ft).

Comparison with Current U.S. Status

U.S. Activities

Although the United States established a clear position of international leadership in CVHAS in the mid-1990s, the level of activity in this area has declined significantly since then. There have been several R&D efforts continued in recent years but at relatively modest funding levels. The following experiments have used full–scale vehicles with partial or full control of driving functions and V2V or V2I cooperation:

- Transit bus lateral guidance and steering control—University of California PATH Program and University of Minnesota ITS Institute, with support from the Federal Transit Administration, ITS Joint Program Office, and their respective State Departments of Transportation.
- Heavy truck longitudinal platoon control—University of California PATH Program, with support from FHWA's Exploratory Advanced Research Program.
- CACC—University of California PATH Program, with support from FHWA's Exploratory Advanced Research Program, Caltrans, and Nissan.

There has also been a simulation study of the operation of arterial intersections with fully automated vehicles—using a slot reservation protocol to provide system–level coordination of their movements—by the University of Texas at Austin with support from FHWA's Exploratory Advanced Research Program.

General Motors has entered the CyberCar world with their development of a two-person, two-wheeled dynamically balanced vehicle called the *EN/V* (pronounced *envy*) in collaboration with Segway. The first technical documentation of this vehicle was presented at the 2011 ITS World Congress in Orlando, FL, combined with a public demonstration of the vehicle (which was also exhibited very prominently at the 2010 Shanghai World Expo).(32) The EN/V showed sophisticated short–range obstacle detection and avoidance and automated platooning capabilities, including completely unmanned and remote–controlled operations, which appear to exceed the technical capabilities of the analogous but more highly publicized European developments.

Much media attention has been attracted by the DARPA Challenges for autonomous automated vehicles and the subsequent announcement by Google that it is experimenting with autonomous automated vehicles on public roads in the vicinity of its headquarters. A variety of university research groups have also been working on autonomous automated driving research, but these activities are outside the scope of this review.

Similarities and Differences Between Overseas and U.S. Situations

This review of current international status on road vehicle automation has revealed some significant similarities and differences between the situations overseas and in the United States. Resources to support new developments are tight everywhere, but the current level of activity appears to be higher overseas and the planning horizons are longer.

Similarities

The growing use of hybrid–electric and all–electric powertrains has increased the in-vehicle electrical power availability and voltage significantly, making it easier to add electronic and electro-mechanical subsystems, such as the sensors and actuators needed for automated driving. Electronic actuation systems for steering, braking, and engine control are becoming standard equipment on more vehicles, leading to increased production economies of scale.

The research teams working on automation have encountered some of the same primary operational concept dilemmas as the NAHSC did in the 1990s, without resolving them. These dilemmas are as follows:

» To what extent do automated vehicles need to be segregated from general non–automated traffic to ensure their safety?

» How much of the vehicle control responsibility should be transferred from the driver to the vehicle automation systems and under which conditions?

» Is it better for automated vehicles to be totally autonomous, or is it better for them to communicate and actively coordinate maneuvering with each other and/or with guidance or even some degree of control from the infrastructure?

Institutional issues, such as uncertainties about liability exposure, are impeding more active development and implementation of automated driving systems. Vehicle manufacturers are reluctant to provide functions that could remove the driver from the vehicle control loop without some assurance about their liability exposure in the event of a crash. In Europe, the situation is further complicated by the Vienna Convention and legal systems that handle this issue differently, motivating the need for European–level harmonization of policies and possibly legislation.

Differences

» The primary motivation for applications of vehicle automation in Europe and Japan is saving energy and reducing CO_2 emissions, whereas the primary motivations in the United States have been associated with mobility, safety, and driver convenience.

» The primary public sector support for vehicle automation system development in Europe and Japan has come from agencies whose missions are oriented toward economic competitiveness, the information technology industry, or more general research and technology enhancement. By contrast, transportation technology support in the United States has historically come from the U.S. Department of Transportation (or Department of Energy), which are more directly focused on the improvements in transportation measures of effectiveness or energy efficiency and self-sufficiency.

» The European thinking about driving automation has been colored significantly by the Vienna Convention on Road Traffic, which specifies a uniform set of rules and policies. Some of the Vienna Convention language about driver responsibilities has loomed large over automation discussions in Europe, although these concerns appear quaint from a U.S. perspective, because the Convention does not apply in the United States (or Japan) and can be amended if necessary.

