

Nirupama Bulusu • Sanjay Jha
editors

WIRELESS SENSOR NETWORKS

A Systems Perspective

Wireless Sensor Networks

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Wireless Sensor Networks

Nirupama Bulusu
Sanjay Jha

Editors



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Preface and Acknowledgments

In 2003, I was asked by Dr. Ümit Özgüner, Ohio State University professor and then chairman of the IEEE Intelligent Transportation Systems Council, to present a tutorial on intelligent vehicle systems as part of that year's IEEE Intelligent Vehicles Conference. As one who makes a point of staying abreast of goings-on in the IV industry, I was happy to accept.

A few months later I received a call from Mark Walsh, Acquisitions Editor at Artech House Publishers. He suggested that this material could be converted into book form. Blissfully unaware of the amount of work this would entail, I accepted.

In fact, I plunged into this project because I have long felt that the tantalizing field of intelligent vehicles is known only to a relatively small band of engineers, scientists, and government policy makers. IV systems are not well known in the broader engineering realm and for that matter are only beginning to get attention within the larger automotive industry.

And yet, these systems draw together one of the most interdisciplinary mixes of experts to tackle some very challenging technical tasks. So, with this book, it is my hope to introduce a broader swath of the technical community to this field and also provide a doorway for new contributors to enter it. Furthermore, I hope to introduce a wider range of government policy makers to the significant societal benefits offered by intelligent vehicle systems.

Information is everywhere. A recent Google search on “intelligent vehicles” produced over two million hits. Some of the information that is on the web will be more up to date than this book shortly after it is published. So, why a book?

Every industry can benefit from a horizontal cut across its myriad technical and business activity. The role I seek to fulfill in the IV world is focused in this way. A senior technology manager once observed that three ingredients are needed for the kind of innovation that keeps an industry (or a technology company) vibrant. The first two are obvious—there must be domain knowledge and expertise. The third and last ingredient is key: for innovation to occur, there must also be perspective. For the most part, I do not design or build the systems you will read about in this book. Instead, from keeping an eye on the key activities worldwide, I can offer breadth and hopefully some useful insight, leading to perspective.

Further, many readers familiar with specific IV systems will doubtless read some things they already know in this book. Hopefully, new knowledge from other sectors of the industry will prove to be valuable.

In bringing this material together, I paused more than once in complete awe and respect at the amazing functional capabilities brought forth by the designers of these intelligent vehicle systems, as well as those who somehow manage to bring them to

market as affordable and user-friendly products. My hat is off to the genius and creativity of these scientists, engineers, software developers, and business managers, whom I am also glad to count as my colleagues and friends.

In particular, I am very appreciative of the generosity of the organizations and individuals who so willingly shared of graphics and photos, as well as background information, to enhance this book. Thanks to Walter Hagleitner of ADAS Management Consulting; Jos Jansen of Advanced Public Transport Systems bv; Phil Kithil of Advanced Safety Concepts; Martin Lowson and Richard Teychenné of Advanced Transport Systems; Teruo Yamauchi of AHSRA; Dean Pomerleau of AssistWare Technology; Kevin Romanchok of Bendix Commercial Vehicle Systems LLC; Susanne Breitenberger of BMW AG; Dietrich Manstetten of Bosch; Jim Misener, Steve Shladover, Bill Stone, and Wei-Bin Zhang of California PATH; Li Bin, Chinese National Center of ITS Engineering and Technology; Dave Duggins, Jay Gowdy, and Aaron Steinfeld of CMU; Hanne Umlauf of Continental Teves AG & Co.; Kim Fowler of Coolstream Consulting; Christophe Bonnet, Uwe Franke, Dariu Gavrilă, Frank Linder, Hubert Rehborn, Gerhard Rollman, Matthias Schulze, and Berthold Ulmer of DaimlerChrysler AG; Milton Beach of Delphi; Miyoko Honma of Denso; Tom Mattox of Eaton VORAD Technologies; General Motors Corporation; Ralf-Peter Schafer, Institute of Transport Research, German Aerospace Center; Peter Hendrickx of Groeneveld Transport Efficiency, B.V.; Bernd Lichte of Hella KG Hueck and Co.; Jim Keller of Honda R&D Americas; Ulrich Lages of IBEO Automobile Sensor GmbH; Michel Parent of INRIA; Walter Scholl and the partners of the INVENT program; Jean Marc Boucheret of Irisbus; Chris van dan Elzen of Iteris, Inc.; Edwin Bastiaansen of LINC Innovations bvba; Jean-Marc Blossville of LIVIC; Sadayuki Tsugawa of Meijo University; Michael Lambie of Meritor-WABCO; Hiroshi Makino and Takashi Nishio of MLIT in Japan; Meny Benady of Mobileye; the National Highway Traffic Safety Administration; Kenichi Egawa, Hiroshi Kawazoe, and Hiroshi Tsuda of Nissan Technical Center North America; Claudio Hartzstein of RoadEye; Tom Schaffnit of Schaffnit Consulting; Martin Hummel and Alfred Hoess of Siemens VDO Automotive AG; Bart van Arem and Marjolein Baart of TNO; Etsuo Hashino, Kevin Webber and Mike Wolterman of Toyota Motor Corporation; Alastair Buchanan of TRW; Bob Sweet of UMTRI; Brian Cronin and Ray Resendes of USDOT; Scott Pyles of Valeo-Raytheon; Tom Dingus and Vicki Neale of the Virginia Tech Transportation Institute; Tim Tiernan of Visteon; Tim Meisner of Yamaha Motor Europe n.v.; and Rick Weiland, now of Ygomi LLC.

A hearty thanks also to my comrades at the Classic Cup Café, whose soft chairs and stirring latte's kept me going through many a long morning. As well, I'm deeply grateful to my fellow students and teachers at the TAI-SOPHIA Institute for cheering me on. You provided the "infrastructure" upon which this vehicle traveled!

Lastly, my most heartfelt appreciation to my wife Harriet and son Jimmy for their support and patience in this endeavor, which has been invaluable. You guys are awesome!

*Richard Bishop
Granite, Maryland, USA
February 14, 2005*

Foreword

My view of modern day Intelligent Vehicles began with ERGS (Electronic Route Guidance System), which was studied by the US DOT (United States Department of Transportation) and their partners in the late 1960's to early 1970's. I see its significance to this new book in the close cooperation of intelligent vehicles with the infrastructure to sense traffic patterns, compose strategies, and provide route guidance information via communication. This would allow the driver to have more security in driving. Maybe being too advanced for its time, activities started to wane, but in the 1980's a group of visionaries called "Mobility 2000" proposed a National Initiative and set the stage for what was then named IVHS (Intelligent Vehicle Highway Systems).

One of the early goals of IVHS was to show the world that it was in fact possible to greatly enhance safety and efficiency of land transportation using advanced technology. A large-scale demonstration of this technology was presented to experts and the public in 1997 along the I-15 corridor in San Diego. The systems presented were collectively called AHS (Automated Highway Systems), and included concepts from partial to fully automated intelligent vehicles. Even though it rained during the opening ceremony (highly unusual in San Diego in summer) I was one of the many fortunate people that were pleasantly surprised at the security felt in being in an "automated" vehicle. I wondered whether we would in the future ask friends, "What's the best car you've never driven?"

Again, I should mention that AHS was not only about total automation, but to show the feasibility of a suite of technologies that may collectively lead to total automation. Elements of the this program continue to have significant meaning just as sending a man to the moon and back in the 1960's had meaning in stimulating technological development in following decades. The AHS program was conducted by the National AHS Consortium and managed by the U.S. Federal Highway Administration, with the author being the Program Manager. This suite of technologies needed for realizing Intelligent Vehicles are addressed in this book.

Even as close as a decade ago, many such systems had been talked about as "science fiction", but it is telling to look at what is available today. As is covered extensively in this book, there are cars that keep a constant time gap to the car in front, cars with night vision, systems that help you to keep from drifting off the road, etc. In recent years, the interest has been increasing at greater speed than ever before, and the U.S. Department of Transportation has identified accident prevention using such technologies as one of the major keys to enhancing future safety. Their very active program is complemented by similar R&D activities in Europe and Asia.

I first met the author at the National Academy of Science in Washington, D.C. in 1996, and since then have recognized him as one of the most well known people in the field of intelligent vehicles, not only in the US, but also in Asia and Europe. Stimulating new ideas in an open, creative environment is crucial in the early stages of innovation, as new ideas seldom stem from a critical environment. Also, I believe that a continuing interaction between experts is very important in highly interdisciplinary worlds such as the Intelligent Vehicles arena. Mr. Bishop is quite active both in stimulating ideas and in providing such interactive environments. As a key example, he established and still chairs the ITFVHA (International Task Force on Vehicle Highway Automation), which began in 1997 and meets annually. At ITFVHA, you will see attendance of a who's who in the world of intelligent vehicles. Furthermore, his involvement extends beyond his base in the U.S. – he is depended upon in Asia and Europe to promote intelligent vehicles. This also provides him an excellent viewpoint from which to write such a comprehensive overview of intelligent vehicle activities.

Intelligent Vehicle Technology and Trends covers the topic from various angles. Starting with major goals and visions, the book gives a perspective as to how Intelligent Vehicles fit into the picture. This is followed by a categorical explanation of various systems. Since Intelligent Vehicles in many cases require involvement with the Government, many new initiatives are first conducted as a Government-Industry partnership. Therefore, two chapters are devoted to understanding priorities that this cooperation had focused upon, for both government and industry. After describing technical and human factor aspects of various functions, Mr. Bishop again returns to the theme of public-private partnership by addressing the heart of IVHS, or Cooperative (meaning cooperation with Infrastructure) Systems and leads on to what a decade ago seemed impossible to imagine for many, and that is automated vehicles. The book concludes with chapters addressing what is needed other than technology itself to make Intelligent Vehicles a reality.

Knowing the past and present will provide a better understanding of the “trajectory” of events into the future. This book presents this trajectory from Richard Bishop's long and continuing experience and active involvement in this very important arena: Intelligent Vehicles.

Hiroshi Tsuda
Director, Intelligent Transportation Systems Research
Nissan Technical Center North America, Inc.

Introduction

1.1 Machine Intelligence on the Road

Our society is awash in “machine intelligence” of various kinds, from smart thermostats in our homes, to expert systems and design aids in our workplaces, to jet aircraft landing safely in treacherous weather under computer control. Over the last century, we have witnessed more and more of the “drudgery” of daily living being replaced by devices such as washing machines, microwave ovens, motorized transport, and the enhanced productivity and convenience offered by personal computers and information technology.

Over this period the hazards to our well-being have been greatly reduced, as well—medical technology can detect cancers and other diseases earlier and treat them better; buildings have become less susceptible to fire; floods are much less frequent; and travel is safer in general.

In essence, therefore, much of our technological progress has been focused on lessening the occurrence of unexpected and traumatic death and injury and protecting our physical assets.

One remaining area of both drudgery and danger, however, is the daily act of driving automobiles. Every moment of our time traveling the roads, we are exposed to the dangers of poor road conditions, other drivers whose skill or judgment we may question (!), and even our own fatigue or lapses of attention. In fact, the drudgery of the typical driving experience is liable to lead to these lapses of attention, as the act of driving in normal conditions places only a very modest cognitive load on the brain—leading us to be less responsive to the unexpected conditions that cause crashes. Driver error is the main cause of the vast majority of crashes, with roughly half of these instances due to delays in recognition. Thankfully, we are better protected when a crash occurs due to advances in vehicle crashworthiness and occupant protection—yet any crash is a traumatic experience, and we would certainly prefer to avoid them completely.

While the likelihood of having a road crash for a single individual, on average, is in the range of once every 25 years (in developed countries), society as a whole pays a crushing price for the cumulative effects of crashes—over 40,000 deaths per year for Europe and the United States [1], with over 8,000 deaths annually in Japan [2]. The per-capita crash rate is quite similar in all three regions. Worldwide, 1.2 million people were killed in traffic crashes in 2002, which was 2.1% of all global deaths and the 11th ranked cause of death [3]. If this trend continues, an estimated 8.5 million people will be dying every year in road crashes by 2020. Further figures for the United States are illustrative for the developed countries: over two million

injury-producing crashes, over four million crashes resulting in property damage, and an estimated 10 million crashes total on an annual basis. Over 100 people die *every day* on average. Road crashes consume a greater share of national health care costs than do any other single cause of illness or injury—in fact, the U.S. Department of Transportation has estimated the overall societal cost of road crashes annually in the United States at greater than \$230 billion [4].

Furthermore, human limitations in sensing and control of individual vehicles multiplies when hundreds or thousands of vehicles are sharing the same roads at the same time, leading to the all too familiar experience of congested traffic. Traffic congestion undermines our quality of life in the same way air pollution undermines public health. Sources of air pollution have been attacked with a wide variety of government policies and new technology—why has the same not occurred with traffic congestion? The answer lies in the fact that traffic flow consisting of cars controlled by people is doomed to inefficiency due to our very human aspects of delayed response to traffic conditions. When we detect brake lights ahead, time is expended as we assess the situation and proceed to apply our own brakes, if needed. When traffic ahead accelerates, a similar lag time is incurred to sense that condition and follow suit. The aggregate effect of these factors creates “accordion effects” or “shock waves” in dense traffic flows, as well as the relatively slow clearance time for intersections controlled by traffic signals. Traffic congestion is also caused by the sheer volume of vehicles attempting to use roadways, exceeding physical capacity limitations.

Around 1990, road transportation professionals recognized the emergence of affordable information, computing, and sensor technologies and began to apply them to traffic and road management. Thus was born the intelligent transportation system (ITS). Starting in the late 1990s, ITS systems were developed and deployed, providing transportation authorities with vastly increased information on real-time road network conditions, which they in turn provided to the public through Web sites and other means. In developed countries, travelers today have access to significant amounts of information about travel conditions, whether they are driving their own vehicle or riding on public transit systems. Further, ITSs have greatly enhanced the ability of authorities to respond to crashes or other incidents on the road, so that delays are minimized. Since one minute of lane blockage typically translates to 10 minutes of congestion, the benefits of such efficiencies are clear.

Regarding safety, both government researchers and engineers within automotive industry laboratories have been developing technology to help drivers avoid crashes. In Japan, a significant amount of work actually occurred in the 1980s, with initial systems introduced in that market, but the costs and capabilities of the technology limited the extent of these systems. Research and development (R&D) accelerated in the early 1990s via government-industry partnerships—in Europe, the Prometheus program was initiated, producing initial prototypes for many types of functions, including lane monitoring, electronic copilots, and autonomous vehicles [5,6]; the Japanese initiated the advanced safety vehicle program to develop advanced crash avoidance technologies; and in the United States, both crash avoidance research and the National Automated Highway System Consortium (NAHSC) programs were initiated [7]. Beginning in the latter half of that decade, systems introduced to the market in all three regions were, to some degree, the fruits of these research programs. Called advanced driver assistance systems (ADAS), product

introductions continue and R&D is in full swing for even more advanced systems. The net result is that we are beginning to see systems within cars, buses, and trucks that are capable of sensing dangerous situations and responding appropriately in circumstances where the driver is not. Intelligent vehicles are a reality, and they will steadily become a welcome part of the central fabric of society in coming years.

Further, the advent of cooperative systems—in which vehicles exchange information with one another and roadside systems—will open the way toward smoother and more efficient traffic flows, as the human inefficiencies noted above are gradually replaced by machine sensing and control.

On the scale of several decades, in fact, most automotive technology professionals agree that this technology will progress to the point that self-driving vehicles, robust in handling a wide variety of traffic conditions, will be available. Various forms of automated vehicles have been successfully prototyped and demonstrated in Europe, Japan, and the United States, and fully automated bus transit systems are now in operation within special facilities. Automated cars may not be coming soon to a showroom near you, but they are on the far horizon.

At the same time, however, it must be acknowledged that computers are not the ultimate saviors of humanity in any domain, and certainly not on the roadway. The significance of technology's role lies in its ability to complement human intelligence. Essentially, driving a vehicle consists of four basic functions: monitoring, perception, judgment, and action. Electronic sensing and computing is superb in monitoring, as 360-degree coverage is possible and attention never wavers. Perceiving the important dynamics within a traffic situation and judging the best response is classically a human strength, although machine perception is steadily making strides—in fact, this is a core pacing factor in intelligent vehicle (IV) product introductions. Last, for actuation of vehicle functions such as braking, computer-controlled subsystems can respond in a small fraction of the time a human would require. So, the ideal IV system appropriately allocates functionality between the driver and the supporting technology.

1.2 Definition of Intelligent Vehicles

Because the term “Intelligent Vehicles” is somewhat generic, a definition is in order for the purposes of this book. Simply put, IV systems sense the driving environment and provide information or vehicle control to assist the driver in optimal vehicle operation. IV systems operate at the tactical level of driving (throttle, brakes, steering) as contrasted with strategic decisions such as route choice, which might be supported by an on-board navigation system.

IV systems are seen as a next generation beyond current active safety systems, which provide relatively basic control assist but do not sense the environment or assess risk. Antilock braking systems, traction control, and electronic stability control are examples of such systems.

1.3 Overview of Chapters

Intelligent Vehicle Technology and Trends is intended to provide an overview of developments in the IV domain for engineers, researchers, government officials, and

others interested in this technology. Readers will gain a broad perspective as to the overall set of activities and research goals; the key actors worldwide; the functionality of IV systems and their underlying technology; the market introductions and deployment prospects; the user, customer, and societal issues; and the author's prognosis for the future rollout of products and integrated vehicle-highway systems.

The book opens with “big picture” considerations, introduces the major players in the IV domain, and then addresses key functional areas in-depth. The latter portion of the book is devoted to addressing some nontechnical issues, and a view toward the future is offered in conclusion.

The chapters are summarized as follows:

- Chapter 2 reviews government safety goals and takes a look at long-term visions that have been developed by researchers and government agencies in the Asia-Pacific region, Europe, and the United States.
- Chapter 3 reviews the key IV application areas of convenience, safety, productivity, and traffic assistance.
- Chapter 4 examines major government IV R&D programs and strategies. Government-sponsored programs in the Asia-Pacific region, Europe (pan-European and national), and the United States (federal and state) are discussed.
- Chapter 5 examines the stance of the vehicle industry with respect to IV systems. The philosophies and key priorities of both vehicle manufacturers and major suppliers are discussed to provide both a “reality check” and a context for following chapters.
- In the first of five chapters examining functional areas, Chapter 6 focuses on lateral/side sensing and control systems. These are systems that assist drivers in steering and monitoring the areas to the side of the vehicle. Examples are lane departure warning systems, “blind spot” monitoring, and roll stability. Each system type is described, followed by a discussion of market aspects and reviews of ongoing R&D. This format is followed for each of the functional area chapters.
- Chapter 7 focuses on longitudinal sensing and control systems. These systems assist drivers in longitudinal control and speed-keeping. Examples are adaptive cruise control, forward collision warning, and pedestrian detection and avoidance.
- Chapter 8 addresses integrated systems, the next logical step beyond stand-alone lateral or longitudinal systems. These are more comprehensive systems that assist drivers in both longitudinal and lateral aspects. Examples are omnidirectional sensing and lane change assistance.
- Chapter 9 extends the system concept to cooperative vehicle-highway systems (CVHS). The ability of vehicles and the roadway to work together as a system offers opportunities for enhanced performance. CVHS can make safety systems more effective and will act as a key enabler for traffic-enhancing IV systems. Major CVHS application areas are described, including intersection collision countermeasures, intelligent speed adaptation, and traffic performance enhancement. As CVHS relies on vehicles communicating with the

roadside and each other, relevant communications issues are discussed. The chapter also speaks to business case issues and deployment initiatives, including the major new initiative in the United States called Vehicle Infrastructure Integration.

- Fully automated road vehicles, a dream long-held by futurists, are the focus of Chapter 10. Many average drivers as well have wondered how long it would take for technology to advance sufficiently such that their car takes over driving on those long, boring stretches of road. This chapter describes the major research areas in autonomous driving and particular areas of focus. Examples include cybercars, low-speed automation, truck automation, and military unmanned urban vehicles. Potential deployment paths are reviewed as well.
- Chapter 11 speaks to floating car data (FCD) systems, a relatively near-term IV application that can extend the “information horizon” for both drivers and automatic crash avoidance systems. FCD systems use wireless communications techniques to collect data relevant to traffic, weather, and safety from individual vehicles (probes) and then assimilates that data and distributes it to travelers, other vehicles, and road authorities. Relevant projects and their status are discussed.
- A review of IV systems would be incomplete without examining the interaction of drivers with IV technology. Chapter 12 addresses IVs as human-centered systems. This is an intentionally brief overview of the human factors that arise with IV systems and how they are being addressed. The full range of the human aspects of IV systems involves in-depth expertise and complex questions that are beyond the scope of this book. Instead, the intent is simply to introduce the reader to the issues.
- Chapter 13 moves beyond the technology to examine challenges in product introduction. IV system design must be responsive to customer and societal issues to be successful in a market-driven arena. This chapter deals with nontechnical issues that affect market penetration, such as public perception, regulatory, and legal issues. Development of a code of practice for design and testing of IV systems, as well as relevant standards activity, are discussed as well.
- Chapter 14 looks forward to identify enabling technologies important to future progress. The author also takes the bold (and possibly foolhardy!) step of speaking to future trends and estimating product introduction timelines.
- For those still with us after 14 chapters of “IV-dom,” Chapter 15 offers a brief synthesis of the overall IV domain and some observations on the part of the author.

Intelligent Vehicle Technology and Trends endeavors to provide a thorough treatment of the topic, yet it is not intended to be completely comprehensive. The book is intended to provide perspective and, for readers new to the field, to provide a “jumping-off point” for deeper investigations. Projects described are illustrative, and, regrettably, many worthy projects could not be included due to space limitations. Further, it is not the intent of this book to offer significant depth as to the

sensor technologies, subsystem designs, and processing algorithms—for this level of detail, the reader is referred to the voluminous technical literature available from a variety of sources.

The obvious must be stated, as well. Significant private R&D to develop future products is under way within automotive industry laboratories; while general information is available on some activities, large portions are kept confidential for competitive purposes. Nevertheless, I believe this book presents a reasonably accurate picture of industry activity.

Many references refer to articles on <http://www.IVsource.net>, which is an informational Web site I publish. Videos of many of the systems and technologies in operation are available for download at the site, as well as additional supporting information.

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Goals and Visions for the Future

As noted in Chapter 1, the early portion of *Intelligent Vehicle Technology and Trends* is intended to provide a “big picture” view before going deeply into the functional areas. Therefore, this chapter provides an overview of safety goals and long-term visions for the road transportation network in which IVs are expected to play a pivotal role. This information serves to frame the problem space and provide a sense as to how the solution space may evolve.

With over one million people killed worldwide in traffic accidents each year, road safety is an ever-present concern on the part of governments and international organizations. Curiously, though, the level of concern (and funding) has historically been modest at best. I offer two reasons for this conundrum. First, although it is politically correct to emphasize road safety, in practical terms it tends to get overshadowed by more politically volatile issues. Second, the public seems to accept, at least to some degree, that road fatalities are a necessary price to pay for a highly mobile society. In fact, as a review of the newspapers will attest, public outcry focuses more on traffic congestion than road safety, particularly at the local level.

Nevertheless, even modest attention at a national level translates into major programs. In the last two decades in particular, substantial road safety and traffic programs have made for better road design and vastly improved crashworthiness and occupant protection in automobiles.

Even more promising is the recent trend to bring a fresh emphasis on preventing road fatalities, and crashes in general, which has taken hold in the industrialized nations. High-level working groups are active in Europe, significant government research investments are occurring worldwide, and bold goals have been pronounced by all. As one indication of this heightened attention, the World Health Organization (WHO) devoted the 2004 World Health Day specifically to road safety—the first time in WHO history.

IVs play a key role in achieving these goals. As Dr. Jeffrey Runge, National Highway Traffic Safety Administrator within the U.S. Department of Transportation (DOT) said in 2003, “crash avoidance is ‘fertile ground’ for reaching these goals, as the ‘easy gains’ have already been made in traditional safety areas such as seat belt usage and prevention of impaired driving during the last 20 years.” [1]

Beyond safety, the need to improve mobility remains a vital societal need. Yet, many pronouncements lament that road congestion is an unavoidable fact of life. This may be true to some degree, but there is reason for hope. The promise of IVs is to provide a degree of driving efficiency so that roads can better handle the travel demand placed upon them. IVs, working in conjunction with traveler information

systems and market-based road pricing approaches, can potentially form a vastly improved milieu.

Although not the topic of this book, another primary technology focus for advanced vehicles is in the area of fuel consumption and emissions. Driving is seen as bad for society when fossil fuel is burned and emissions are produced, yet road travel is essential to the quality of life for millions of people and a fundamental part of their economic life.

Fundamentally, it seems that society wants the option to drive in an unimpeded manner without destroying the Earth's future. Most would say this combination is not possible (i.e., one must choose between mobility or the environment). However, a daring alternative is the concept of green mobility—high-quality lifestyles based on ease of movement and environmental sustainability. Fortunately, as fuel cell technology surges forward, the environmental aspect may indeed be solved over time. Moreover, as noted above, IVs can make a major contribution to mobility.

In this vein, the following sections provide a review of IV-oriented goals and visions. This information will provide a context for the reader as to the increased importance placed on these topics by governments and international organizations. A variety of views toward safer, more connected, and more efficient travel is offered.

2.1 Government Safety Goals

A sampling of road safety goals worldwide follows. Not all developed countries are listed, as defining quantitative goals is not a universal strategy. Further, some countries are more active in publicizing their goals than others. As can be seen from this brief review (summarized in Table 2.1), some are much more specific than others, and different measures are used. The degree to which specific and measurable goals are published tracks more or less directly with investments in IV safety systems R&D, as will be seen in Chapter 4.

2.1.1 Asia-Pacific Region

Australia A national road safety strategy for 2001–2010 and corresponding action plans were adopted by the Australian Transport Council in 2000 [2]. The council comprises federal, state, and territory ministers with transport responsibility.

The target of the strategy is to reduce the annual number of road fatalities per 100,000 population by 40%, from 9.3 in 1999 to no more than 5.6 in 2010. The council estimates that achieving this target will save an estimated 3,500 lives by 2010 and reduce the annual road toll in 2010 by approximately 700.

Active safety systems are seen as one of several components in achieving these reductions, with their role expected to be modest in the current period and becoming more significant after 2010.

Japan In 2003, the Japanese prime minister announced an objective to cut the number of traffic accident fatalities in half within 10 years, enabling Japan to become the safest nation in the world in terms of road traffic [3]. A focused approach to addressing elderly drivers was mentioned as a key component of

Table 2.1 Road Safety Goals—National and Regional

<i>Road Safety Goals—National and Regional</i>					
	2007–2008	2010	2013	2015	Long-term
<i>Asia-Pacific</i>					
Australia		40% reduction in fatalities			
Japan		15% reduction in crashes	50% reduction in fatalities		50% reduction in all crashes
<i>Europe</i>					
European Commission		50% reduction in fatalities			
ERTICO		20% of new cars equipped with ADAS			
Netherlands		10% reduction in fatalities			40% reduction in fatalities by 2020
Sweden	50% reduction in fatalities compared to 1996 (2007)				No road fatalities
United Kingdom		40% reduction in fatalities and serious injuries (for nonmotorways) 10% reduction in minor injuries (all roads) 50% reduction in fatalities/serious injuries of children (all roads)			
<i>North America</i>					
United States	Reduce crashes per 100M vehicle miles from the current 1.51 to 1.0 (2008)			Deployment of intersection collision avoidance systems (ICA) at 15% of the most hazardous signalized intersections nationally	
	Reduce large-truck related fatality rate 1.65 per million truck miles (2008)			In-vehicle ICA support in 50% of the vehicle fleet	

reaching this goal, given the aging society in Japan. The Japanese government further set the goal of implementing advanced cruise-assist highway systems (AHSs) to address 75% of crashes. From AHS introduction, the goal is to reduce the number of crashes by 15% by 2010 in high crash locations. The long-term aim is to reduce all traffic crashes by half.

To this end, the Japanese Ministry of Land, Infrastructure and Transport (MLIT) is overseeing the building of a strategic monitoring system and implementation of measurable goals to determine the step-by-step progress toward the national goals. Crash rates, as well as time lost and financial impacts resulting from congestion, are being monitored. A major initiative called Smartway is under way for research and implementation of safety and road efficiency measures, including the work of the AHS Research Association (AHSRA) and the advanced safety vehicle (ASV) program. See Chapters 4 and 9 for more information on these activities.

2.1.2 Europe

Pan-European As noted in the introduction, a significant new level of attention to road safety has emerged in recent years. This is particularly true in Europe. Within the context of the European Road Safety Action Program (RSAP), the European Commission (EC) has set a goal of reducing road fatalities by 50% by 2010 [4].

Further, ERTICO, the ITS industry association for Europe, echoes the EC goals and has set a goal of 20% of new cars equipped with some form of driver assistance system by 2010 [5].

Netherlands From the current level of just over 1,000 deaths annually, the Dutch government aims to reduce traffic fatalities by 10% (to 900) by 2010. The goal is to reach a level of 640 or fewer fatalities by 2020.

Sweden Sweden instituted the Vision Zero initiative regarding traffic deaths in 1995; this program is further described in Section 2.2. Quantatively, the nation's goal is to reduce fatalities by 50%, compared to 1996, by 2007 [6].

United Kingdom Based on average crash figures for the period 1994–1998, the U.K. Department for Transport has set safety targets for 2010 as follows [7]:

- A 40% reduction in the number killed and seriously injured (for nonmotorways);
- A 10% reduction in slight casualties (both motorways and nonmotorways);
- A 50% reduction in the number of children killed or seriously injured (all roads).

2.1.3 North America

United States [8] The overall U.S. DOT goal is to reduce crashes per 100 million vehicle miles from the current 1.51 to 1.0 by 2008. Within the U.S. DOT, the Federal Highway Administration has set a target of 2,292 fewer road departure crashes, 860 fewer fatalities at intersections, and 465 fewer pedestrian deaths by this date. Also, the Federal Motor Carrier Safety Administration aims to reduce the large truck-related fatality rate from 2.8 per million truck miles (1996) to 1.65 by 2008.

The U.S. DOT has also set goals with regard to the deployment of cooperative intersection collision avoidance systems (CICAS) [10]. (See Chapter 9 for a full description of ICA approaches.) The goals call for the deployment of ICA systems at 15% of the most hazardous signalized intersections nationally, with in-vehicle support in 50% of the vehicle fleet by 2015.

Government data from 2003 provides a context for these goals. A total of 43,220 fatalities occurred as Americans drove 2.88 billion miles. Both the death rate and the mileage were up by an almost identical degree (just under 1%) from the previous year. This translates to an overall road fatality rate of 1.5 per 100 million miles. During this time, 217 million vehicles were operating on U.S. roads. It is useful to note that, of the fatalities, approximately 40% were alcohol-related and 43% occurred to unbelted occupants—situations where travelers increased personal risk significantly due to their own careless choices.

Due to vehicle crashworthiness and collision mitigation features such as airbags, fatality rates have tended to level off in recent years. A more complete picture is gained by looking at all crashes, rather than just fatalities. In 2003, over 6 million nonfatality police-reported crashes occurred in the United States. This is the domain in which IV safety systems can have their greatest impact. Similar data for 2001 is shown in Figure 2.1.

2.2 Visions for the Future

How do we achieve these safety goals? What are broader visions for the entire road transport network? The following sections describe some visions being promoted by research institutes and governments worldwide, beginning with safety-focused visions and then expanding into more holistic visions.

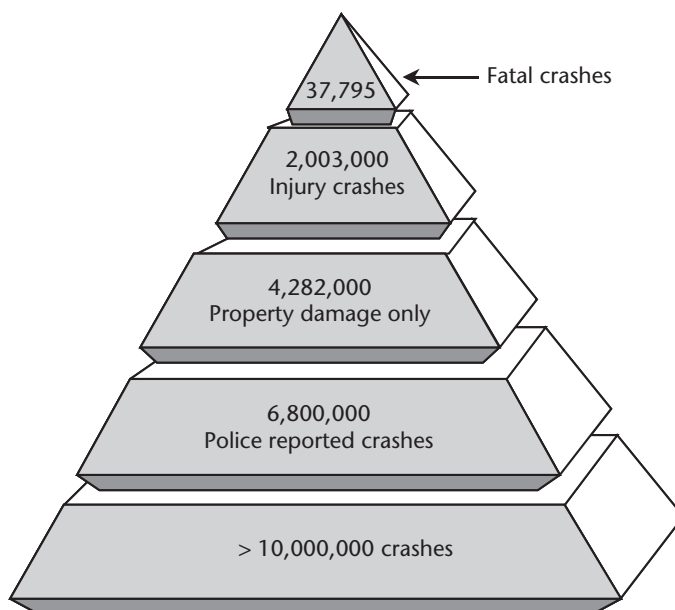


Figure 2.1 U.S. crash data for 2001. (Source: U.S. DOT.)

2.2.1 Europe's eSafety Vision [4]

The European RSAP, developed by the EC, lays out the over-arching European strategy to road safety, including road design and operations, vehicle design (crashworthiness), emergency response, and active safety (eSafety). The concept of active safety is firmly established within the RSAP as an important program component. For example, some potential government policy and program measures discussed in the RSAP are the following:

- Regulatory measures for active safety systems;
- Development of a plan to implement vehicle-vehicle and vehicle-roadside communications systems;
- Fiscal incentives for purchasers of active safety systems.

“eSafety,” a key component of the RSAP, is a government-industry initiative for improving road safety by using information and communications technologies. The overall objective is to join forces to create a European strategy to accelerate the research, development, deployment, and use of “intelligent integrated road safety systems” to achieve the 2010 goal noted above. Systems envisioned are collision warning and mitigation, lane-keeping, vulnerable road user detection, driver condition monitoring, and improved vision. Other technologies will provide for automatic emergency calls, adaptive speed limitation, traffic management, and parking aids.

As an indication of the significance of the eSafety initiative, eSafety strategy is led by a high-level group consisting of top executives in the automotive industry and government organizations. Implementation is then the responsibility of an eSafety working group, which is composed of key professionals in these domains.

eSafety focuses on both stand-alone IV safety systems and cooperative systems that will enable essential safety information to be exchanged between vehicles and the infrastructure. This broader access to situational information will allow more accurate assessment of risk and a more robust response.

Recommendations from the initial eSafety strategy group included the development of an implementation road map that balances business, societal, and user issues; development of digital maps capable of supporting safety systems; incentives to stimulate and support road users and fleet owners to buy vehicles with intelligent safety functions; and increased levels of international cooperation in areas such as standardization, development of test methodologies, legal issues, and benefits assessment.

Participants describe the eSafety vision as follows:

“The driver is sitting behind the steering wheel and is driving at 70 km/h. He [or she] steers the vehicle into a corner. To do so he [or she] uses information acquired by looking at the total road picture, the surroundings and his [or her] in-car instruments. The in-car applications continuously receive information from cameras (visible light and infrared), in-vehicle radar systems, digital maps, GNSS satellites for location information, vehicle-infrastructure communication, information from other vehicles and the like. The information collected by these sensors is verified by the in-vehicle control unit, integrated, analyzed and processed, and presented to the driver.

The driver is aware that his [or her] car is equipped with a sophisticated safety system. Depending on the degree and timing of the danger the system would inform him [or her], warn him [or her], actively assist him [or her] or ultimately actively intervene to avoid the danger. If the intervention cannot avoid the crash completely, intelligent passive safety applications will be deployed in an optimal way to protect the vehicle occupants and possibly other parties involved in the accident (vulnerable road users). The system will also automatically contact the emergency services indicating the severity and location of the accident.”

A significant set of R&D projects are now under way in Europe under the eSafety banner, as described in Chapter 4.

2.2.2 Sweden’s Vision Zero [11]

Sweden has led the way in safety by introducing its Vision Zero concept—a future in which no one will be killed or seriously injured in road traffic. Vision Zero has strong backing from the Swedish parliament and forms the foundation for road traffic safety initiatives in Sweden.

A key principle is to ensure that roads and vehicles are adapted to the limitations of human drivers, including automatic means of limiting vehicle speeds as appropriate to the situation. While full implementation will take many years, since the introduction of Vision Zero in 1995 and the beginning of road safety improvements, deaths and serious injuries on Swedish roads have not increased despite an increase in traffic.

Vision Zero comprises the following eleven priority areas:

- A focus on the most dangerous roads;
- Safer traffic in built-up areas;
- An emphasis on the responsibility of the road user;
- Safer bicycle traffic;
- Quality assurance of transport (shippers and freight carriers);
- Winter tire requirements;
- Better use of new Swedish technology;
- The responsibilities of designers of the road transport system;
- Societal handling of traffic crime;
- The role of voluntary organizations;
- Alternative methods for financing new roads.

From a vehicle perspective, the approach encompasses greater cooperation between the automotive industry and road designers, as well as safer vehicle design in terms of crashworthiness and occupant protection. The continued development of IV safety systems by domestic car manufacturers Saab and Volvo is also supported.

2.2.3 ITS America’s Zero Fatalities Vision [12]

The Intelligent Transportation Society of America (ITS America) was established in 1991 to coordinate the development and deployment of ITS in the United States. A

wide variety of organizations from the private and public sectors are currently members. ITS America's mission is to improve transportation by promoting research, deployment, and operation of ITSs through leadership and partnerships with public, private, educational, and consumer stakeholders.

In 2003, ITS America committed to a strategic goal of "zero fatalities." ITS America sees the zero fatalities vision as the next critical step in the evolution and sophistication of our transportation system. The organization notes that it is important to begin looking at mobility and safety as a unified goal, as Americans both want to travel and to feel safe when traveling. ITS America is working with key organizations, agencies, and legislators to energize this vision.

2.2.4 ITS Evolution in Japan

The Japanese ITS program is centered in the National Institute for Land and Infrastructure Management (NILIM) within the Road Bureau of MLIT. Drawing from [13, 14], the NILIM vision is described here.

Within the overall ITS program, two platforms in Japan, now in advanced development and deployment, are promising for future deployment of advanced cooperative safety systems:

- In-car navigation systems incorporating the vehicle information and communications system (VICS);
- Electronic toll collection (ETC) based on dedicated short-range communications (DSRC).

Today's Japanese navigation systems combine digital road maps for route guidance, safety information, and tourist and local information with real-time information. The VICS real-time information system, which is deployed nationwide, provides extensive data to drivers regarding congestion ahead, road surface conditions, crashes, road obstacles, roadwork, restrictions, and parking lot vacancies.

Over 2 million car navigation with VICs were sold in 2002, representing 54% of all new passenger vehicles sold. This is expected to reach close to 100% by 2010. Therefore, these systems are well on their way to becoming standard equipment for vehicles in Japan. Through interacting with onboard navigation systems, drivers are becoming accustomed to interacting with support systems on their vehicles.

Nationwide ETC using 5.8-GHz active DSRC was launched in 2001. (DSRC is further described in Chapter 9). A total of 1.8 million units have been installed since the launch, with 10 million installed units expected by 2007. Prices have dropped by approximately a third since project inception to less than \$100.

Further evolution and integration is occurring as an increasing number of vehicles become equipped with these two platforms. Many tests and deployments are ongoing, in areas such as parking lot access, data transfer, electronic payment, gas purchase, and Internet access. The goal is to realize ITS services with a common, multiapplication onboard unit in vehicles. Next generation digital road maps (DRMs) and extensive information infrastructure will enable advanced message services, including safety messages. Proving tests at selected sites in Japan have been under way since 2002.

A parallel progression is the ongoing rollout of IV systems sold on cars in Japan, with functions such as adaptive cruise control, lane keeping, and crash mitigation using active braking.

Thus, NILIM envisions road vehicles becoming steadily smarter and advanced message services proliferating, leading to “cruise-assist services,” which are defined as cooperative vehicle-highway systems for safety and traffic efficiency. Current planning by MLIT calls for the deployment of roadside transponders in 2006. Manufacturing and availability of onboard units would also begin in 2006, with full deployment in vehicles by 2008. Figure 2.2 sums up the following progression.

A comprehensive picture of the services to be provided is shown in Figure 2.3. Road-vehicle communications will be key to providing critical safety information to vehicles, as well as private-sector information services. Road management is enhanced by data coming from vehicles. These services and enabling technologies are expected to complement one another such that a successful business case can be made for each.

2.2.5 The Netherlands Organization for Scientific Research (TNO) [15]

TNO is a central figure in developing practical short- and long-term implementations of cooperative vehicle-highway systems. TNO experts see separate road and vehicle developments gradually integrating, moving first to a coordination phase and then to full road-vehicle interaction.

This progression is shown in Figures 2.4–2.6. In each figure, the vertical axis shows several “waves” of activity: “initiation” referring to pilot testing and initial deployment phases, “popularization” referring to extending the deployment widely throughout the road network or vehicle fleet, “management” referring to a mature and comprehensive implementation of the technology, and “integration and coordination” in which vehicle and road systems can begin to link with one another.

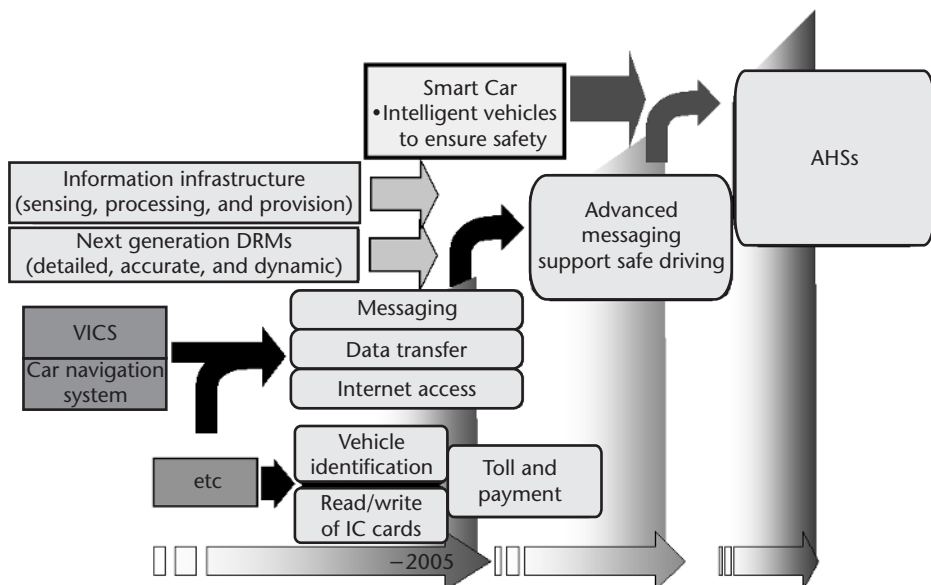


Figure 2.2 Japanese Smartway evolution. (Source: NILIM.)