- European and Japanese auto manufacturers have already introduced a wider range of advanced driver assistance systems across a wider range of vehicle models, including those in moderate price ranges, in their home markets than in the United States. This means that drivers in those countries have been exposed to more sophisticated warning and control assistance systems than their U.S. counterparts, in large part because they have shown more willingness to pay a higher price to gain those greater capabilities.
- European and Japanese projects have been focusing their attention primarily on partially automated systems rather than fully automated systems and have tended to start from the assumption that new dedicated lanes will not be available for use by automated vehicles. This appears to be a consequence of their higher density urban development patterns and high urban land costs. In the United States, with somewhat lower density and land costs, significant attention has been given to automated vehicles that could be physically segregated from other road users.
- European and Japanese projects have increased their emphasis on automation issues within the past 4 years, whereas the United States has funded very little work on automation within the past decade after establishing an international leadership role in this area in the 1990s.

Implications of These Contrasts for Future U.S. Actions

The United States pioneered thinking about and development of road traffic automation systems for several decades, from the GM Futurama of the late 1930s(8) through the NAHSC research and demonstration of the late 1990s. During the past decade, Army research, the DARPA Challenges, and the ensuing Google development work have advanced technologies for individual vehicle-oriented automation, largely independent of traffic considerations. At the same time, the levels of activity in road traffic automation have increased significantly in Europe and Japan, to the extent that at this point in time they probably have the leading expertise in the world in several key areas:

- Automated truck platooning (Energy ITS in Japan).
- Automated buses (several European projects).
- PRT (e.g., ULTra PRT at Heathrow and 2getthere at Masdar).
- Human factors and partial automation concepts (HAVEit project in Europe).

The sponsors of the European and Japanese work have strong interests in industrial competitiveness and in developing their ability to export products to the rest of the world. Unless the United States invests some effort in automation systems soon, it will have no choice but to import the systems from Europe and Japan when it needs them.

The European and Japanese systems, however, have been developed based on somewhat different requirements, needs, and economic and societal constraints derived from the characteristics of their transportation systems. For example, the density of development and land costs in Europe and Japan are substantially higher than in the United States, which leads them to reject the concept of dedicated lanes for automated vehicles *a priori*. The automobiles currently being sold in other countries are substantially better equipped with advanced driver assistance systems than are U.S. vehicles (and indeed most of the vehicles that have these systems in the United States are imported from Europe or Japan). This means that the incremental costs of adding automation capabilities are likely to be smaller in Europe and Japan, because they are starting from a higher baseline. Both of these factors tend to tilt toward more vehicle-intensive solutions in other countries than what may be ideal for U.S. applications.

The United States still retains some important strengths relative to Japan and Europe in the field of automation:

- Availability of comprehensive traffic safety and crash data to provide more insight into traffic safety and crash causality specific to the U.S. environment. As a result, the safety–oriented system designs can be targeted most effectively at solving the most important and relevant safety problems.
- A well–developed transportation human factors research community that can focus on designing systems that are safe and easy to use, without creating new safety or usability problems.
- A substantial research community with vehicle automation knowledge and experience developed over decades of work in both the road transportation and military domains.
- A road network with a relatively high percentage of travel on limited–access highways, where it is likely to be simplest to implement automation technologies.
- Recent and current projects that can provide the technological foundations for new developments (GM's EN-V, Google's driverless cars, PATH's automated trucks and buses and CACC, GM's Exploratory Advanced Research project on partial automation).
- System engineering approaches and expertise, to design and develop solutions to problems rather than solutions looking for problems.

The United States can build on the combination of its extensive heritage of experience and capabilities relative to automated road transport, its current areas of international leadership, and the knowledge being developed in current programs in other countries to develop a robust program in automated road transportation. The focus should be on areas in which U.S. needs differ from the needs of other countries and where it can build on the strengths that it already has. Suggested actions include:

- Conduct concept studies of a range of automation applications to address transportation problems in the United States in an effort to identify which could be most beneficial. This should be done to establish an "application pull" approach to automation system development, in contrast to some of the international activities which have been more of a technology push.
- Build on the BASt study of legal issues in Germany, focusing on the differences between German and American law, to establish what the realistic legal issues and constraints are in the United States.
- Build on the recent GM studies of driver interactions with partially automated vehicles to develop a systematic set of data regarding drivers' ability to resume control of a vehicle after they have been engaged in non-driving activities for an extended time.
- Pursue more in–depth work on truck platooning to complement current activities in Japan and Europe. This should include refining the concepts of operation for truck platooning systems to address both urban and intercity applications, experimental work to develop reliable quantitative data about the fuel and emissions-saving potential of the concepts, and benefit–cost studies to support the definition of business cases for further development and deployment.
- Seek opportunities to collaborate with the European and Japanese programs where synergies can be identified. The technical issues are sufficiently challenging that it should be to the benefit of everybody to distribute the needed work among the experts on all continents so that progress can be accelerated.

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Office of Operations Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

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