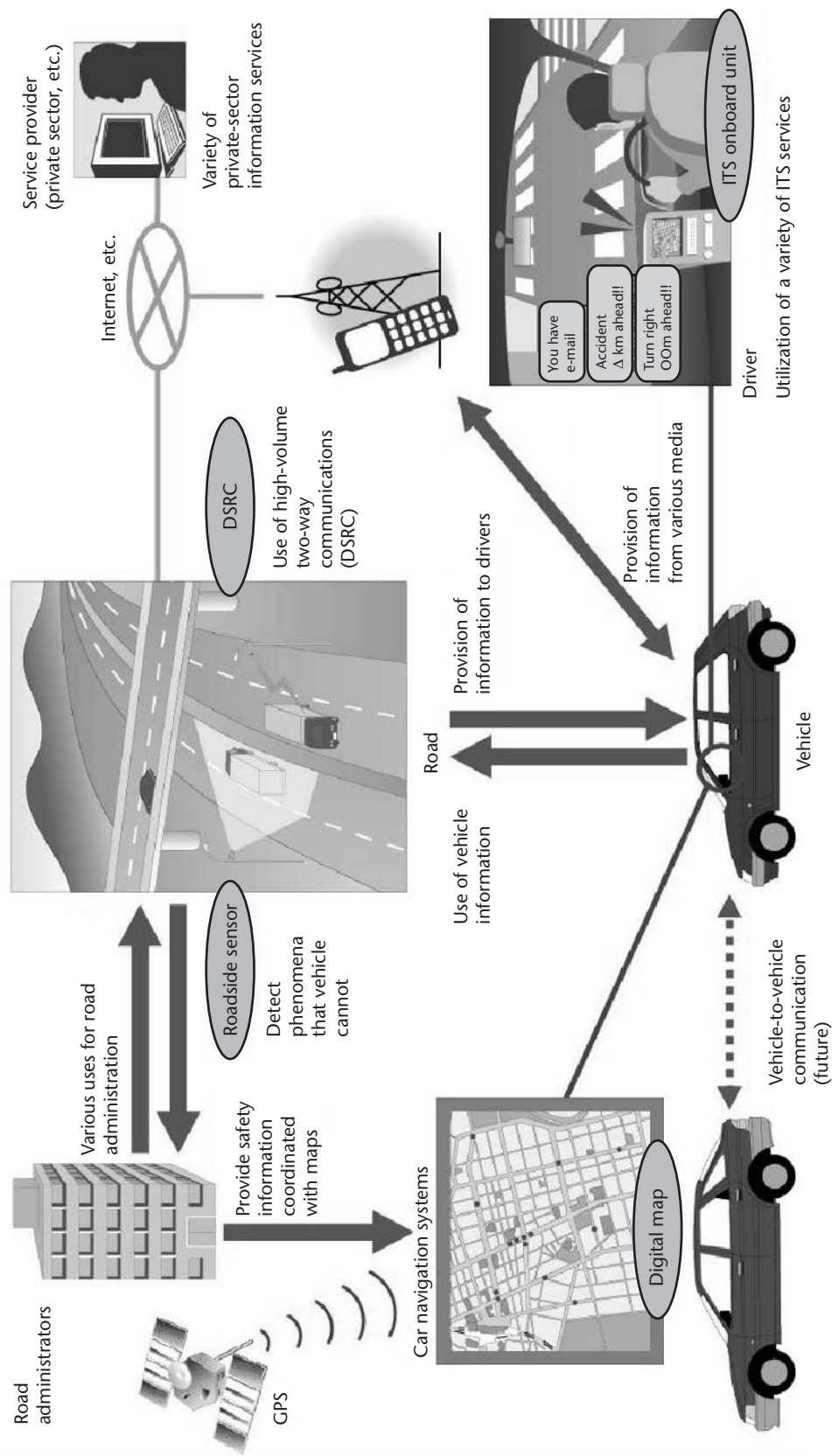


Figure 2.3 Japan's vision for Smartway services. (Source: NILIM.)

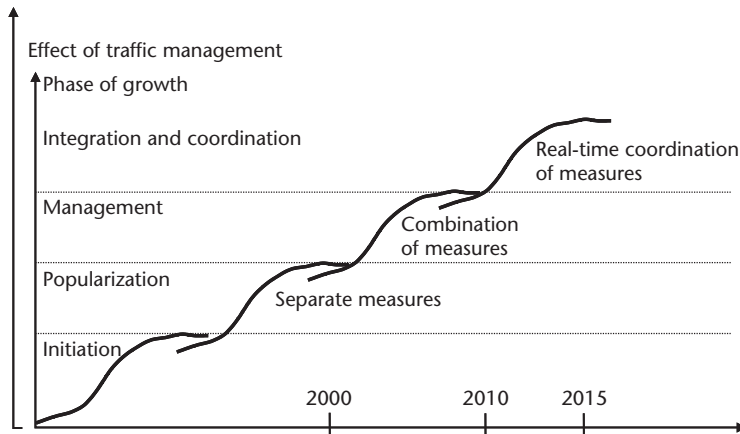


Figure 2.4 Evolution of roadside traffic management. (Source: TNO.)

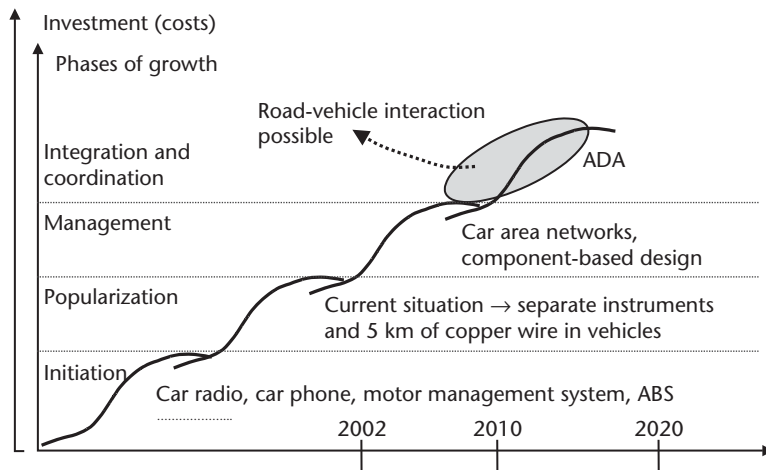


Figure 2.5 Evolution of the IV. (Source: TNO.)

In Figure 2.4, the evolution of roadside traffic management is depicted beginning with the many intelligent transportation measures already implemented, such as traffic responsive signal timing, coordinated incident management, and electronic message signs. These measures then combine as popularisation progresses, both functionally as well as geographically, to create an intelligent network of highway systems in the 2010 timeframe. At that point, extensive real-time coordination of roadside systems can be realized.

With regard to vehicle systems, the last 10 years or so have seen the initiation and popularization of various electronic systems in the vehicle that are basically stand-alone, as shown in Figure 2.5. The current situation is now evolving from separate instruments and individual wiring to extensive information networks, a process that TNO estimates will mature around 2010. Advanced driver assistance systems are seen as coming into broad usage from 2010 through 2020, creating the opportunity for intelligent road-vehicle interaction.

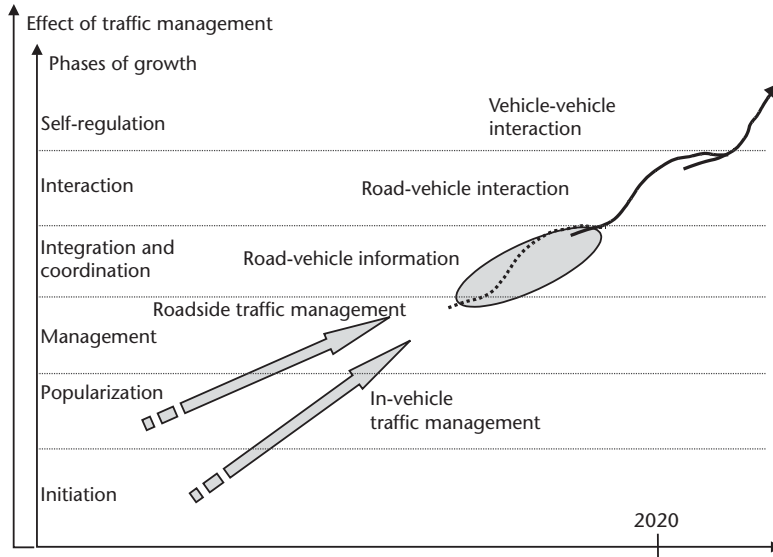


Figure 2.6 Evolution of a cooperative intelligent road-vehicle system. (Source: TNO.)

Thus, in the final chart of the series, Figure 2.6, the cooperative intelligent road-vehicle system emerges as roadside traffic management and in-vehicle systems mature. Early stages focus on the sharing of information, such as traffic or road conditions ahead, moving onward to real-time road-vehicle interactions. For example, a collision warning system would automatically adjust the timing of driver warnings based on information about slippery road conditions ahead, so that the driver would be alerted sooner if an obstacle were to be detected. Road-vehicle interaction of this type would culminate around 2020, at which time vehicle-vehicle interactions would come into play, such as cooperative adaptive cruise control.

2.2.6 France [16]

A more detailed vision of an intelligent road-vehicle future has been developed by French researchers within their ARCOS program (described further in Chapters 4 and 9). They have defined the concept of “target functions”—driver assistance functions that could be deployed in incremental steps with supporting research. The three levels of target functions that have been defined are described below.

Key discriminators between the targets are different levels of technical challenge and development maturity. Key parameters are information capture capabilities (e.g., sensing) and an extension of spatial usability (i.e., availability on all or part of the road network).

Target 1 (Figure 2.7) is basically a combination of autonomous sensing functions and basic vehicle-vehicle communications. Here, the vehicle has knowledge of braking capacity, usable longitudinal friction, visibility distance, vehicles ahead in the same lane (using forward sensing), and downstream hazards (using simple data broadcast techniques from vehicles ahead). Knowledge of distances and closing rates to both the front and rear, visibility distance, driver reaction time, local longitudinal road friction, and vehicle maximum braking capability are combined to create a “risk function.” Driver warnings or control interventions are based on the risk function.

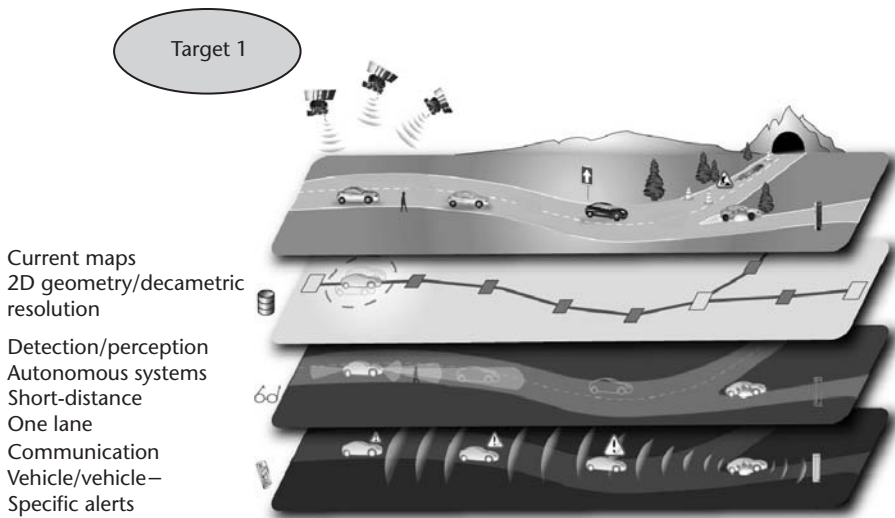


Figure 2.7 French ARCOS target 1. (Source: LIVIC.)

Target 2 (Figure 2.8) increases the sensing perimeter and introduces vehicle-highway cooperation. Here, digital maps are at the submetric level, vehicles are communicating with each other and the roadway, and autonomous sensing capabilities are expanded to create a situational awareness of vehicle activity in both the current lane and adjacent lanes (using both forward and side sensors). A cooperative infrastructure informs the vehicle about relevant infrastructure elements (e.g., guardrails and road edges) and downstream road traction conditions via vehicle-highway communications. Knowledge of road-tire friction is also enhanced by vehicle-based traction sensors that provide both lateral and longitudinal friction. In this case, then, the risk function is expanded to include adjacent lane traffic,

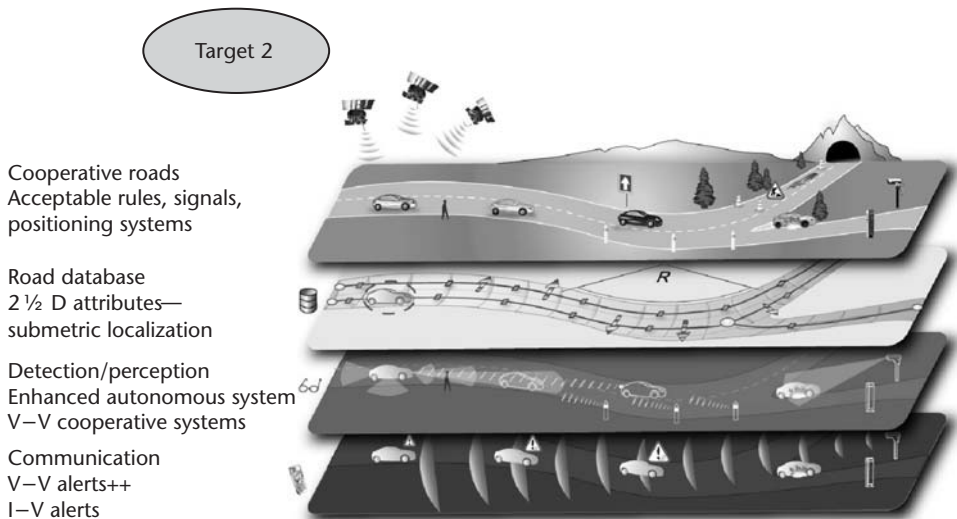


Figure 2.8 French ARCOS target 2. (Source: LIVIC.)

two-dimensional road-tire friction, upstream traction conditions, and geometric characteristics of the road.

Target 3 (Figure 2.9) focuses on spatial extension of cooperative road elements (i.e., to more roads and types of roads), even more accurate digital maps (if needed), multisensor fusion, extended vehicle-infrastructure communications, and extended vehicle-vehicle communications (exchanging information such as vehicle operating characteristics and maneuver intentions). The perception ability extends quite far downstream due to the extensive communications network. The risk function then expands to include both a richer set of data for local conditions and more extensive downstream information on traffic conditions and the intentions of other vehicles.

As an example, the three target levels can be considered in terms of a road departure scenario on a sharply curving road. In target 1, the vehicle has only forward sensing to rely upon for both forward obstacles and the road edge and no more than coarse information about the upcoming curve. Therefore, support is provided via instantaneous sensing to the degree possible as the road curves, with the look-ahead distance for both driver and sensors limited by the road geometry. In target 2, the vehicle has precise information as to the upcoming road geometry due to more detailed digital maps and knowledge of road friction in the curve via road-vehicle communication. In this case, the driver may be alerted to reduce speed if the road friction is low. In target 3, due to information sharing along the roadway, the vehicle is also aware of hazardous downstream events such as stopped traffic that may be within the curve—a situation beyond the view of onboard sensors.

Target 1 has immediate safety benefits due to the ability to detect obstacles using onboard sensing. Target 2 offers higher benefits due to expanded situational awareness and vehicle-infrastructure information exchange—as a result, high-quality

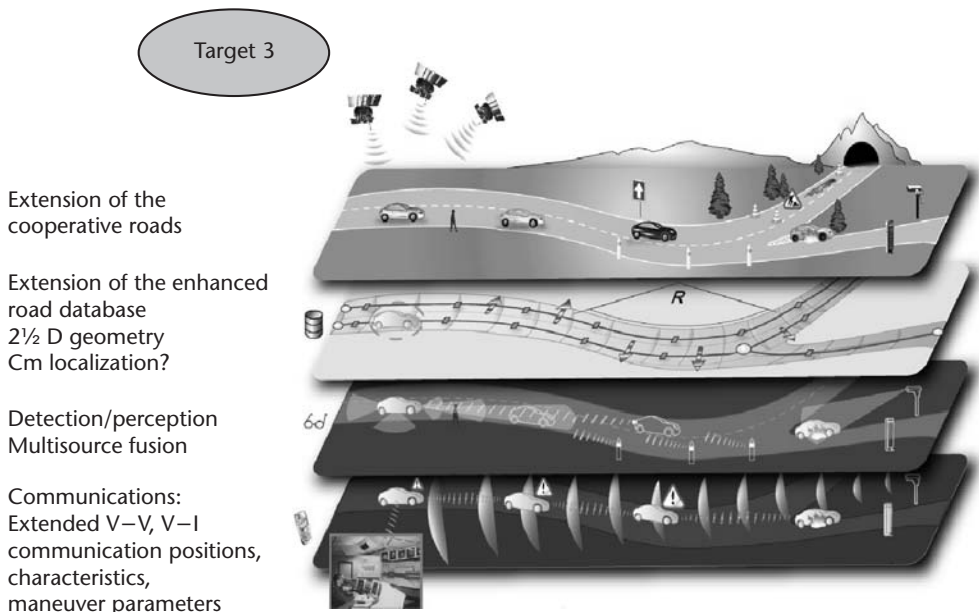


Figure 2.9 French ARCOS target 3. (Source: LIVIC.)

information exists as to the situation immediately around the vehicle as well as conditions downstream on the roadway. However, reaching target 2 functionality will take time, as roadside communications systems must be deployed and detailed map databases must be created. In the long term, target 3 shows the potential for significant gains in both safety and road capacity.

2.2.7 The Cybercar Approach [17]

While most future visions address the proliferation of IV systems in automobiles, an alternative public vehicle approach is being promoted by the Cybercars project (further described in Chapter 10). Cybercars are characterized as road vehicles (microcar to minibus to buses) that are capable of low-speed driving automation in urban areas where their operations are segregated from regular road traffic (for example, in pedestrian-only areas). They operate as highly flexible public personal transport vehicles in these settings.

The typical evolution to automated driving for private vehicles relies on individual cars becoming increasingly more intelligent over the years via onboard sensing and computing systems. Over the long term, automatic driving becomes possible. Their capabilities apply to virtually every road situation encountered by the vehicle.

The cybercar alternative more or less inverts this process. It begins with fully automatic vehicles, but their geographic extent is very limited because they operate in areas segregated from regular traffic. Initially, operations may be in pedestrian zones or private campus settings. However, as deployments proliferate, operations zones may be linked and spread across a city. Eventually, intercity tracks can be implemented as well as automated travel lanes. These road facilities may be accessed by properly equipped private vehicles, as well, to create a path to full automation for both public and private vehicles.

2.2.8 Vision 2030 [18]

A visioning and scenario planning process was begun in 1999 by the U.K. Highways Agency, using a 30-year timescale to encourage forward thinking. As starting points for the visioning process, three socioeconomic scenarios were created. The first was called “global economy” and referred to a market-driven approach. The second scenario, “sustainable lifestyle,” focused on community-based living and was described as “rural bliss in a hi-tech haven.” The third scenario, called “control and plan,” was based on greater regulation of movement, described as “responsible regulated living.” Each of these was described in terms of policy, economic, societal, technological, legal, and environmental issues.

Within Vision 2030, twelve transport visions were created:

- Green highway: Strongly environmentally driven;
- Zero accidents: Assumes strong political support and government action for safety, relying on extensive deployment of ADAS;
- The connected customer: Keys on high-quality information to enable management of congested networks and provide real-time and predictive journey information to travelers;

- **Freight foremost:** Focuses on a seamless integration of logistics services, as well as a strong shift from road to rail transport to decrease the numbers of trucks on the road;
- **Favoring public transport:** Calls for reliable, integrated public transport that can compete with the car; it would include widespread use of automatically guided buses and/or dedicated transit lanes, and possibly bus platooning;
- **Understanding the customer:** Focuses on responsive service and a high-quality travel experience, sophisticated matching of customer needs with road space, and proactive traffic management;
- **Easy interchange:** Optimizing the role of transport nodes as interchange points;
- **Institutional change:** Requires high levels of performance from the network operator; to achieve this end, innovation and flexibility are seen as more important than financial, contractual, and organizational arrangements;
- **Managing supply:** Focuses on dynamic allocation of road space, highly automated and real-time management of highway transportation, intercity travel by magnetic levitation trains, and real-time pricing of transportation facilities;
- **Managing demand:** Encourages the public to travel less, with road-pricing, slot allocation, journey booking, and strong enforcement to support these measures;
- **Cooperative driving on the automated highway system (AHS):** AHS techniques used to enable predictable and reliable journey times and segregation of freight and car traffic;
- **Land use planning:** Active planning and development control used to influence future patterns of supply and demand to achieve sustainable, integrated land use.

Based on expert assessments, three visions were considered promising and recommended for further evaluation and analysis:

- Green highway;
- Cooperative vehicle-highway systems (drawing upon elements of the cooperative driving on the AHS vision);
- Freight foremost.

Analysis of deployment paths to implement various services based on cooperative vehicle-highway systems is currently under way (see Chapter 9).

2.3 Summary

The “vision zero” concept regarding road fatalities is becoming increasingly popular and will likely take root globally. Given the way roadway deaths have been accepted as a fact of life for so many decades, it is both astounding and heartening that such a vision could be seen as viable. Can our society achieve this goal? An intense partnership between government and industry is essential, along the lines of the current eSafety

program. Consumers, as well, must do their part in choosing to purchase safety equipment on new cars. Of course, however, any crash is damaging and traumatic, whether fatal or not—the ideal is to avoid crashes altogether, via the combination of sensing, information flow, and vehicle intelligence with driver intelligence.

Onboard systems will do the lion's share of the work in detecting developing crash situations and taking the proper steps to avoid crashes. In cases where a hazard is not within the sensor's field of view, however, information must flow to the vehicle from either other vehicles or infrastructure sensors. Therefore, vision zero cannot be achieved without the progression to CVHS depicted by the NILIM, TNO, and ARCOS visions. CVHS will almost surely require synergy with private, nonsafety services to create the necessary business momentum for deployment to proceed.

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IV Application Areas

The range of applications for IV systems is quite broad and applies to all types of road vehicles—cars, heavy trucks, and transit buses. While there is some overlap between the functions, and the underlying technology can in some cases support many functions at once, IV applications can generally be classified into four categories: convenience, safety, productivity, and traffic assist.

The following sections describe applications in these areas along with basic information regarding products and supporting technologies to provide context. More in-depth information is provided in subsequent chapters.

IV applications can be implemented via autonomous or cooperative systems. Autonomous systems rely upon onboard sensors to provide raw data for a particular application, whereas cooperative systems augment onboard sensor data with information flowing to the vehicle from an outside source. Using wireless communications techniques, this data can be derived from infrastructure sensors or via information sharing with other vehicles. Data from other vehicles can be received either directly through vehicle-vehicle communications or through an innovative technique called floating car data (FCD) or “probe data.” The FCD concept (further discussed in Chapter 11) relies upon vehicles reporting basic information relevant to traffic, road, and weather conditions to a central data center, which is aggregated and processed to develop a highly accurate picture of conditions across the road network and then disseminated back to vehicles.

In the discussion below, the reader will gain an applications-level understanding of how both autonomous and cooperative techniques can be employed.

3.1 Convenience Systems

The term “convenience system” came into being in the late nineties when auto companies were ready to offer IV driver-assist systems to their customers but were not yet ready to take on the legal implications and performance requirements that would come with introducing a new product labeled as a “safety system.” Fundamentally, convenience systems are driver-support products that may assist the driver in vehicle control to reduce the stress of driving. In some cases these products are safety-relevant—and drivers commonly consider them to be safety systems—but they are not marketed as safety systems.

3.1.1 Parking Assist

Parking-assist systems help drivers in avoiding the minor “dings” that can come with parking maneuvers. This is particularly true in urban areas in Europe and Japan in which parking spaces are very tight.

The simplest form of parking-assist system is a rear-facing video camera, which offers a view of the area behind the vehicle but no sensing or driver warnings. The video image is displayed on the driver’s console screen, which otherwise acts as the navigation display when the vehicle is moving forward. Typically, the rearview image appears automatically on the screen when the vehicle is shifted into reverse gear. In this way, the driver can see small objects to the rear and assess distances to walls and obstacles.

Parking-assist sensor systems generally use ultrasonic sensing of the immediate area near the car, on the order of 1–2m. More advanced systems use radar to cover an extended range and provide the driver with more precise information as to the location of any obstacle. When combined with a rear-looking video display, calibrated scales can be overlaid on the screen to indicate to drivers the precise distance from an obstacle.

A fascinating form of advanced parking assist was recently introduced by Toyota, in which the complex steering maneuvers required for parallel parking are completely automated [1]. When the driver shifts into reverse gear, a rearview video image is displayed. Overlaid on this image is a rectangle that is sized to represent the host vehicle. The driver uses arrow keys to position this rectangle over the desired parking space within the image. After a “set” key is pressed, the driver is instructed to proceed by operating the accelerator and brakes, while the system takes care of steering to maneuver the vehicle precisely into the parking space.

3.1.2 Adaptive Cruise Control (ACC)

The primary convenience system currently available for highway driving is ACC. ACC allows a driver to set a desired speed as in normal cruise control; if a vehicle immediately ahead of the equipped vehicle is moving at a slower speed, then throttle and braking of the host vehicle is controlled to match the speed of the slower vehicle at a driver-selectable time headway, or gap. The desired speed is automatically reattained when the roadway ahead is unobstructed, either from the slower vehicle ahead leaving the lane or the driver of the host vehicle changing to a clear lane. These operating modes are illustrated in Figure 3.1. Systems currently on the market monitor the forward scene using either radar or lidar (laser radar); future systems may also use machine vision.

Current generation ACC systems operate only above a speed threshold on the order of 40 km/hr. The braking authority of the system is limited; if the host vehicle is closing very rapidly on a vehicle ahead and additional braking is needed to avoid a crash, the driver is alerted to intervene.

Users generally report that the system substantially reduces the tedium of braking and accelerating in typical highway traffic, in areas where conventional cruise control is all but unusable due to the density of the surrounding traffic.

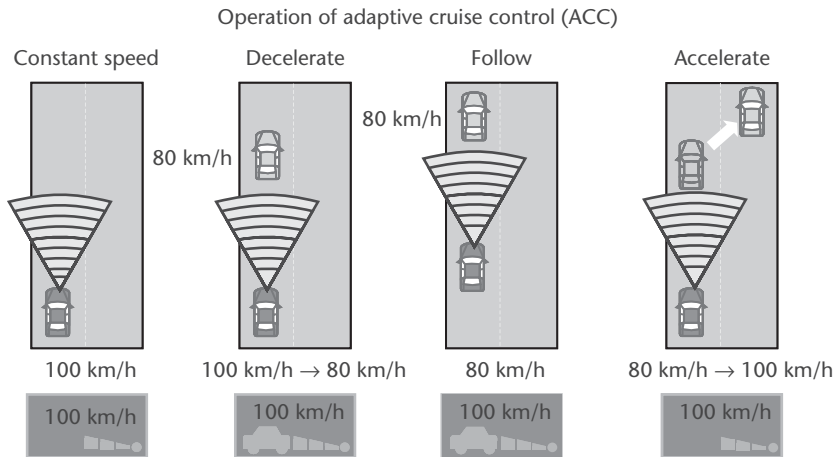


Figure 3.1 Operating modes for ACC. (Source: Nissan.)

3.1.3 Low-Speed ACC

Low-speed ACC is an evolution of ACC functionality, which operates in slow, congested traffic to follow the car immediately ahead. When traffic clears and speeds return to normal, conventional ACC would then be used. This type of product is sometimes called “stop-and-go ACC.” Early versions may only perform a “stop and wait” function, requiring that the driver initiate a resumption of forward movement when appropriate. This is because manufacturers are hesitant to offer a system that automatically starts from a stop in complex low-speed traffic environments, which may include pedestrians. Other low-speed ACC systems operate down to a very low speed (approximately 5 km/hr) and then require the driver to intervene if needed to both stop and restart vehicle motion. Low-speed ACC was introduced to the Japanese market in 2004.

3.1.4 Lane-Keeping Assistance (LKA)

LKA offers a “copilot” function to drivers in highway environments. Research has shown that the many minute steering adjustments that must be made by drivers on long trips are a significant source of fatigue. LKA uses machine vision technology to detect the lane in which the vehicle is traveling, and steering actuation to add torque to the steering wheel to assist the driver in these minute steering adjustments. The experience can be imagined as similar to driving in a trough, such that the curving vertical sides of the trough create a natural steering resistance to keep the vehicle in the center. As the developers are fond of saying, the experience is “like driving in a bathtub.”

Lane-keeping systems generally are set to operate only at the speeds and typical curvatures of major highways, such as the U.S. interstate highway system or major motorways in Europe and Japan. The system will disengage if sharp curves are encountered. Further, the driver must continue to provide steering inputs; otherwise the system will sound an alarm and turn off—this is to ensure that drivers are not tempted to use it as a “hands-off” system.

More advanced versions of LKA could conceivably allow for full automatic “hands-off” steering, but driver vigilance issues would have to first be worked out.

3.1.5 Automated Vehicle Control

While still quite far in the future, the ultimate in “driving convenience” for many would be the proverbial “car that drives itself.” While the joy of driving is unmatched on a winding mountain road on a sunny day, daily driving is an experience that typically fatigues, frustrates, and frazzles us as drivers. To have the alternative of handing control of the vehicle over to a trustworthy technology agent is quite attractive. Prototype vehicles of this type have been developed and demonstrated, and professionals knowledgeable in automotive technology generally agree that self-driving cars are inevitable some time within the next few decades.

An early form of automated vehicle control likely to be very popular is low-speed automation (LSA). This application simply combines full-function low-speed ACC with full hands-off lane keeping to completely take care of the driving task in congested traffic. Conceptually, the system would alert the driver to resume control of the vehicle when the traffic clears and speeds increase to normal. Various forms of LSA are currently in the R&D stage.

3.2 Safety Systems

As noted in Chapter 2, traffic fatalities range into the tens of thousands in developed countries and the numbers of crashes are in the millions. Given the massive societal costs, governments are highly motivated to promote active safety systems for crash avoidance.

Further, based on experience with airbag systems, it has been well established that “safety sells” in the automotive showroom, and therefore automotive manufacturers have a good business case for offering active safety systems on new cars.

Active safety system applications within the IV realm are many and varied. From the following list of collision countermeasures (also described in the following sections), it can be seen that virtually every aspect of vehicle crashes is represented:

- Assisting driver perception;
 - Adaptive headlights;
 - Night vision;
 - Animal warning;
 - Headway advisory;
- Crash prevention;
 - Forward collision warning/mitigation/avoidance;
 - Lane departure warning;
 - Lane/road departure avoidance;
 - Curve speed warning;
 - Side object warning (blind spot);
 - Lane change support;

- Rollover countermeasures;
- Intersection collision countermeasures;
- Rear impact countermeasures;
- Backup/parking assist;
- Pedestrian detection and warning;
- Degraded driving;
 - Driver impairment monitoring;
 - Road surface condition monitoring;
- Precrash;
 - Prearming airbags;
 - Occupant sensing (to inform airbag deployment);
 - Seatbelt pretensioning;
 - Precharging of brakes;
- External vehicle speed control.

3.2.1 Assisting Driver Perception

IV systems can enhance the driver's perception of the driving environment, leaving any interpretation or action to the driver's judgment. Adaptive headlights provide better illumination when the vehicle is turning; night vision provides an enriched view of the forward scene; roadside systems can alert drivers to the presence of wildlife; and headway advisory provides advice to the driver regarding following distance.

Adaptive Front Lighting (AFS) Adaptive headlights illuminate areas ahead and to the side of the vehicle path in a manner intended to optimize nighttime visibility for the driver. Basic systems, already on the market, take into account the vehicle speed to make assumptions as to the desired illumination pattern. For instance, beam patterns adjust down and outward for low-speed driving, while light distribution is longer and narrower at high speeds to increase visibility at farther distances. More advanced systems also incorporate steering-angle data and auxiliary headlights on motorized swivels. In the case of a vehicle turning a corner, for example, the outer headlight maintains a straight beam pattern while the inner, auxiliary headlight beam illuminates the upcoming turn. The system aims to automatically deliver a light beam of optimal intensity to maximize the illumination of oncoming road curves and bends. Next generation adaptive lighting systems will use satellite positioning and digital maps so as to have preview information on upcoming curves. Headlights are then aimed into the curve even before the vehicle reaches the curve, at just the right point in the maneuver, to present the driver an optimal view.

Night Vision Night vision systems help the driver see objects such as pedestrians and animals on the road or the road edge, far beyond the view of the vehicle's headlights. Typically this is displayed via a heads-up display. Advanced forms of night vision process the image to identify potential hazards and highlight them on the displayed image.

Animal Warning Obviously, not all cars have night vision systems. To provide alerts to wildlife near roads for all drivers, road authorities are experimenting with

roadside sensors that detect wildlife such as deer and elk in areas where they are known to be frequently active. If animals are present, drivers are advised by electronic signs as they approach the area.

Headway Advisory The headway advisory function, also called safe gap advisory, monitors the distance and time headway to a preceding vehicle to provide continuous feedback to the driver. Gap thresholds can be applied to indicate to the driver when safety is compromised. Fundamentally, headway advisory performs the sensing job of ACC without the automatic control.

3.2.2 Crash Prevention

The following sections describe crash prevention systems in various stages of development. Some are in the R&D stages, while others have been introduced to the public as optional equipment on new cars.

Forward Collision Warning/Mitigation/Avoidance IV safety systems augment the driver's monitoring of the road and traffic conditions to detect imminent crash conditions. Systems to prevent forward collisions rely on radar or lidar sensing, sometimes augmented by machine vision. Basic systems provide a warning to the driver, using a variety of means such as audible alerts, visual alerts (typically on a heads-up display), seat vibration, or even slight seat-belt tensioning to provide a haptic cue. More advanced systems add automatic braking of the vehicle if the driver is not responding to the situation. An initial version of active braking systems is termed "collision mitigation system." These systems primarily defer to the driver's control; braking serves only to reduce the impact velocity of a collision if the driver is not responding appropriately to an imminent crash situation. Collision mitigation systems were originally introduced to the market in Japan in 2003. The next functional level, forward collision avoidance, represents the ultimate crash avoidance system, in which sufficient braking is provided to avoid the crash altogether.

Lane Departure Warning Systems (LDWS) LDWS use machine vision techniques to monitor the lateral position of the vehicle within its lane. Computer algorithms process the video image to "see" the road markings and gauge the vehicle's position within them. The driver is warned if the vehicle starts to leave the lane inadvertently (i.e., turn signal not activated). A favored driver interface is to emulate the "rumble strip" experience by providing a low rumbling sound on the left or right audio speaker, as appropriate to the direction of the lane departure. LDWS were initially sold in the heavy truck market; they were first introduced to the public in Japan and entered the European and U.S. automobile markets in 2004.

Lane/Road Departure Avoidance (RDA) Lane departure avoidance systems go one step farther than LDWS by providing active steering to keep the vehicle in the lane (while alerting the driver to the situation). In the case of RDA, advanced systems assess factors such as shoulder width to adjust the driver alert based on the criticality of the situation. For instance, a vehicle drifting onto a wide, smooth road shoulder is a relatively benign event compared to the same situation with no shoulder. Prototypes of such RDA systems are currently being evaluated.

Curve Speed Warning Curve speed warning is another form of road departure avoidance that uses digital maps and satellite positioning to assess a safe speed threshold for an upcoming curve in the roadway. The driver is warned if speed is excessive as the vehicle approaches the curve. Prototypes of curve speed warning systems have been built and evaluated.

Side Object Warning Side object monitoring systems assist drivers in changing lanes by detecting vehicles in the “blind spot” to the left rear of the vehicle (or right rear for countries such as Japan with right side driver positions and left-hand road driving). Blind spot monitoring using radar technology has been used by truckers in the United States for many years and is expected to enter the automobile market soon. Figure 3.2 shows detection zones for side object awareness, as well as other applications. This is a good example of “bundling” such applications.

Lane Change Support Lane change support systems extend monitoring beyond the blind spot to provide rearward sensing to assist drivers in making safe lane changes. Advanced systems also look far upstream in adjacent lanes to detect fast approaching vehicles that may create a hazardous situation in the event of a lane change. This is especially important on high-speed motorways such as the German Autobahn. These systems are in the advanced development phase.

Rollover Countermeasures Rollover countermeasures systems are designed to prevent rollovers by heavy trucks. While electronic stability control to avoid rollovers of passenger cars is becoming widely available, the vehicle dynamics for tractor trailers are very different—the truck driver is unable to sense the initial trailer “wheels-up” condition that precedes a rollover, and rollover dynamics change with the size and consistency of the cargo. Rollover countermeasure systems approximate the center of gravity of the vehicle and dynamically assess the combination of speed and lateral acceleration to warn the driver when close to a

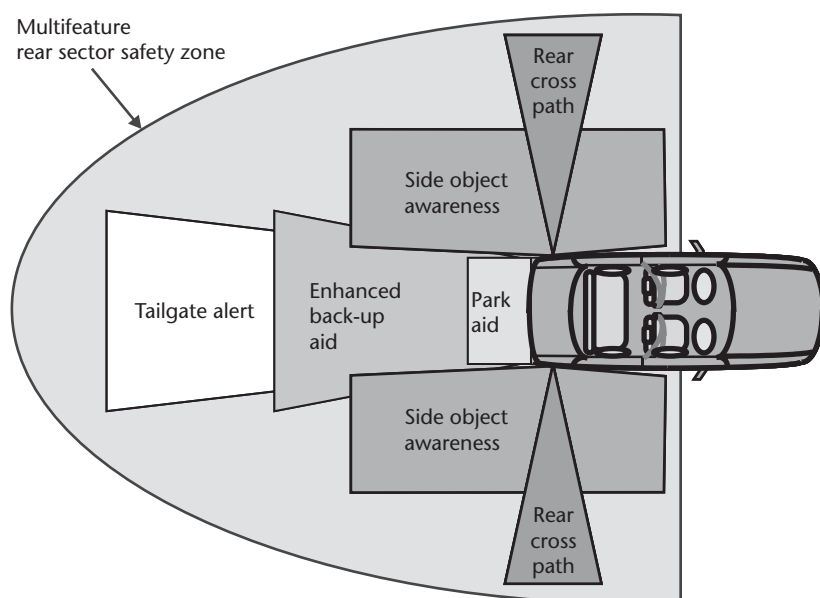


Figure 3.2 Detection zones for side object awareness and other applications. (Source: Visteon.)

rollover threshold. Systems currently on the market automatically slow the vehicle to avoid the rollover event. Rollover countermeasures systems recently became available in the heavy truck market.

Intersection Collision Countermeasures Intersection collisions represent a disproportionate amount of the fatal collisions since vehicles often collide at right angles and with significant speed. Development of intersection collision countermeasures systems represents a significant challenge, as threat conditions often cannot be detected by vehicle sensors alone. This is because, at many intersections, crossing traffic may be obscured by buildings near the road or other vehicles. In such cases, cooperative road-vehicle systems are used: Roadside systems detect dangerous situations, such as a vehicle violating a traffic signal, and communicate that information to drivers. Initial systems will warn drivers via roadside signs, and more advanced future systems will also provide the information on in-vehicle displays when communications connectivity is available in vehicles. Another approach to ICA calls for vehicles to communicate their direction and speed to each other as they approach an intersection, with processing and interpretation of that data occurring onboard each vehicle to assess any hazards. In this case, no roadside infrastructure is involved. All such intersection collision countermeasures are currently in the research stage.

Rear Impact Countermeasures Rear impacts are a particular problem for transit buses that make passenger stops on busy city or suburban streets where other traffic would not normally stop. These buses are susceptible to being struck from behind by following vehicles whose drivers are inattentive. Since the bus is most at risk, rear impact countermeasures rely upon sensing hardware on the rear of the bus to detect fast closing vehicles. When this situation is detected, vivid warning flashers are activated to—it is hoped—attract the following driver's attention in time to avoid a crash.

Backup/Parking Assist Backup/parking assist systems were described in the convenience systems section, but they can also play a role in avoiding the tragic accidents that occur when small children, who cannot be seen by the driver, are struck by a backing vehicle. Backup assist systems under development use radar or infrared technology to detect children or animals behind the vehicle and highlight this on a video display of the rearward view. Such systems are still several years away from market introduction.

Pedestrian Detection and Warning Pedestrian detection systems are most useful in urban city centers, where pedestrians are walking near traffic and could decide at any time or place to cross the street. In these situations, sensing systems, typically based on machine vision, must perform real-time processing to detect pedestrians, monitor their movements, and assess the potential danger when pedestrians enter the roadway. Robust detection of pedestrians while avoiding false alarms presents a major challenge to the technical community; nevertheless, steady progress is being made, and first generation systems are in advanced development.

3.2.3 Degraded Driving

In degraded driving conditions, the driver is impaired (due to alcohol or fatigue, for example), or the road surface may be degraded, typically due to inclement weather.

Driver Impairment Monitoring Impaired driver detection has been the subject of extensive scientific study. Basic systems that can detect severe drowsiness have been developed using various methods. Monitoring of lane-tracking behavior, steering inputs by the driver, head movements, and eyelid movements are among the primary methods examined. A key challenge is to detect the early signs of the onset of drowsiness, so that a driver can effectively respond to a warning before drowsiness is severe. These systems can take the form of a “fatigue meter” that provides continuous feedback to the driver, or a warning that sounds when dangerous fatigue conditions are detected. Basic driver drowsiness monitors were on the market in Japan for a short time during the 1980s. First generation products targeted at long-haul truck drivers are currently being sold in the aftermarket, and driver-monitoring products are currently in development for the automobile market.

Road Surface Condition Monitoring Knowledge regarding degraded road surface conditions, such as wet or icy pavement, is obviously important to the driver. This information can also enable ACC systems to adjust intervehicle gaps and crash countermeasures systems to adjust warning timing based on lower traction, for instance. Spot conditions can be detected to some degree by vehicle systems such as anti-lock braking and traction control, but the ideal case is to have advance knowledge. Such advance warning can be provided by roadside detectors that send messages to the vehicle, or from other vehicles through floating car data techniques or vehicle-vehicle communications.

3.2.4 Precrash

The precrash domain refers to the case where sensing systems (typically using ACC sensors) have determined that a crash is inevitable; therefore, action is taken to optimally protect the vehicle occupants via seatbelt pretensioning and prearming or prefiring airbags. In addition, the braking system can be precharged so that maximum braking force is provided immediately upon initiation by the driver.

Precrash systems are generally seen as precursors to more advanced collision avoidance systems, as a bridge between occupant protection measures, which are very mature technologically, and crash avoidance measures, which are in earlier stages of development and product maturity.

3.2.5 External Vehicle Speed Control (EVSC)

EVSC, also called intelligent speed adaptation (ISA), assists drivers in keeping the vehicle's speed to the government-defined speed limit.

Proponents of EVSC include residents of small towns through which highways pass. Too often, long-distance drivers do not slow down sufficiently when entering the town, creating safety concerns for residents. Residents of urban neighborhoods have similar concerns when their roads are used as “shortcuts” by commuters to avoid traffic jams on major roadways. More generally, government initiatives to totally eliminate traffic fatalities include a strong component to keep vehicle speeds to the legal limit.

The emerging EVSC approach is to use onboard satellite positioning working in conjunction with a digital map database that includes speed limits for the road network. Via an active accelerator pedal, the vehicle will automatically “resist” attempts to drive faster than the speed limit; however, the system can be overridden in the case

of an emergency. More advanced versions of EVSC would allow for dynamic speed limits that are adjusted based on factors such as traffic volumes, time of day, and weather conditions. EVSC development is occurring primarily in Europe.

3.3 Productivity Systems

The concept of productivity applies to commercial vehicles and transit buses. Productivity can be increased in terms of operational cost (such as fuel consumption) or time (such as more efficient maneuvering).

3.3.1 Truck Applications

In the commercial trucking area, ACC is considered to be both a driver convenience system as well as a productivity tool. This is due to improved fuel economy when using ACC. Improvements in fuel consumption on the order of 5% are not unusual, which translates directly to increased profits for trucking companies [2].

Systems that reduce driver fatigue, such as ACC and LKA, are also seen as productivity systems, because they enable truck drivers to be more alert to the traffic and road conditions around them. In the United States, driver retention is a challenge for trucking companies, and equipping fleet vehicles with these types of systems can increase driver satisfaction and help retain workers.

3.3.2 Transit Bus Applications

Transit bus IV applications also offer increases in productivity. In particular, there is strong interest in the United States and other parts of the world in implementing bus rapid transit (BRT) systems. Using BRT techniques, buses are able to operate faster than normal traffic due to traffic signal priority and/or having an exclusive lane [3]. Offering shorter trip times, as compared to regular traffic, provides a powerful incentive for travelers to choose bus service.

BRT systems employing exclusive lane operations can provide passenger capacity approaching that of light rail transit at only a fraction of the cost; however, it is very challenging to claim the space for such a lane in highly developed city street grids. LKA systems enable buses to operate on very narrow lanes, minimizing the impact on the street space. Lane width space savings of as little as a few inches can be key to the viability of a new transit service. A BRT system of this type, called Phileas, recently became operational in Eindhoven, Netherlands (see Figure 3.3).

Another area of interest for transit buses is in precision maneuvering. Large buses are not always a good fit in tight city streets and maneuver assistance systems can help drivers (particularly less experienced drivers) successfully negotiate tight spaces, avoiding property damage or worse consequences. A special case of precision maneuvering is precise docking, in which the bus aligns itself within a few centimeters of the loading platform when picking up passengers. This allows for quick and easy roll on/off for strollers and wheelchairs, as well as a more rail-like experience for all passengers. Such features are important to implementing efficient service, which, again, is key to attracting travelers to use the transit service.



Figure 3.3 Phileas guided bus system. (Source: Advanced Public Transport Systems bv.)

3.4 Traffic-Assist Systems

Per Figure 3.4, congestion has been with us for a very long time, entering the scene not long after the proverbial invention of the wheel. Traffic congestion is a pervasive ill within society, but due to the distributed nature of road traffic, congestion is a “distributed disaster” as distinct from the “spot disasters” of road crashes. Therefore, enhancing safety generally gets higher priority within government programs. Also, safety improvements are a more tractable domain as compared to addressing traffic congestion—a crash avoidance system on a single vehicle can be highly effective and marketed in new cars, whereas many cars must be equipped and cooperating either with the roadway or each other (or both) for traffic flow to be improved. At the same time, it must be said that, in industrialized countries, traffic congestion

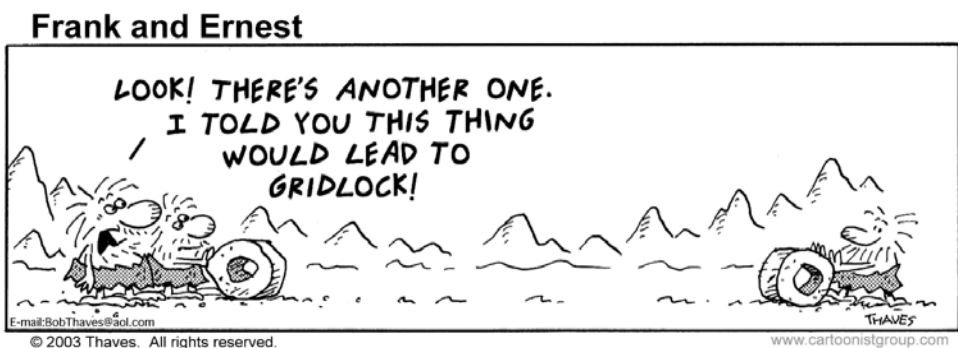


Figure 3.4 The beginnings of traffic gridlock. (© 2003 by Thaves. Used by permission of Thaves and the Cartoonist Group. All rights reserved.)

affects the lives of hundreds of millions of drivers every day, whereas safety critical situations—as encountered by individual drivers—are rare by comparison. From both a societal perspective and a market-pull viewpoint, there is ample reason to develop technological means of reducing congestion, if it is indeed possible.

Many government ITS programs focus on managing existing congestion rather than improving traffic flow, with roadway expansion and new roads seen as the only way to combat congestion. The prevailing view is that “there is nothing we can do” to improve traffic and we must learn to “live with it.” However, IV systems combining vehicle communications with advanced vehicle control techniques offer the potential for improving traffic flow in the long term. In this respect, the potential of IV systems that improve traffic flow through cooperation between vehicles and the road operator have long been studied in the academic research domain and have recently attracted the attention of automotive laboratories. Several forms of traffic-assist systems have been proposed, simulated, prototyped, and tested. These are described at a high level in the following sections and further elaborated in Chapters 9 and 10.

3.4.1 Vehicle Flow Management (VFM)

One approach to traffic flow improvement is VFM, in which vehicles are responsive to speed advisories transmitted by a central traffic management center. The speed advisories would be calculated based on real-time traffic conditions and predictive modeling aimed at smoothing and improving the traffic flow.

An example of VFM that has been proposed is responsive ACC (R-ACC), which takes advantage of adaptive cruise control and wireless communications capability on vehicles. Drivers—typically in a commuting scenario—would voluntarily enable the R-ACC function to respond to speed advisories generated by the traffic management center, exchanging personal control of speed for a more efficient trip. The strength of the concept lies in the ability of such a traffic management system to generate precise speed commands at specific locations. Such precision would provide traffic managers with new and powerful tools to manage traffic.

An alternative R-ACC implementation would rely upon continuous information exchange by all vehicles in the traffic stream, such that the vehicles collectively achieve an optimum flow through distributed computing and individual speed adjustments.

3.4.2 Traffic-Responsive Adaptation

Long seen as the domain of road authorities, the automotive industry recently began exploring traffic assistance applications. These applications focus on ways that individual vehicle systems can improve their response to various types of traffic, without assistance from roadway systems or one another. In traffic-responsive adaptation systems, ACC-equipped vehicles sense various traffic conditions (e.g., dense flow and congestion) and adjust ACC parameters to slightly improve flow and dampen shock waves.

3.4.3 Traffic Jam Dissipation

Typically, when the end of a traffic jam is encountered, the driver has been lulled into lethargy by being in stop-and-go traffic for some time and is slow to recognize that the

way ahead is clearing. In the traffic jam dissipation application, vehicle systems sense this “accelerate to normal speed” condition immediately to assist the driver in accelerating efficiently, thus facilitating a quicker dissipation of the traffic congestion. Because the duration of a traffic jam is highly dependent on the aggregate effects of individual driver actions, such small improvements in response by individual vehicles can make a big difference in the overall performance of the traffic stream.

3.4.4 Start-Up Assist

The situation at traffic signals is similar to that at the end of a traffic jam—lag times are incurred as individual drivers respond to the initiation of movement by vehicles ahead. In this case, the controlling factor is the traffic signal turning from red to green. To implement start-up assist, vehicle systems detect the traffic signal state and the acceleration of preceding vehicles and then control throttle to most efficiently clear the intersection. The driver can of course override the system in unusual situations. These types of systems have been prototyped and tested in Europe.

3.4.5 Cooperative ACC (C-ACC)

C-ACC is a more advanced application that requires communications connectivity between ACC-equipped vehicles following one another in the same lane. By exchanging braking and acceleration data, headways between vehicles in a string can be decreased without compromising safety. Simulations have shown significant flow improvements from this approach.

3.4.6 Platooning

Platooning is essentially the C-ACC concept taken to its maximum limit. Platoons of several vehicles are formed longitudinally on the roadway and intervehicle communications is used to continually exchange essential information such as braking and speed. The key difference from C-ACC is that all vehicles are aware of the state of all other vehicles in the platoon, whereas in C-ACC only information from the preceding vehicle is communicated. Platoon operations tested thus far are of limited length, on the order of 10 vehicles.

Given the physical closeness of vehicles in these operations, platooning is seen as requiring full automation of driving functions. Further, platooning concepts typically call for a dedicated lane to deliver significant improvements in traffic flow.

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Government-Industry R&D Programs and Strategies

An extensive array of IV R&D programs have been initiated worldwide as a component of government research focused on ITS generally. Primarily, these programs are focused on improved road safety, given that this is a key responsibility of public road authorities. In almost all cases, programs are conducted on a cost-shared basis with the automotive industry, which lends relevance and credibility and recognizes the consumer market as a factor in deployment of IV systems.

This chapter briefly reviews activities at regional, national, and state (U.S.) levels to offer a comprehensive high-level review, with further detail on the projects described provided in subsequent chapters. Where available, government policy perspectives, institutional sponsors, and funding levels are provided as context.

4.1 Asia-Pacific

4.1.1 Australia [1–3]

The Australian federal and state governments are very active in ITS and are in the early stages of exploring IV systems for road safety. Key priorities are in core ITS areas such as interoperability for tolling systems, architecture, and standards. These can be seen as building blocks for future cooperative systems. Ten-year ITS strategies have been developed for implementation. With regard to safety, the current focus is on understanding safety benefits and issues, including driver distraction, and to prioritize safety applications. ITS Australia is planning a major demonstration of IV technology in 2005 to showcase the future potential for safety.

One area of investigation focuses on how to handle the advent of active safety systems within the Australian New Car Assessment Program (ANCAP). ANCAP has historically rated cars in terms of their crashworthiness via crash testing. The key question: How might this process be extended to assess active safety systems and rate vehicles based on performance in avoiding crashes, in a manner that communicates effectively to the public?

IV research is primarily occurring at the university level. For instance, activities at the Accident Research Center at Monash University include the following:

- TAC SafeCar project: Field evaluation of effectiveness and acceptability of intelligent speed adaptation (ISA), following distance warning, and seatbelt reminder systems;

- Intelligent access project: Trial and evaluation of ISA to remotely monitor heavy vehicle speeds;
- Evaluation of fatigue warning devices via a driving simulator.

Another center of activity is the Intelligent Control Systems Laboratory at Griffith University. Intelligent vehicle capabilities under development for road transport include the following:

- Vehicle distance control;
- Lane following and vehicle detection (enabling a vehicle to identify, approach, and overtake a slower vehicle);
- High speed automated cruise;
- Collision avoidance;
- Intervehicle communications;
- Cooperative driving;
- ISA.

In the area of vehicle-highway automation, there is some interest in electronic tow-bar operations for heavy trucks, given the monotonous long-distance drives encountered by many truck operators. In fact, Australia has the distinction of being home to one of the first deployments of vehicle automation—autonomous mining trucks operating on unpaved roads in large open-pit mining areas.

4.1.2 China [4]

As the Chinese economy continues to thrive, global automotive companies are investing in establishing research centers there to take advantage of in-country expertise at relatively low cost. So far, though, IV R&D in China is performed mainly by universities and research institutes with government funding support, in particular the National Center of ITS Engineering and Technology within the Chinese ministry of communications.

Several prototype R&D vehicles have been developed. One vehicle, developed by First Auto Works (the largest auto manufacturer in China) and the National University of Defense Technology is capable of autonomous driving based on machine vision.

At Jilin University, the Intelligent Vehicle Research Group has developed an IV system based on machine vision and laser scanner sensors. Driver behavior monitoring is performed as well as driver assistance. Also, this group is designing a CyberCar autonomous vehicle for the 2008 Beijing Olympic Games, as shown in Figure 4.1. It is intended to provide passenger transport service for officials, athletes, and visitors between various Olympic facilities.

For active safety, the THASV-1 vehicle employs machine vision and millimeter-wave radar as shown in Figure 4.2 to implement ACC and collision warning.

Another center of research is Tsinghua University, which has developed the THMR-V research vehicle, equipped with a color CCD camera and navigation using dead reckoning and differential GPS.



Figure 4.1 CyberCar design envisioned for the 2008 Olympics. (Source: National Center of ITS Engineering & Technology, China.)

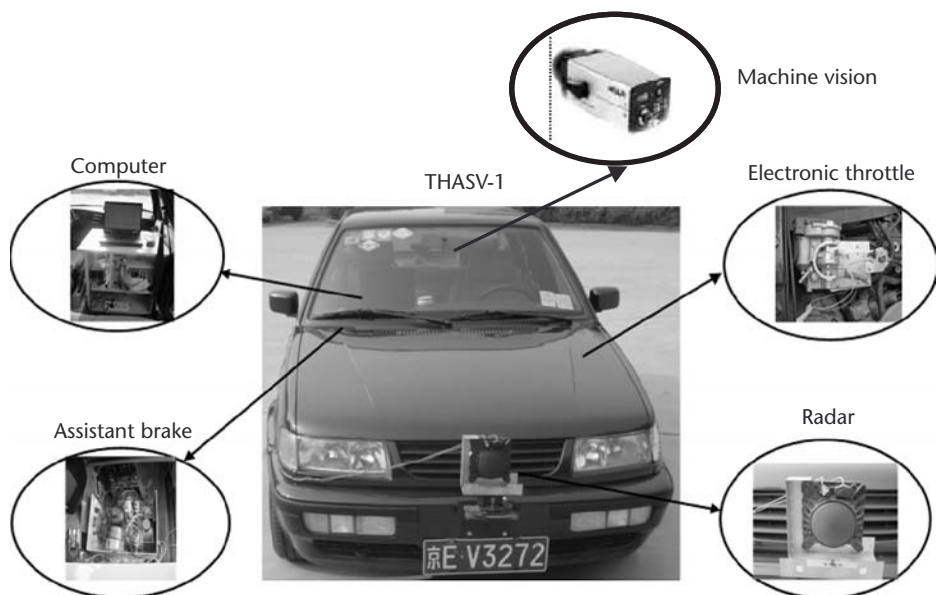


Figure 4.2 THASV-1 experimental vehicle of the IV Research Group at Jilin University. (Source: National Center of ITS Engineering & Technology, China.)

Chinese researchers are developing an intelligent highway system (IHS), which is defined as “an integrative system [which is] based on the road infrastructure and provides the vehicle with information services, safety alert, and automated operation.” Such a system would be centered on road infrastructure intelligence and based on cooperation between roads and vehicles. Human factors would comprise one particular emphasis area.

An incremental evolutionary approach is planned, with an initial emphasis on safety assistance via driver information systems and, later, control systems. In a subsequent phase focusing on both safety and traffic efficiency, automatic driving would be employed relying on cooperative systems and eventually infrastructure control.

A prototype IHS test system is being developed by ITS China in the Ministry's proving ground for highway and traffic. Current research focuses on automated lane-keeping, based on magnetic markers in the road and in-vehicle devices working cooperatively. A sketch of the prototype system is shown in Figure 4.3.

4.1.3 Japan [5–8, 41]

MLIT The Japanese ITS program is centered within MLIT. Major activities to advance IV R&D and deployment are the AHSRA and the ASV program.

AHSRA, founded in 1996, focuses on test, evaluation, and implementation of cooperative vehicle-highway systems for the purpose of improving road safety. Membership consists of automotive and electronics companies within Japan. Cooperative vehicle-highway systems are a major focus, based on the principle that onboard sensor systems are limited by the laws of physics and therefore cannot detect all hazardous situations. This is especially true for the winding curved highways that follow Japan's mountainous terrain.

During AHSRA's first phase, which concluded in 2003, three driver support levels were initially defined: information, control, and full automation. Research then focused most strongly on the information and control levels, with automation deferred for future phases. Concepts and requirements were defined for seven user services key to safety improvements, which together comprise their "Smart Cruise" system:

- Support for prevention of collisions with forward obstacles;

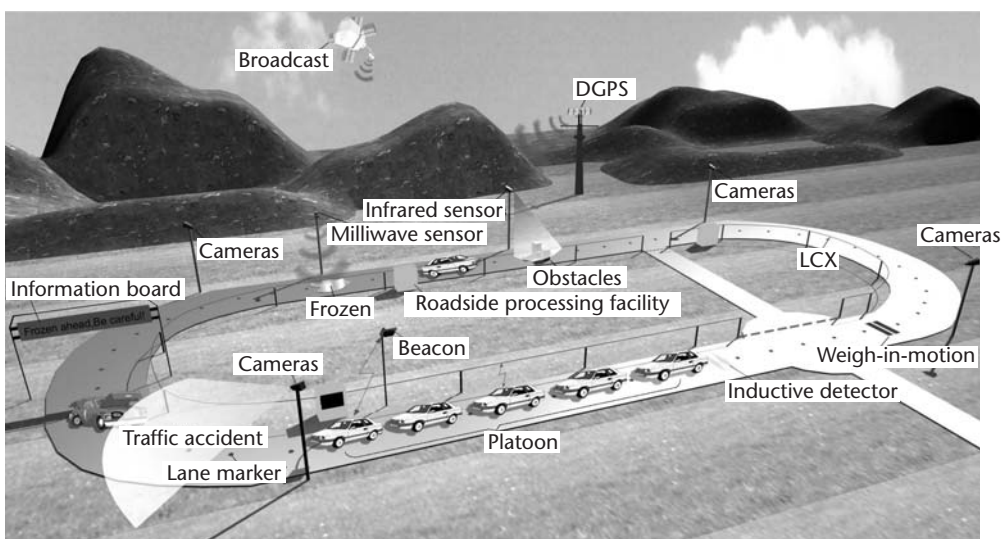


Figure 4.3 Intelligent highway system test facility planned by the Chinese Ministry of Communications (Source: National Center of ITS Engineering & Technology, China.)

- Support for prevention of roadway departure on curves;
- Support for prevention of lane departure;
- Support for prevention of crossing path collision at intersections;
- Support for prevention of right-turn collision at intersections;
- Support for prevention of pedestrian collisions;
- Provision of road surface condition information for maintaining a safe headway.

These user services are illustrated in Figure 4.4.

AHSRA prototyped and tested initial versions of these systems, which culminated with a major event called Demo 2000. The testing validated the effectiveness of the services. Since then, extensive evaluation has been under way, using driving simulators, test track trials, and deployment to seven hazardous highway sites. Researchers have reported promising results; for instance, drivers reduce speeds appropriately when alerted to hazards around blind curves. Based on these results, MLIT has announced plans for deployment of these types of systems under its Smartway program, as described in Chapter 2. AHSRA is now performing further research and testing in support of Smartway deployment. AHSRA is also focusing on the reduction of traffic congestion at roadway “sags” (declines followed by inclines) and tunnels, areas where traffic tends to naturally slow. Via roadway monitoring, lane advice can be provided to drivers to smooth traffic.

Another area of interest for AHSRA is the Guidelight cooperative road-vehicle illumination system, which supports drivers in merging onto motorways. Guidelight relies on infrastructure sensing of traffic on the motorway to illuminate a series of lights along the merging lane to indicate the presence of merging vehicles. Drivers can synchronize their speed based on these moving light indicators to allow entering vehicles to efficiently merge into traffic.

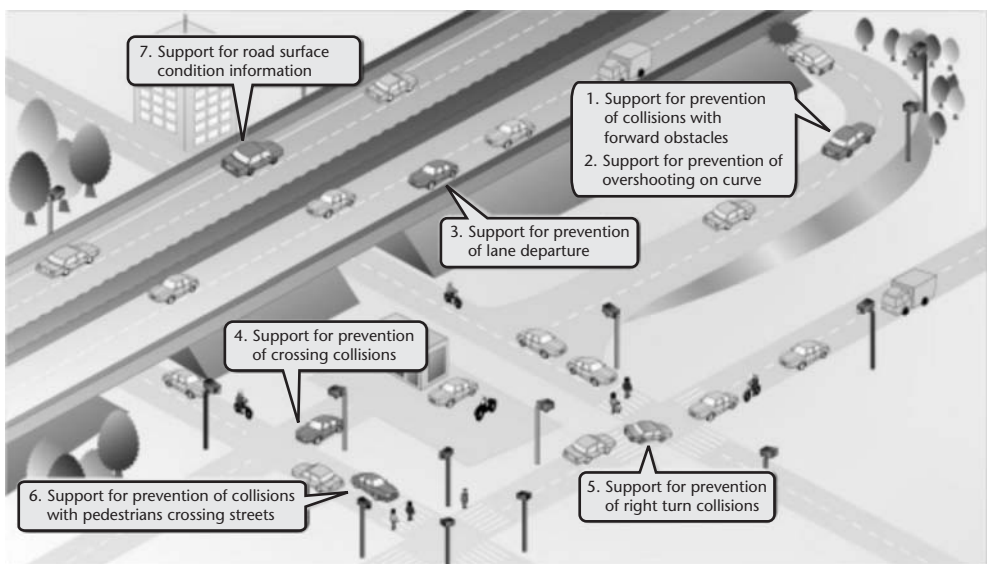


Figure 4.4 AHSRA R&D focuses on seven user services. (Source: NILIM, Japan.)

The ASV program focuses on the development of autonomous active safety systems. All Japanese automotive manufacturers are participants. The first phase of the ASV program ran from 1991 to 1995 and established the technological feasibility of crash-avoidance systems. During phase 2 (1996–2000), design principles and guidelines were established and demonstration vehicles were constructed. This phase culminated with the demonstration of 35 ASV advanced crash-avoidance vehicles at Demo 2000. Several of these systems have since been introduced into the Japanese market.

Major systems developed in ASV-2 included the following:

- Forward obstacle collision avoidance;
- Curve overshooting prevention system;
- Full-speed range ACC;
- Lane-departure prevention system;
- LKA system;
- Blind spot obstacle collision avoidance system;
- Advanced front lighting system;
- Vehicle body adaptation for mitigating pedestrian injury;
- Drowsiness warning system;
- Nighttime pedestrian monitoring system.

Phase 3 runs from 2001 to 2005 and is promoting user acceptance and the market success of these systems, as well as developing next generation systems such as an intertraffic communications system, which will be based on vehicle-vehicle communications (further described in Chapter 9).

METI Within METI, the National Institute of Advanced Industrial Science and Technology (NIAIST) pursues a variety of research paths looking toward the long term. These include a driver-adaptive driver assistance system, an elderly driver assistance system, and standardization studies on intervehicle communications. For instance, NIAIST has defined the “ITS view-aid system,” described further in Chapter 12, in which driver monitoring is integrated with driver assistance to make warnings more driver-adaptive and less annoying.

Expo 2005 Japan will take a high profile in the IV arena worldwide when the 2005 world exhibition opens in Aichi. The intelligent multimode transit system, a futuristic driverless bus system developed by Toyota, will be in service to carry visitors between Expo sites.

4.1.4 South Korea [9, 10]

Within South Korea, the Korean Ministry of Construction and Transportation is handling ITS traffic management and vehicle safety test and evaluation, and the Ministry of Commerce, Industry, and Energy is handling vehicle safety technology development. Development of DSRC technology and applications is the responsibility of the Ministry of Information and Communication.

Major areas of planned IV technology development include collision avoidance systems, a speed limit warning system using communications between the road and vehicles, and an intelligent automatic driving vehicle, which will be capable of platooning with other automated vehicles.

Additional IV research is being conducted by the ITS Research Center within the Korea Transport Institute. An ASV project is running from 2001 to 2006. Funded at approximately \$1 million, the objectives are the development of ASV test and evaluation technologies and building cooperative vehicle-infrastructure systems. Participating organizations are the Korea Transport Institute, the Korean Automotive Testing and Research Institute, the Korean Automotive Technology Institute, and SungKyunKwan University.

Development work includes scenario development/evaluation, field tests, the use of vehicle/road simulators, and the development and use of a remote-controlled car. Functional areas of focus include ACC, forward collision warning, and a traffic impediment warning system. A major activity is under way to construct an ASV test and evaluation center at the Korean Automotive Testing and Research Institute to support this work.

4.2 European Programs

An extensive set of IV R&D activities are under way in Europe at both the European and national levels. At the regional level, the EC funds European-level work and the DeuFrako program supports joint French-German projects. Nationally, France, Germany, the Netherlands, Sweden, and the United Kingdom are major players in IV research, with each having a slightly different emphasis. In each case, multiple projects are under way via cost-shared government-industry partnerships. As will become evident in Chapter 5, major European auto manufacturers and suppliers are active participants in these projects.

4.2.1 Pan-European Activities Conducted Through the EC

The EC provides the lion's share of public funding for European research, including ADAS R&D. Contributions from member states are pooled and redistributed to research areas seen as important to the overall European society.

Of the EC's 17 policy directorates, most ADAS R&D is sponsored by the Information Society Directorate (IST), with a modest number of projects also sponsored by the Energy and Transport Directorate (TREN) and the Research Directorate. IST projects are typically industry-led and of a more technical nature, whereas TREN projects tend to focus on nontechnical and/or societal level issues. Research Directorate projects have a longer time horizon.

EC research is defined by "framework programs" that set the tone and priorities for 4–5 year periods. The framework priorities are developed by extensive discussion and debate within the EC and the European parliament, with significant involvement by member states at all levels in the process. Currently the Sixth Framework Program (6FW) is under way, with a run from 2003 to 2008. Research projects from the Fifth Framework Program (5FW) (1998–2002) are either complete or in their final stages; these projects have produced a broad set of interesting results,

particularly in the areas of cooperative vehicle-highway systems and vehicle safety communications.

The eSafety initiative described in Chapter 2 is moving strongly into an implementation phase through the 6FW IST projects. An eSafety forum and a number of eSafety working groups are active to coordinate and provide momentum to the ongoing work. The forum steering group includes representatives from automotive manufacturers, automotive suppliers, insurance companies, and automobile clubs, as well as the EC. Within the forum, the following working groups are active:

- Emergency call (e-call);
- Accident causation data;
- Human-machine interaction;
- Business rationale;
- Deployment road maps;
- R&D;
- Traffic and travel Information;
- Heavy-duty vehicles.

A document entitled *Information and Communication Technologies for Safe and Intelligent Vehicles* [11] was published in 2003, providing the EC's forward thinking for eSafety. According to the document, information and communication technologies (ICTs) are seen as the most important set of tools enabling commercial industry to meet the eSafety goals. IV systems seen as having good prospects for near-term safety gains are listed as safe speed, lane keeping support, safe following, pedestrian protection, improved vision, driver monitoring, and intersection safety systems. The document affirms a wide array of actions the EC intends to take to accelerate the development, large-scale deployment, and use of such systems in Europe.

During the 5FW period (1998–2002), a great number of ADAS-oriented projects were initiated by IST. Essentially, every aspect of ADAS was covered to some degree, and the great diversity of activity was coordinated by a “horizontal” project. For the 6FW, the EC sought a more coherent approach, which spawned the concept of integrated projects (IPs). IPs are large, overarching projects, within which are numerous subprojects. So, whereas the 5FW had dozens of ADAS projects, the 6FW has very few. The 6FW subprojects are analogous to the 5FW projects in terms of size and scope. 5FW and 6FW projects are described below, with Table 4.1 providing funding levels for selected projects to provide a sense for the degree of investment.

5FW ADAS Projects [12] IST ADAS projects within the 5FW program constituted an investment of over 100 million euro. These projects were coordinated by the ADASE horizontal project. As a key European discussion forum, ADASE directly addressed system architecture; technology road maps; human-machine interface; sensor technologies; ADAS impacts on society; and cooperative vehicle-highway system approaches, including wireless media, location-based addressing, and scenarios for market introduction.

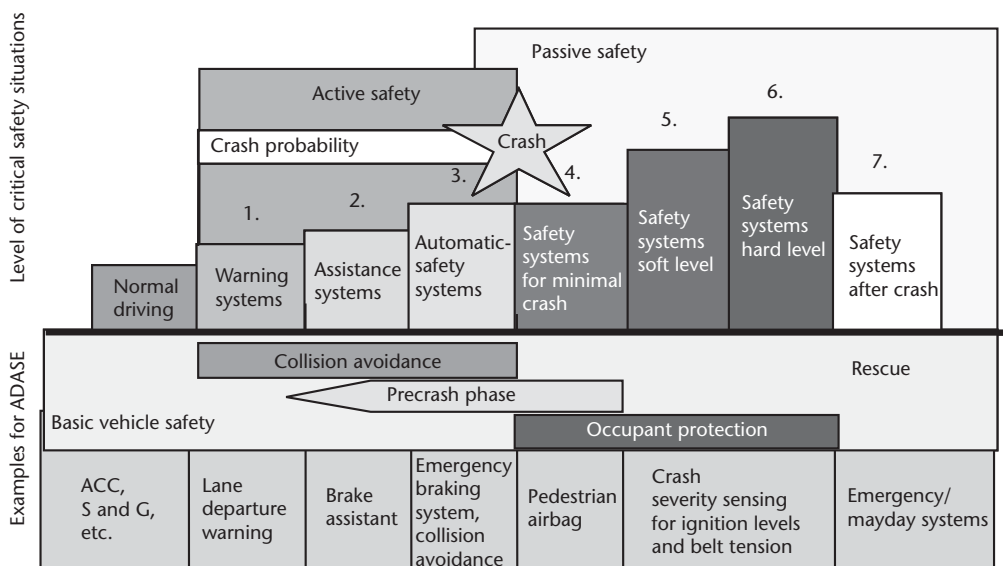
As shown in Figure 4.5, ADASE took a holistic approach to safety, encompassing functions that apply to normal driving (such as ACC), the precrash domain in

Table 4.1 Funding Levels for Selected European Projects

Framework program	Project	Funding level (euros)
5FW	ActMAP	3.7 million
	ADASE2	1.2 million
	AWAKE	6.3 million
	CARSENSE	7.1 million
	CARTALK	3.8 million
	CHAMELEON	4.7 million
	CHAUFFEUR II	10.0 million
	CYBERCARS	10.0 million
	DENSETRAFFIC	5.2 million
	EDEL	6.0 million
	PEIT	3.6 million
	PROTECTOR	4.4 million
	RADARNET	7.6 million
	RESPONSE2	1.5 million
	SAVE-U	8.0 million
6FW	AIDE	12.4 million
	PReVENT	~70.0 million

which developing crash situations can be countered (by means such as lane departure warning), and occupant protection measures taken in the postcrash phase. Figure 4.6 provides a “road map” for ADAS in Europe that has been widely accepted as a guidepost for European R&D. With time progressing from bottom to top, Figure 4.6 displays the relative safety contribution of a particular function on the far left, while the other columns portray the relative complexity of functions in both political and technical dimensions.

Projects within the 5FW IST ADAS cluster include the following:

**Figure 4.5** ADASE holistic safety approach. (Source: ADASE2.)

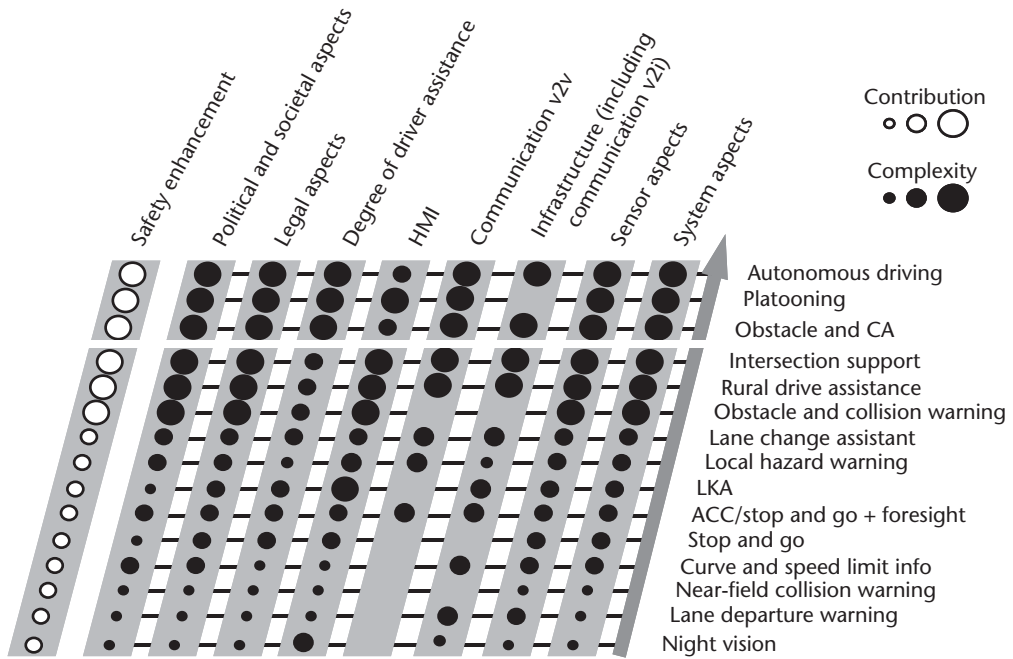


Figure 4.6 The European road map for ADAS. (Source: ADASE2.)

- ACTMAP: Development of techniques for dynamic updating of in-vehicle map databases;
- AWAKE: Driver monitoring combined with traffic situation awareness to provide countermeasures for driver drowsiness;
- CARSENSE: Sensor fusion for intelligent perception within a complex urban environment at low speeds;
- CARTALK: Implementation of safety applications based on multihop car-to-car messaging;
- CHAMELEON: Precrash sensing for triggering occupant protection systems;
- CHAUFFEUR: Electronic tow bar for heavy trucks, including automated operation in vehicle platoons;
- CYBERCARS: Automated rubber-tired transport for passengers in urban areas;
- DENSETRAFFIC: Second generation radar systems for low-speed ACC and complex traffic situations in general;
- EDEL: Development of a fully integrated driver support system based on near-infrared night vision sensors;
- IN-ARTE: Integration of digital map techniques to ADAS applications such as curve speed warning, traffic sign information, and front obstacle warning;
- NEXTMAP: Identification of attributes for digital maps supporting ADAS applications;
- PEIT: Development of an “intelligent powertrain;”

- PROTECTOR: 1) Initial research in vision-based pedestrian detection and 2) use of transponders to enhance safety for pedestrians, cyclists, and motorcyclists based on the interaction with on-vehicle receivers and sensors;
- RADARNET: Development of a low-cost, multifunctional radar network;
- RESPONSE: Examining legal and user issues toward defining a code of practice (CoP) for the design, testing, and market introduction of ADAS;
- SAVE-U: Development of an integrated system to detect pedestrians in the forward vehicle path and mitigate or avoid a collision;
- STARDUST: Assessing driver perceptions and behavior in using (via driving simulators) ACC, ISA, lane keeping, and CyberCars; also impact assessments of such systems on roadway networks.

Relevant 5FW projects sponsored by TREN include the following:

- ADVISORS: Development of a methodology to assess ADAS impacts in terms of the safety, efficiency, and environmental performance of the road transport system; also development of scenarios for introducing ADAS;
- EUCLIDE: Fusion of far-infrared and microwave radar sensors to implement a system that supports the driver in situations of reduced visibility conditions;
- PROSPER: Horizontal project coordinating national-level ISA projects;
- SPEEDALERT: Institutional and technical efforts to develop an in-vehicle speed alert system to increase drivers' awareness of speed limits.

Within the Research Directorate, the NETMOBIL project was conducted to examine future sustainable urban transportation systems based on automatic guided vehicles.

6FW IST ADAS Activities [12–15] The areas of interest designated by IST for 6FW safety-oriented integrated projects are listed as follows:

- Protective safety;
- Preventative safety;
- Human-machine interface;
- Architecture;
- Accidentology;
- Rescue and services.

Of most interest here is the preventative safety IP, which focuses on advanced driver assistance systems. For this area, 80 million euro was allocated by the EC in 2003 for “eSafety of roads and air transport.” Industry-led consortia provided research proposals and several major IPs were funded:

- AIDE: Focusing on human-machine interface technologies required for safe and efficient integration of ADAS and nomad devices into the driving environment;
- AISES: Development of an electronic architecture for driver workload support;

- Global System for Telematics (GST): Studying the integration of a safety information channel, postcrash rescue, and enhanced FCD;
- PReVENT: Development of second generation crash avoidance systems that also take the driver's state into account;
- SPARK: Development of advanced drive-by-wire techniques and components.

As the largest IP within preventative safety, PReVENT is the central ADAS R&D activity for Europe over the next several years. The total PReVENT budget is ~70 million euro, with the EC contributing ~30 million euro.

PReVENT focuses on developing second generation active safety systems, with particular attention given to defining safety function fields, integrating different in-vehicle systems, and combining them with telematics services into a complete network of "integrated safety systems." Systems developed within PReVENT will be capable of sensing danger, assessing the traffic state, and assessing the driver condition to provide warnings and/or intervene to avoid a crash based on enhancements to "situation capture" and development of intelligent response techniques. In addition to technical goals, PReVENT seeks to facilitate the necessary stakeholder cooperation to gain the earliest possible implementation of such systems on the European market. The integrated project is being conducted by a broad team of over 50 partners, with the major auto manufacturers and suppliers within Europe active in project leadership.

PReVENT is structured into both functional and cross-functional areas.

Functional subprojects are listed as follows:

- Safe speed and safe following: Focuses on situations related to excessive speed or insufficient headway, typically with an obstacle or a curve ahead. System response also incorporates data obtained by onboard sensors and received by communication regarding the situation ahead (e.g., road condition, traffic, and weather). The area also includes a wireless local danger warning. Two subprojects called SASPENCE and WILLWARN are active in this area.
- Lateral support and driver monitoring: Driver support of the lane keeping and lane changing task, as well as prevention of lateral or blind spot crashes, particularly in low-visibility conditions. Driver monitoring systems are integrated into these applications. The subprojects in this area are SAFELANE and LATERALSAFE.
- Intersection safety: Implementation of applications related to approaching or passing intersections, with emphasis on cooperation between infrastructure and vehicles. INTERSAFE is the subproject in this area.
- Vulnerable road users and collision mitigation: Focuses on the phase just prior to a crash to mitigate the effects of a collision and optimize the response of occupant protection systems. Detection and avoidance of vulnerable road users (such as pedestrians) is also a key focus. The subprojects in this area are APALACI, COMPOSE, and UserCams.

These functions are illustrated in Figure 4.7.

Cross-functional subprojects are listed as follows:

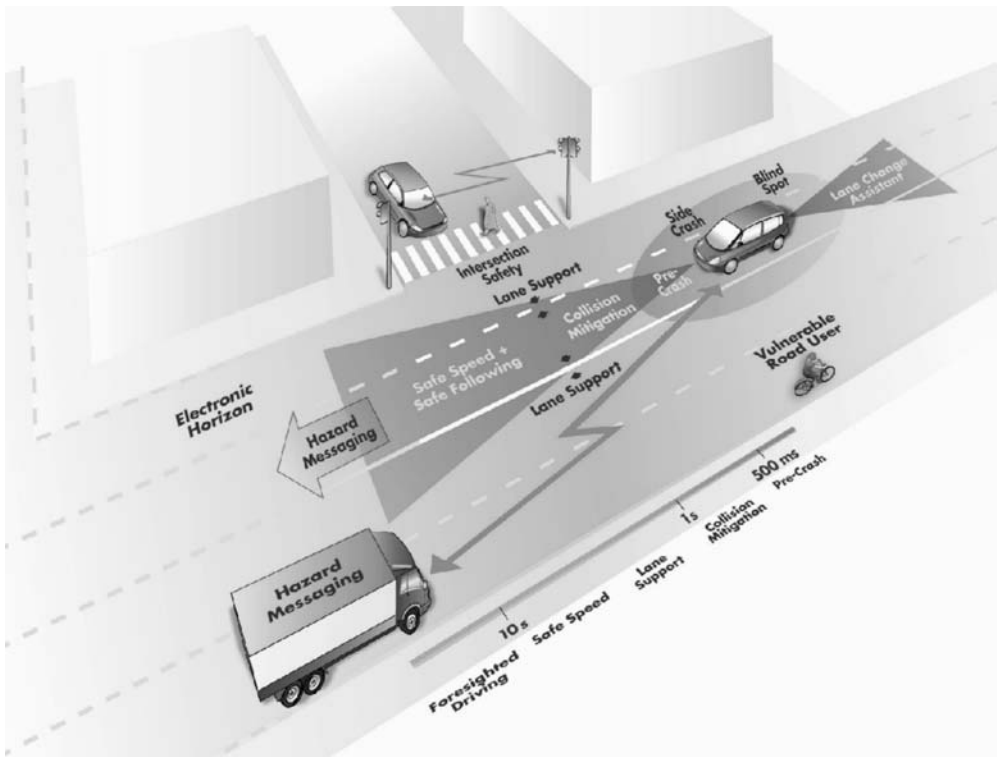


Figure 4.7 Complementary functions being developed within PREVENT. (Source: ERTICO—PREVENT Dissemination.)

- **RESPONSE:** Establishment of a CoP for development and testing of ADAS, as well as impact assessments;
- **MAPS & ADAS:** Development, test, and validation of digital maps to support ADAS, which will in turn extend the “electronic horizon” and assist in interpreting sensor data;
- **ProFusion:** Defining state-of-the-art in robust sensors and optimized sensor data fusion as well as defining technology gaps in this area.

In 2007, PREVENT will sponsor an exhibition of results called the Safety Roadshow, in which 21 test platforms will demonstrate multiple approaches to the applications described above.

Looking beyond the current activities, the EC is planning further calls for proposals within preventative safety, one of which will focus specifically on CVHS.

4.2.2 The DeuFrako Program [16]

DeuFrako is a joint activity of the French government PREDIT program (focused on research and innovation in land transport), the German Federal Ministry of Education and Research, and the German Federal Ministry of Transport. Two projects pursued in recent years have a bearing on IV systems:

- The intervehicle hazard warning (IVHW) project, which ended in 2002, was one of the earliest activities focused on vehicle-vehicle communication. Its objective was to develop a hazard warning system in which disabled vehicles would broadcast a warning for receipt by all nearby vehicles, thereby enabling approaching drivers to proceed with greater caution.
- The SafeMAP project, which is investigating the application of digital maps and satellite positioning to ADAS.

4.2.3 French Programs [17, 18]

In France, road safety became a “national cause” in recent years, and programs to reduce road crashes have had active support at the highest levels of the government.

A central focus of French IV research is the Laboratory for the Interactions between Vehicles, Infrastructure, and Conducteurs (drivers) (LIVIC). LIVIC is a joint research unit of the French national research centers National Institute for Transport and Safety Research (INRETS) and the Central Laboratory for Roads and Bridges (LCPC). LIVIC’s ADAS focus is on developing concepts, advancing less mature technology, performing experimental validations, and coordinating national projects.

The LIVIC philosophy has a dual focus:

- Driver assistance usable on all road types to improve safety;
- Driving automation on highly constrained roads to improve comfort, safety, and road capacity.

Another major participant in French IV research is the National Institute for Research in Computer Science and Control (INRIA). INRIA’s IV R&D focuses strongly on the CyberCars work noted above and described further in Chapter 10. Additionally, INRIA is involved in sensor fusion and intersection collision avoidance R&D at the European level.

During the 1990s, LIVIC and INRIA together developed the La Route Automatisée (LaRA) concept, which offers a long-term vision of fully automated vehicle operation. LaRA provides a conceptual framework to the work in progress today.

In addition to involvement in European projects described above, the main IV projects in France are listed as follows:

- ARCOS;
- LAVIA intelligent speed assistant;
- Truck automation deployment analyses.

LIVIC’s work in truck automation is examined in Chapter 10. ARCOS and LAVIA are briefly described below.

ARCOS ARCOS is the largest of the French national research projects, funded at 18 million euro. The project lasted from 2001 to 2004 and includes 60 French partners from both industry and academia.

ARCOS focuses on four functional areas:

- Prevention of dangerous headways;
- Prevention of collision with obstacles;
- Prevention of lane and road departure;
- Prevention of secondary accidents by means of vehicle-vehicle communication.

Research topics are as follows:

- Collecting situational information: Perception techniques, visibility and friction measurement, wireless communication;
- Defining optimal vehicle trajectories: Information processing, actuator design, accidentology, and the machine reasoning necessary to choose the correct path;
- Defining the proper level of human-machine cooperation depending on the situation;
- Assessing potential solutions: Acceptability (individual and societal), socio-economic impacts, liability, regulation, and conducting experiments.

“Target functions” and an overall deployment road map defined within the ARCOS project were outlined in Chapter 2. The objective for the current phase of ARCOS is to demonstrate Target 1 functionality (i.e., a combination of autonomous vehicle sensing functions and basic vehicle-vehicle communications). Final results of this phase of ARCOS were presented in late 2004.

LAVIA: The French Project of Adaptive Speed Limiter The French Ministry of Transport and the Directorate of Research and Scientific Business and Techniques is supporting experimentation to assess ISA in terms of acceptance by drivers and effects on their driving behavior. The Limiter Adjusting to the Authorized Speed (LAVIA) project aims to accomplish this by exploring functional approaches ranging from advisory to mandatory. The project began in 2001, and results are expected in 2005.

In addition to LIVIC, the LAVIA partnership includes the following:

- The Laboratory of Behavioral Psychology and the Department of Assessment and Research in Accidentology of INRETS, which are charged with the experimental design;
- Automakers Renault and PSA Peugeot Citroën, which are responsible for implementing the adaptive speed-limiting systems as well the data collection systems;
- The joint PSA-Renault Laboratory of Accidentology and Biomechanics, which is assessing the potential effects of LAVIA on road safety.

More information on LAVIA is provided in Chapter 9.

4.2.4 IV Research in Germany

IV research in Germany has been concentrated within two programs: INVENT and FleetNet.

INVENT [19, 20] As in the rest of the world, private corporate research dominates IV research in Germany. In the highly competitive environment of the automotive industry, little or no information is released regarding these activities. At the precompetitive level, however, the German government has a long history of funding automotive technology development. During the nineties, the MOTIV program developed advanced collision avoidance systems and approaches to low-speed ACC, for instance.

MOTIV's successor, called INVENT, is one of the most forward-looking programs worldwide, reaching beyond the classic field of autonomous safety systems to investigate cooperative approaches (for instance, examining ways that vehicles can cooperate with each other to improve traffic flow). The program focuses on "extending the information horizon" of the vehicle through communication and is developing applications in active safety, congestion assistance, cooperative maneuvering, and FCD techniques. A central principle is to avoid reliance on infrastructure systems, given uncertainties as to how (or if) the various national governments in Europe would deploy supporting infrastructure.

INVENT is a 76 million euro program, which began in 2001 and is set to finish in 2005. Of its funding, 45% is from the German Federal Ministry of Education and Research, and the remainder is contributed by the domestic vehicle industry. INVENT partners consist of the major automakers in Germany, as well as key technology suppliers and academia. Presentation of final program results will occur in 2005.

The program is divided into five areas of focus, which are briefly described as follows.

Detection and Interpretation of the Driving Environment Basic sensing of the driving environment, via radar and other sensors, is relatively mature technologically. More sophisticated sensing is needed to accomplish more complex functions.

The goals for this program component are to specify sensors in a unified and standardized manner, create a comprehensive inventory of performance characteristics of sensors, and define a detailed set of scenarios and real-world objects that can be used for validation testing. Researchers seek to use the sensor suite to create a synthetic image of the driving environment available to all driver support systems operating on the vehicle.

Congestion Assistant Congestion Assistant supports drivers in "stop-and-go" traffic situations (i.e., congested low-speed traffic). The goals are to use driver assistance technology and vehicle-vehicle cooperation to gain steadier traffic flow and more homogenous vehicle headway distribution, allow more rapid dissipation of congestion, and reduce the "fender-bender" rear-end collisions that are common in this type of traffic. The topic of improving traffic flow via IV systems is addressed in-depth in Chapter 9.

Driver Behavior and Human-Machine Interaction (HMI) Methodological approaches are being developed that can translate to design guidelines for HMI. Task complexity, burden, and risk are assessed for various traffic situations. A searchable and extendable driver behavior database is being created for application to current and future questions.

Key goals include the development of a “self-explanatory driver assistance system” and the development and standardization of an objective evaluation procedure for driver-assist systems. HMI issues for IV systems are explored in-depth in Chapter 12.

Anticipatory Active Safety Research in anticipatory active safety is aimed at addressing crash situations with more sophisticated systems than those currently on the market. Systems are being developed for lateral control assistance, intersection assistance, protection of pedestrians and cyclists, and predictive control of vehicle dynamics. These functions are being evaluated with respect to feasibility and prospective safety benefits. Testing is under way using both simulators and demonstrator vehicles.

Traffic Impact, Legal Issues, and Acceptance A wide array of traffic, legal, and user acceptance issues are under investigation by the INVENT team. These are described further in Chapter 13.

FleetNet [21] Another project, FleetNet, active from 2000 to 2003, explored the potential of ad hoc communication networking techniques for vehicle communications. FleetNet participants included DaimlerChrysler, Bosch, NEC Europe, and several universities in a cost-shared arrangement with the German Ministry for Research and Education. FleetNet is further discussed in Chapter 9.

4.2.5 Activities in the Netherlands

The Netherlands is an active and quite interesting locus of IV R&D. From the government side, Dutch IV activities are focused within the Transport Research Center (AVV), part of the Ministry of Transport, Public Works, and Water Management. Significant research is also ongoing with the national laboratory TNO. A major academic research program called AIDA is centered at the University of Twente, and, as noted in Chapter 3, one of the most advanced bus transit systems worldwide (Phileas) is now operating in the city of Eindhoven.

AVV [22, 23] The policy framework of the Dutch ministry of transport is to promote the safety and utilization of the national road infrastructure by simulating and encouraging improved vehicle technologies. Automated vehicle guidance (AVG) is seen as a key technology towards this end. The AVG strategy entails the following:

- Monitor developments;
- Conduct field operational tests;
- Stimulate the market and provide incentives;
- Identify impacts on safety and throughput;
- Identify infrastructure impacts and requirements;
- Develop a vision and implementation scenario for the future.

A key focus in recent years was field trials of lane departure warning assistance (LDWA), which were completed in late 2003. The aims were to gain insight into the

effects of LDWA on traffic flow, capacity, and road safety, as well as to give publicity to driver-assistance systems and LDWA to improve understanding of the concepts. The LDWA trial focused on professional drivers operating heavy-duty trucks and long-distance buses. More information is available in Chapter 6.

TRANSUMO [24] More recently, the TRANSUMO program was initiated by AVV. A partnership involving Dutch industrial, governmental and knowledge institutes, TRANSUMO focuses on using in-vehicle telematics as a “breakthrough technology” to improve quality of travel and sustainable mobility via assessing the potential of such systems in terms of safety, throughput, reliability and environmental effects. The IV project within TRANSUMO, funded at 5 million euro, addresses areas such as autonomous in-car systems (e.g., ACC and lane keeping) and cooperative vehicle-vehicle-based systems (such as C-ACC and cooperative collision avoidance). The IV component is led by TNO, with Delft University of Technology and the Technical University of Twente as key contributors.

To transition from the current road-vehicle system toward a sustainable intelligent road-vehicle system, TRANSUMO researchers are addressing challenges such as defining human-centered functional concepts; assessing the outcomes of these concepts on driving, safety, and traffic performance; assessing the value of the outcomes in the eyes of key stakeholders; and developing implementation strategies and policies.

Roads to the Future Working closely with TRANSUMO, AVV’s “Roads to the Future” program has been created to identify and evaluate innovative sustainable mobility solutions for traffic and transport problems that focus more on the near term. An early step within the program will be to sponsor a pilot called “The Assisted Driver” in 2005. The intent here is to highlight the potential safety and traffic efficiency benefits of advanced forms of ADAS, such as combined ACC and lane-keeping support.

TNO [25] TNO is a central figure in developing practical short- and long-term implementations of cooperative vehicle-highway systems. TNO has continuing involvement in European projects and is one of the world’s leading developers of traffic simulation models and vehicle design and testing tools.

As reviewed in Chapter 2, TNO experts see separate road and vehicle developments gradually integrating, moving first to a coordination phase and then to full road-vehicle interaction.

Based on this vision, TNO has established the SUMMITS program, whose key objectives are the following:

- Develop concepts and systems for the intelligent road-vehicle system in 2015;
- Develop a set of advanced integrated tools for design, testing, and evaluation;
- Apply concepts, systems, and tools in pilot projects.

SUMMITS runs from 2003 to 2006 and involves the participation of six institutes within TNO and a budget of approximately 5 million euro. The organization envisions partnering with European governments and the vehicle industry to define and conduct the pilot projects.

Preliminary concepts developed in SUMMITS to date are listed as follows:

- Fail-safe and technically robust IVs;
- Cooperative and assisted traffic merging at road discontinuities, such as free-way entrance ramps and bottlenecks;
- Cooperative traffic management and dynamic navigation.

In the simulation models, consistency is being implemented to integrate the modeling levels of driver, vehicle, and systems. Integrated assessment of this type is essential to facilitate trade-offs between:

- Traffic safety (including risk levels);
- Traffic efficiency;
- Environmental issues (e.g., emissions and noise).

The initial phases of SUMMITS focus on vision development, tool selection, and early design of concepts. The middle phase will emphasize integrated tool development, early assessment of concepts, and seeking international collaboration. In the final phase, pilot projects will be conducted.

AIDA [26–28] The AIDA research center, set up by TNO and the University of Twente, addresses the application of integrated driver support systems and services. Its aim is to carry out innovative research and to educate students working in the field of driver-support systems. Research themes include the interaction between IVs and intelligent infrastructure, assessment of system effects, and user needs and impacts of integrated driver-assistance systems.

Ongoing research projects are addressing the effects of various forms of ACC on traffic, effects of ACC at motorway on-ramps, and design and assessment of a cooperative road-vehicle system to support the interaction between vehicles and traffic lights.

4.2.6 IVSS in Sweden

Sweden has acted as a pioneer in several ITS areas, with ITS research led by the Swedish National Road Administration (SNRA). A current area of IV focus is its IV safety systems program, which is geared toward promoting the development of safety applications. Running from 2003 to 2008, IVSS is supported by \$45 million in funding from SNRA and the Swedish Agency for Innovation Systems and matching industry funding of \$35 million.

Sweden's contribution to one specific aspect of the IV field—ISA—cannot be overstated. SNRA conceived, developed, and field-tested the concept such that some form of ISA will likely come into being on European roads and vehicles in the coming years. Its focus on speed compliance is driven by Sweden's vision zero commitment to completely eliminate road fatalities, as outlined in Chapter 2. As further discussed in Chapter 9, SNRA conducted initial ISA research during 1999–2002, with field operational tests in four cities. Approximately 5,000 vehicles were driven by approximately 10,000 drivers. The purpose of this research was to study driver attitudes and use of the systems, assess road safety and environmental impacts, and define conditions for large scale implementation. The tests were seen as successful,

and SNRA is now proceeding to implement ISA on a wider scale. Also, SNRA is now leading the PROSPER project, which examines ISA on a European level.

Another area of SNRA leadership has been in FCD systems. Its Optimized Traffic in Sweden (OPTIS) project was initiated with the purpose to develop a sufficient and cost-effective method of collecting data on traffic to create good traveler information. FCD for this purpose is seen as a precursor for ADAS systems enhanced by FCD. This effort also came to a successful conclusion and a more extensive FCD deployment is now under way for Gothenburg and Stockholm. Ongoing Swedish FCD work is outlined further in Chapter 11.

4.2.7 United Kingdom [29–31]

A wide variety of IV R&D is ongoing in the United Kingdom, a portion of which is described here. The nation's Vision 2030 results were outlined in Chapter 2.

CVHS Program The U.K. Department for Transport has defined CVHS as a priority within its ITS program. CVHS is defined by the U.K. Department of Transport as “an array of vehicle and road-based sensors, processors, and communication links, that enable two-way interaction between both the road infrastructure and individual vehicles, and directly vehicle to vehicle.” A major CVHS study was commissioned in 2003, funded at £246,000 (~\$380K). This study is further described in Chapter 9.

ISA-U.K. U.K. researchers participated in early phases of European ISA research during the late 1990s. The current phase of ISA work is examining driver behavior with and without speed limiters activated. The project is funded by the Department for Transport and is being led by the University of Leeds and the Motor Industry Research Association (MIRA). This research is further described in Chapter 9.

AutoTaxi AutoTaxi is a two-year collaborative project that is developing a safety critical sensor system for autonomous vehicles within the ULTra guideway system. It is based on fusing data to enable collision avoidance and automatic guidance, incorporating the sensing technologies of radar, video, and optical ranging devices. ULTra is further described in Chapter 10.

Millimetric Transceivers for Transport Applications (MILTRANS) [32] The MILTRANS project is a three-year project supported by U.K. government funding, led by the BAE Systems Advanced Technology Center. The aim is to design, build, and demonstrate a high-speed data link between mobile and stationary terminals operating in the band of 63–64 GHz, as a technology building block for vehicle-infrastructure and vehicle-vehicle communications. MILTRANS is further discussed in Chapter 9.

Radar Automated Lane Following (RALF) Within the U.K. Foresight Vehicle program, the RALF project, completed in 2003, was focused on examining the feasibility of developing lane markings that would be “visible” to radar. RALF was funded at £120,000 (~\$185K) on a cost-shared basis with industry.

SLIMSENS SLIMSENS focuses on integrating communications capability with 76-GHz long-range radar. This project is further discussed in Chapter 9.

4.3 United States

4.3.1 U.S. DOT [33]

The U.S. DOT initiated its ITS program around 1990 and has conducted significant IV R&D since that time. From 1992 to 1997, research and prototyping of AHSs was conducted, culminating in the very successful Demo '97, showcasing automated vehicle technology on highways in California. During that time, early work in developing performance requirements for first generation crash avoidance systems was also conducted.

In 1998, work was refocused to emphasize near-term safety research under the Intelligent Vehicle Initiative (IVI) program. IVI continued through 2004, at which point new initiatives were defined that took into account progress to that point and future trends. R&D under IVI and the new activities are reviewed here.

The significance of active safety systems for meeting U.S. road safety goals has been recognized. The chief of the National Highway Traffic Safety Administration (NHTSA) within the U.S. DOT, Dr. Jeffrey Runge, stated in 2004 that his agency should “shift the focus of safety efforts to avoiding crashes instead of simply protecting people when a crash happens. The future will be about crash avoidance.” [34]

IVI Program The stated IVI program goal is in “preventing traffic crashes and the fatalities and injuries they cause.” The program objectives are two-fold: to prevent driver distraction and to facilitate the accelerated development and deployment of crash avoidance systems.

IVI addresses four classes of vehicles: light vehicles, commercial vehicles, transit vehicles, and specialty vehicles. The program is focused on improving safety under three driving conditions:

- Normal driving conditions;
- Degraded driving conditions;
- Imminent crash situations.

As shown in Table 4.2, the majority of the IVI investment in the last five years has been in the imminent crash domain.

Table 4.2 U.S. IVI Program Funding Allocations

(\$141 Million in Total Funding During 1998–2003)

<i>Domain</i>	<i>System type</i>	<i>% System type</i>	<i>% Domain</i>
Normal driving			14%
Degraded driving			18%
	Vision enhancement	2%	
	Vehicle stability	10%	
	Driver condition	6%	
Imminent crash			69%
	Rear end	30%	
	Road departure	19%	
	Intersection	12%	
	Lane change/merge	7%	

The U.S. DOT's vision of the evolution of IVs focuses on first generation individual vehicle-based sensor systems evolving toward integration of multiple sensors and systems. In parallel, infrastructure-based sensors will be developed and deployed. With the advent of roadside-vehicle communications, IV systems and intelligent infrastructure systems converge so that CVHS can then be deployed for added safety benefit.

Some key projects are highlighted in the following sections.

Naturalistic Driving Study Naturalistic driving is being studied in a one-year program in which 100 vehicles are equipped with unobtrusive instrumentation to observe regular drivers on actual roadways. This study is the largest instrumented vehicle study ever attempted. The intent is to deepen the scientific understanding of how drivers drive in normal situations to provide a baseline for other research. If successful, larger studies are planned in coming years. Researchers report that, in addition to significant amounts of basic data, several crashes have occurred in equipped vehicles so far, providing a unique opportunity to understand crash dynamics. Further information is provided in Chapter 12.

Collision Avoidance Metrics Partnership (CAMP) [35] Several projects are under way through this partnership consisting of BMW, DaimlerChrysler, Ford, GM, Navigation Technologies, Nissan, Toyota, and Volkswagen.

Driver workload metrics and test procedures are being developed to assess the impact of various in-vehicle systems on driver workload. These tools will enable car manufacturers to make informed decisions as to which functions should be available to drivers while driving. Experiments are being conducted using a driving simulator, test track, and public roads.

In the Enhanced Digital Maps project, funded at \$8.2 million, the feasibility of improved digital maps to support collision-avoidance systems has been investigated. Over 60 safety-related applications have been identified that could potentially benefit from improved digital maps.

Requirements for forward collision warning systems have been a key focus of the CAMP work from its inception. An initial set of requirements was completed in 1999, and current work focuses at a more detailed level.

In the vehicle safety communications project, the potential of DSRC for supporting collision avoidance systems is being investigated. This work is further described in Chapter 9.

Passenger Car Rear-End Collision Warning In the Automotive Collision Avoidance System (ACAS) project, the largest operational test within the IVI program, the U.S. DOT has partnered with General Motors, Delphi, and others to equip 10 Buicks with both forward collision warning and ACC. The cost-shared project is funded at \$35 million. A key goal of the testing is to determine if this technology can truly lead to fewer crashes and if the performance of the system can meet customer expectations. This work is further reviewed in Chapter 7.

Passenger Car Road Departure Avoidance A \$16-million field operational test is under way to help drivers avoid road departure crashes. The system warns drivers when they are about to drift off the road and crash into an obstacle, as well as when

they are traveling too fast for an upcoming curve. Technologies include a vision- and radar-based lateral drift warning system and a map-based curve speed warning system. The radar sensors enable the system to scan for any roadside obstacles and adjust warning timing appropriately. This project is further reviewed in Chapter 6.

Passenger Car ICA Systems The IVI program's key emphasis in cooperative vehicle- highway systems was in the area of ICA. Such "intersection decision support" systems have been prototyped for traffic signal intersections, stop sign intersections, and left-turn-across-path situations. Demonstrations of these systems were held in 2003 at the Federal Highway Administration R&D center. Both infrastructure-only and vehicle-infrastructure cooperative systems have been developed and are under evaluation.

This research is performed under the Infrastructure Consortium (IC), which is a partnership of California, Minnesota, and Virginia, in-state universities, and FHWA. The purpose of the IC is to develop and evaluate innovative ICA systems. The IC plans to complete its research phase in 2004 and then move on to field operational testing with all system types within 2–3 years. See Chapter 9 for more on this activity.

Evaluation of Active Safety Systems for Heavy Trucks The U.S. DOT maintains an active and ongoing focus on the use of active safety systems to improve truck safety. These activities are focused within the Federal Motor Carrier Safety Administration (FMCSA). Current and recent projects include the following:

- Commercial vehicle driver fatigue management: Developing drowsy driver warning systems for heavy truck drivers has been a high priority for U.S. DOT for many years. Recently, pilot testing has been completed of a commercially available driver alertness monitor that measures eyelid droop via infrared illumination of the eyes.
- Commercial vehicle rollover stability system: An IVI field operational test with Freightliner Corporation resulted in the successful test of its rollover stability advisor and controller. The system warns the driver when the vehicle is at risk of rollover and slows the vehicle to maintain stability if the driver does not respond. This type of system is now offered commercially and is further discussed in Chapter 9.
- Commercial Vehicle Lane Departure Warning—an in-depth test of LDWS is being conducted in a project led by Mack Trucks which will be completed in 2005.
- Commercial vehicle forward collision warning: Commercially available FCW was evaluated in this test using Volvo Trucks within the U.S. Xpress motor carrier fleet.
- Electronically controlled braking systems (ECBS): Field operational testing of ECBS is being conducted by Freightliner Corporation in cooperation with the Walmart trucking fleet. Results will provide U.S. DOT key input in the process to open U.S. markets to ECBS technology.
- Active deployment facilitation: FMCSA is working to facilitate deployment of active safety systems on heavy trucks and buses by working with the industry to define system requirements and assess costs and benefits, with the ultimate

goal of encouraging fleets to purchase these systems in large numbers. Forward collision warning, lane departure warning, and rollover collision avoidance systems are being emphasized.

Special Vehicle Driver Support IV technology shows great promise in supporting professional drivers who must operate in degraded conditions. A key example is winter operations for snowplow, police, and ambulance drivers. The U.S. DOT is working with Minnesota DOT and the University of Minnesota to evaluate a driver-assist system that indicates the vehicle position within the travel lane (on a heads-up display) even when visibility is at or near zero due to blowing snow. The lane information relies on differential GPS, which is augmented by magnetic markings in the pavement. Forward and side-looking collision avoidance provides warnings as to any obstacles ahead.

Transit Bus Collision Warning Systems [36] The Federal Transit Administration (FTA) has partnered with researchers and transit agencies across the United States to prototype and evaluate collision warning systems for forward, side, and rear-impact collisions. While the overall safety record of bus transit is good, minor forms of such collisions are not uncommon and the resulting costs are significant—it has been estimated that these costs are as high as \$800 million annually in the United States, mainly due to legal costs and damage awards from lawsuits.

The outcome of the FTA R&D program will be performance specifications for such systems to guide commercial developers and transit agencies in commercialization. In addition, optimum driver-vehicle interfaces are being investigated, particularly for the case of a system that integrates all of these functions into a single system. Specific activities are described in Chapters 6 and 8.

New Initiatives [37] In 2004, the U.S. DOT ITS program was reorganized into a focused set of nine initiatives. These are listed as follows:

- Mobility services for all Americans;
- Integrated corridor management systems;
- Universal electronic freight manifest;
- Integrated vehicle-based safety systems (IVBSS);
- CICAS;
- Emergency transportation operations;
- Vehicle infrastructure integration (VII);
- Nationwide surface transportation weather observation system;
- Next Generation 9-1-1.

Three of these initiatives are of interest from an IV perspective and are discussed here in brief: IVBSS, CICAS, and VII.

While there is an extensive body of knowledge on countermeasures for unilaterally addressing individual crashes; the IVBSS initiative will be the first attempt to fully integrate these individual solutions. Goals are to do the following:

- Consolidate current information about available countermeasures;

- Perform additional research into integration of the driver-vehicle interface (DVI);
- Develop objective tests and criteria for performance of systems that simultaneously address common types of crashes;
- Design appropriate data acquisition systems.

Building on research conducted to date by the IC, the CICAS program approach will pursue an optimized combination of autonomous-vehicle, autonomous-infrastructure, and cooperative communication systems that address a wide range of intersection crash problems, culminating in a series of coordinated field operational tests. These field operational tests will also help achieve a solid understanding of safety benefits and user acceptance. VII (see below) will provide the enabling communication capability necessary for cooperative crash avoidance systems.

The U.S. DOT's work to pursue VII will potentially result in a sea change in the relationship of roads, vehicles, and drivers. The VII goal is to achieve nationwide deployment of a communications infrastructure on roadways and in all production vehicles and to enable a number of key safety and operational services that take advantage of this capability. The envisioned approach calls for vehicle manufacturers to install the technology in all new vehicles, beginning at a particular model year, while, at the same time, federal, state, and local transportation agencies would facilitate installation of a roadside communications infrastructure to achieve safety and mobility benefits.

To determine the feasibility and an implementation strategy, a partnership has been formed that consists of the seven vehicle manufacturers involved in the IVI, the Association of State Highway and Transportation Officials, and U.S. DOT. Discussions are focused on a decision point in the 2008–2009 timeframe regarding proceeding with full-scale deployment of communications technology in both the vehicles and the infrastructure: what questions must be answered, and what analyses performed to make this decision? As a technology enabler for VII, the U.S. DOT is continuing to support DSRC standards activity and has initiated a program to build prototype DSRC communications equipment to test the viability of these standards.

4.3.2 IV R&D at the State Level

Within the United States, two states—California and Minnesota—have maintained significant and ongoing IV research programs. Their activities are briefly outlined here.

California [38] The California DOT seeks to facilitate and accelerate deployment of advanced vehicle control and safety systems (AVCSS), which it sees as key to relieving congestion and improving safety, efficiency, and environmental impacts. Research is conducted by the Partnership for Transit and Highways (PATH), a research organization within the California university system. Specific objectives are listed as follows:

- Evaluate the relative merits of different technical solutions;
- Optimize systems to solve California problems;

- Integrate vehicle and infrastructure elements to find the best mix;
- Demonstrate technical feasibility;
- Address societal and institutional issues.

One area of emphasis is research toward a robust AHS. Development of basic functions were pioneered by this program, and current work is concentrating on abnormal/fault conditions, deployment staging, development and demonstration of truck and bus automation capabilities, and developing answers for skeptics.

PATH has demonstrated, separately, automated platoons of three transit buses and three tractor-trailer trucks. Implementation of automated operations in these domains is seen as feasible in the middle term and could serve as a pathway toward passenger vehicle automation. For truck operations, the feasibility of deploying exclusive automated truck lanes in high-demand freight corridors is also being examined.

Additionally, Caltrans-PATH are involved in 35 “base” funding projects in areas such as collision warning, vehicle control, and automation concepts. Other state-funded work includes support to BRT research, and development of advanced rotary snowplow automatic steering control. U.S. DOT-sponsored PATH projects include collision warning system development for transit buses in the areas of forward and rear collisions, BRT lane assistance evaluation, and intersection decision support (IDS) system development within the IVI IC.

California also leads a cooperative vehicle-highway automation systems (CVHASs) research program that is supported by pooled funding from eleven states. Because vehicle-highway automation on the regular highway system is seen as long-term, initial CVHAS case studies have focused on “stepping stone” concepts such as BRT and automated freight movement. For instance, a CVHAS case study in the Chicago area focused on truck automation (further discussed in Chapter 10).

Minnesota [39] The University of Minnesota ITS Institute focuses on human-centered technology to enhance safety and mobility. Within the Institute, the IV Laboratory focuses on improving the operational safety, mobility, and productivity of vehicles.

The IV Laboratory uses as experimental testbeds the SAFETRUCK, a heavy truck tractor-trailer; the SAFEFLOW, a full-size plow truck; and the TechnoBus from Metro Transit in Minneapolis. Extensive driver-vehicle interface issues are examined via a state-of-the-art driving simulator. The laboratory’s driver-assist approaches concentrate strongly on differential GPS and high-accuracy digital maps, such that no hardware is required in the road surface.

As one of three partners in the IC, the IV Laboratory has developed an infrastructure-based IDS system that detects approaching high-speed traffic and advises drivers not to make a left turn from a minor road onto a major road when their sight is obscured (further described in Chapter 9).

A key activity is the IVI specialty vehicle testing, described above, which provides driver assistance for low visibility conditions related to snow conditions. A unique and sophisticated heads-up display allows lane boundaries and obstacles to be projected in real time as an overlay to the actual road scene. The IV laboratory has also implemented “gang plowing,” in which vehicles under automatic control

are platooned at a lateral offset to allow simultaneous plowing of several free-way lanes.

Another major activity for the IVs lab is providing steering assist to bus drivers operating their vehicles on highway shoulders in the Minneapolis-St. Paul area. The nine-foot-wide bus operates on a 10-foot shoulder, with the driver-assist system providing haptic feedback regarding lane edges to the driver.

4.3.3 IV R&D Under Way by the U.S. Department of Defense [40]

Research funded by the U.S. Defense Advanced Research Projects Agency (DARPA) and the Army Research Lab (ARL) constitutes a leading edge in IV research that promises to contribute to future systems for regular highway vehicles. ARL R&D has focused on off-road autonomous vehicles to perform the military scout function, for instance.

At DARPA, the Mobile Autonomous Robot Software (MARS) project is seeking to develop perception-based autonomous vehicle driving/navigation, with vehicle intelligence approaching human levels of performance, capable of operating in the full range of on-road environments.

Capabilities targeted for autonomous vehicle operation for the 2007 timeframe include road lane tracking, vehicle detection, obstacle detection and avoidance, entering and exiting highways, highway sign recognition, pedestrian detection, and negotiating road intersections, traffic signals, and stop signs. MARS is further described in Chapter 10.

4.4 Contrasts Across IV Programs Worldwide

From the preceding sections, it is clear that governments worldwide are investing in the potential for IV technology to greatly enhance road safety. The author estimates that well over \$100 million is invested by the public sector in IV R&D on an annual basis.

Several commonalities and contrasts emerge from examining the global set of activities. Depending on the nature of the government role in a particular country, government programs vary in size. In Japan and Europe, in addition to safety, public funding to support technology development is seen as contributing to industrial prowess and international competitiveness. In contrast, the United States focuses more on system evaluation and funding of precompetitive scientific level work, such as driver workload studies.

One example of a unique scientific investigation in the United States is the naturalistic driving studies sponsored by the U.S. DOT. The data collected during this modest test has the potential to be a treasure trove of useful information for developers of driver-assistance systems. No other project of this type is under way elsewhere in the world.

After over a decade of conceptual discussions, R&D is rapidly ramping up to make “communicating vehicles” a reality, taking advantage of the continuing evolution of wireless communications and resulting reductions in component costs. In addition, the relative maturity, from a research perspective, of first generation crash avoidance systems has created “space” to examine more sophisticated system approaches that incorporate vehicle-vehicle and vehicle-infrastructure

communications. A prime example of this is the increasing emphasis on ICA system development, as well as the Vehicle Infrastructure Integration work in the United States and similar activities in other parts of the world. Further, numerous sessions at the 2004 ITS World Congress in Nagoya, Japan, were focused on the CVHS, which was considered a fringe issue only a few years earlier. While Japan has an intrinsic advantage in implementing CVHS due to centralized government and relatively tight control over the vehicle industry, the United States and EC are now also stepping strongly into facilitator roles to bring the vehicle industry together with road authorities to realize the potential of CVHS.

Pedestrian detection is another area of contrast. While R&D in this area is quite active in Europe and Japan, in the United States the only work in pedestrian detection is funded by DARPA as part of the MARS autonomous driving effort. This is a direct reflection of the magnitude of the pedestrian fatality problem in different areas—the problem is most severe in Japan, moderate in Europe, and not a major part of the crash picture in the United States.

The development of countermeasures for drowsy driving has been a priority across the board. It is interesting, however, to note that in the United States the emphasis here is on drivers of heavy trucks rather than cars. In fact, the United States has by far the greatest emphasis on active safety systems for heavy trucks, partly due to the U.S. DOT structure (which includes the FMCSA) and partly due to the high volumes of long-haul truckers on America's roads.

With regard to crash avoidance for transit buses, the United States is completely unique, again reflecting the U.S. DOT structure, which includes the FTA.

With regard to ICA, Japan's AHSRA initially led the way, with the United States subsequently very active in this field since the establishment of the IC. Only recently, with initiation of PReVENT within the 6FW program, has ICA become a major focus in Europe.

Looking toward the future, robust and vigorous programs are under way in all areas, several of which have recently been reaffirmed as public priorities. This is evidenced, for instance, by the content of the European 6FW and the recent reorganization of the U.S. DOT's ITS program, which maintains major IV research content in three of eight major initiatives.

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IV Priorities and Strategies for the Vehicle Industry

With roughly 40 million vehicles produced annually in Europe, Japan, and the United States, the vehicle industry comprises a major component of the world economy. Fundamentally, automobiles are a consumer product and easily one of the largest value purchases made by individuals to support their personal activities. Therefore, every feature offered on a vehicle must be responsive to the needs and desires of individuals, which includes their desire to receive a high value for their money and limit the total amount spent. Generally speaking, the consumer's perception of value, rather than actual cost, rules pricing, particularly for high-tech systems.

IV systems for convenience and safety are generally ranked highly by consumers in terms of function, yet their willingness to pay is much lower. An exception is luxury automobiles, partly because customers are less price-sensitive in general and because an IV system priced at, say, \$2,000, is a much lower portion of the total cost when the vehicle itself sells for well over \$50,000. However, after introduction in the luxury market, IV systems are gradually making their way into mid-range cars and costs are coming down.

Because IV systems, including active safety systems, are not mandated by any governments at this point, the litmus test for the viability of these systems resides with the customer. The level of investment by the vehicle industry in R&D to bring such systems to the market indicates that it expects strong consumer interest to develop over time. Some industry experts have estimated the worldwide market potential for ADAS to reach \$1 billion by 2010 [1].

This section describes the degree of activity under way at both the vehicle manufacturer level and the supplier level, as a "reality check" for the IV systems described in this book. It will likely become evident to the reader that IV systems are indeed taken seriously by the automotive industry.

The vast majority of R&D under way within the vehicle industry is kept confidential for competitive purposes. However, OEMs and suppliers also have an interest in participating in joint precompetitive work and promoting their technological prowess, such that a useful body of information is available to survey automotive industry activity in the IV domain. The following sections provide an indication of the driver support philosophies and emphasis areas for these major industry players. The information is provided as a "quick read," (i.e., only a glimpse of a much broader set of activities any particular OEM may be involved in).

Virtually all of the major automotive companies are involved in cost-shared R&D with the public sector. Referring to the diverse set of programs described in

Chapter 4, Tables 5.1 and 5.2 provide a summary of the involvement of individual companies in selected projects.

5.1 Automobile Manufacturers

5.1.1 BMW [2]

BMW's driver-assist activities fall under their ConnectedDrive program. ConnectedDrive is focused on the intelligent integration of the car, the driver, and their surroundings.

BMW is seen as a leader in technology introduction for driver assist. It was one of the first automakers in Europe to introduce ACC and first generation adaptive headlights, for instance. Activities directly related to product development include backup aids, side object warning, low-speed ACC, brake force display, forward collision warning, map-supported adaptive light control, LKA, and automated parallel parking. BMW is also developing and testing advanced techniques in FCD.

BMW is quite active in joint government-industry projects in Europe and the United States. Areas of activity include radar networks, sensor fusion, ADAS supported by digital maps, vehicle safety communications based on DSRC, human factors, and nontechnical barriers to market introduction. BMW is also active in the European-level eSafety working groups and is a major participant in the German INVENT program.

5.1.2 DaimlerChrysler [3, 4]

DaimlerChrysler (commonly referred to by its stock exchange symbol, DCX) is widely recognized as a world leader in IV R&D, with a stated vision of "cars that don't crash." DCX has also been in the forefront of introducing driver-assist systems, beginning in Europe with ACC for cars and lane departure warning for heavy trucks. DCX was also the one of the first to introduce ACC in the United States, on Mercedes Benz vehicles.

Product-oriented development is focusing on functions such as forward collision warning, advanced backup aids, side object detection, LDWS, low-speed ACC, lane-keeping, driver monitoring, and integration of passive and active safety systems. Advanced R&D is focusing on pedestrian detection and tracking, road sign recognition, low-speed automated driving, and, in general, intelligent perception of complex urban driving environments. Vehicle-based ICA, based on machine vision and radar, is an area of particular interest. In the future, DCX expects that intervehicle communication relying on mobile ad hoc networks will play a key role.

DCX is also one of the few auto manufacturers actively addressing traffic flow improvements. Research in its Telematics Lab combines vehicle intelligence, traffic foresight (via wireless communications), and cooperative maneuvering to improve safety, comfort, and traffic efficiency (see Chapter 9 for further elaboration). FCD techniques are a key area of interest within the lab, as well; DCX researchers are working in partnership with BMW to address advanced approaches (Chapter 11). They envision these telematics features serving to extend the "information horizon" far beyond the view of onboard sensors, enhancing safety and traffic flow and lowering driver stress as a result of fewer "surprises" while driving.

Table 5.1 OEM and Major Supplier Participation in Selected European Commission Projects

Project	Vehicle Manufacturers										Major European Suppliers									
	BMW	DCX	Ford Europe	Ford/ Jaguar	Ford/ Volvo Cars	GM/ Opel	GM/ Saab	GM/ Fiat	PSA	Renault	VW	Volvo Trucks	Bosch	Continental	Hella	Siemens	TRW	Valeo	Other	
ActMAP	•							•								•				
ADASE2	•	X		•				•	•	•										
ADVISORS								•								•				
AWAKE								•								•			Autoliv	
CARSENSE	•									•							•			
CARTALK		X						•					•							
CHAMELION					•		•	X	•	•			•							
CHAUFFEUR II		X						•				•	•							
COMMUNICAR		•			•			•					•							
EDEL				•				•					•							
EUCLIDE		•			•			X					•							
INARTE					•			X		•			•							
IVHW		•							•	•			•							
IPReVENT	•	X	•		•			•	•	•	•		•			•	•		Delphi	
PROTECTOR		•						X								•				
RADARNET	•	•		•	•			•								X				
RESPONSE2	•	•	X			•		•	•		•		•				•	•	Autoliv, Delphi, Denso, Visteon	
SARA	•	X	•	•	•	•	•	•			•		•	•	•		•	•		
SAVE-U		•									•					•				

X = lead organization
• = core partner
• = associated partner

Table 5.2 OEM and Major Supplier Participation in Selected U.S. Projects

	Vehicle Manufacturers (car)								Vehicle Manufacturers (heavy truck)		Major Suppliers		
				General					Freightliner	Mack			
Project	BMW	DCX	Ford	Motors	Honda	Nissan	Toyota	VW	(DCX)	(Volvo)	Volvo	Delphi	Visteon
ACAS FOT				•								•	
CAMP FCW			•	•									
CAMP Driver Workload			•	•		•	•						
CAMP EDMap		•	•	•			•						
CAMP VSCC CVHAs	•	•	•	•		•	•	•					
Electronically-Controlled Braking FOT									•				
FCW/ACC FOT											•		
Lane Departure Warning FOT										•			
Road Departure Warning FOT													•
Rollover Counter-measures FOT									•				
SAV-IT												•	
VII Working Group	•	•	•	•	•	•	•	•					

Further, DCX is a major truck manufacturer, with R&D and product development in both Europe and the United States (Freightliner, Sterling, Western Star). Its focus is on compensating for human errors, at the same time maintaining the driver's role as the most critical factor in controlling the vehicle. At the company's Innovation Symposium 2004, the head of the company's commercial vehicle division estimated that 90% of all crashes could be avoided if all of the new active safety technologies were to be introduced on a broad scale. Products already introduced include forward collision warning, ACC, lane departure warning, and rollover countermeasures. DCX announced at that event that its intelligent braking system, which would be introduced in Europe in 2006, would warn the driver of an impending crash and then take over braking if the driver did not respond appropriately. Also in development are driver drowsiness detection systems.

At the European level, DCX participates in eSafety working groups and many European projects, reflecting its research interests noted above. During the 5FW era,

DCX was the lead organization for the ADASE2, CARTALK, and CHAUFFEUR2 projects. In the 6FW, DCX leads the PReVENT integrated project. DCX is also a major participant in the German programs INVENT and FleetNet and collaborated with French partners to develop the IVHW system. The company is a major participant in U.S. activities, as well, including CAMP, EDMAP, and VSCC.

5.1.3 Fiat [5]

Fiat, Italy's premier automaker, and plays a major role in VII, relies on Centro Ricerche Fiat (CRF) as a key R&D engineering center. CRF maintains staff and laboratories in all aspects of automotive engineering, including safety. IV activities are focused in its Electro Telematic Systems area, which focuses upon the following:

- Safety and traffic efficiency for both private and public transport;
- Comfort and safety in personal mobility applications;
- Seamless portability of applications and services.

Technical activities include system architecture design, onboard networking, wireless technologies (long- and short-range), human machine interfaces, cooperative lane keeping, and satellite positioning systems coupled with advanced DRMs to support driver assistance.

IV systems marketed by Fiat include ACC and blind spot monitoring.

Fiat is extensively involved in European projects. During the 5FW era, CRF was the lead organization for EDEL and EUCLIDE and participated in other projects relating to precrash sensing, driver monitoring, intervehicle communications, next generation radar technology, and nontechnical issues in introducing ADAS systems to the market. CRF is also a core participant in the 6FW PReVENT integrated project.

5.1.4 Ford [6–8]

Ford Motor Company owns the Premier Automotive Group (PAG), whose major members consist of Ford, Jaguar, Land Rover, Mazda, and Volvo. PAG offers the company an opportunity for synergies across vehicles and regions. For instance, new technology can be introduced and evaluated initially in the Japanese market, where customer interest in technology is higher, customers are more forgiving of system limitations, and the liability risks are less severe.

PAG is involved in government-industry collaborative projects to develop new radar and communications technology, as well as safety systems based on advanced digital maps. It is also participating in the evaluation of ISA (through Volvo) and the development of driver workload measures. FCD techniques are also under evaluation; this work is reviewed in Chapter 11.

Recognizing the need to scientifically assess driver workload issues, Ford has built a \$10-million full-scale, moving-base driving simulator laboratory called VIRTTEX to study driver workload and distraction issues related to new in-vehicle electronic devices.

To highlight its IV activities, Ford equipped a Taurus model in 2003 with forward collision radar, low-light cameras, blind spot monitoring, lane-departure, and

rear-collision warnings with telematics information services. An integrated mobile phone can block incoming calls if precrash sensing and navigational data tells the system the driver is too busy to answer.

Within the PAG, the Volvo safety concept car (SCC) is a showpiece of IV systems that may be introduced in future vehicles. The SCC includes the following features:

- Eye detection to adjust seating and pedals;
- Blind spot monitoring;
- Adaptive headlights;
- Enhanced night vision;
- Forward collision warning;
- Lane departure warning;
- Lane change support.

Another area of investigation by Volvo is its intelligent driver information manager, which classifies and prioritizes driver information based on the current traffic situation (as determined by monitoring the driver's steering and braking patterns).

Also, as noted above, Mazda offers the PAG the opportunity to evaluate advanced systems in the more benign Japanese environment. Mazda participates in the Japanese ASV program and, based on its ASV work, has started public road trials of full-speed range ACC with brake control, an advanced front lighting system, and a forward obstacle warning system that detects both vehicles and pedestrians. The obstacle warning system provides automatic braking if the driver does not initiate braking appropriately.

Mazda is also evaluating the use of rearward sensing to protect occupants in rear-end collisions. When an impending crash is sensed, the vehicle system activates seatbelt pretensioners and adjusts headrests automatically.

PAG is well represented in European 5FW projects, with Ford Europe leading RESPONSE2 and focusing on frequency allocations for radar sensors. Jaguar has been involved in projects focusing on next generation radar networks and night vision, with Volvo Cars active in precrash sensing, sensor fusion, ADAS applications enabled by digital maps, and radar networking as well. Further, Ford Europe and Volvo Cars participate in the 6FW PReVENT project, and Ford Europe also participates in the German INVENT project. Within the U.K. Foresight Vehicle program, Jaguar participated in the RALF project described in Chapter 4.

As a cofounder of CAMP in the United States, Ford is actively involved in driver workload evaluations, development of objective test procedures for forward collision avoidance systems, ADAS enhanced by positioning and digital maps, and DSRC-based communications.

5.1.5 General Motors [9–12]

GM leads the world in auto sales and maintains an extensive R&D program at its technical center in Warren, Michigan. GM partnered with the U.S. DOT to evaluate ACC and FCW in the ACAS project, which has been the centerpiece of

the U.S. DOT's IVI program. GM is also a founding member of CAMP and a leading voice in VII discussions. Within CAMP, GM participated in forward collision warning requirements development, driver workload evaluations, ADAS enhanced by positioning and digital maps, and DSRC-based communications. GM also led the NAHSC in partnership with the U.S. DOT during the 1990s.

At a press event in 2003 to kick off ACAS road testing, a General Motors executive in its R&D and planning department offered a view into the company's future technology development plans. Systems now on (or very close to being on) the market, in time-sequenced order, were listed as follows:

- Antilock braking systems;
- Traction control;
- Semiactive suspension;
- Integrated chassis control;
- Adaptive variable effort steering;
- Near obstacle detection;
- Vision enhancement.

GM's advanced technology "development stream" was listed as follows, indicating systems coming to market between 2003 and 2010, again in time-sequenced order:

- ACC;
- Forward collision warning;
- Skid warning;
- Lane sensing/warning;
- Driver performance monitoring;
- Forward collision avoidance (FCA) (braking);
- Lane keeping;
- Road-to-vehicle communication;
- Intersection warning;
- Vehicle-vehicle communication;
- Collision avoidance (steering).

Other areas of interest include computer-controlled steering and adaptive lighting systems.

GM owns the European car manufacturers Saab and Opel. Saab's research activities include development of a driver attention warning system that relies on miniature infrared cameras mounted in the instrument panel to monitor the driver's head, eye, and eyelid movements. Opel is also a member of the German INVENT project. As well, Saab and Opel participated in projects related to precrash sensing, radar frequency allocations, and addressing nontechnical issues in ADAS market introduction within the 5FW program.

5.1.6 Honda [13, 14]

Honda is working to provide “safe, secure, and comfortable” mobility that will harmonize safety, security, comfort, good environment, and smooth traffic. Its driver-support system research encompasses crash prediction, crash avoidance, and cooperative vehicle-infrastructure research.

Honda introduced its intelligent driver support system in Japan in 2002, which incorporates radar-based ACC, LDW, and LKA (see Figure 5.1). Also in 2003, Honda was the first company worldwide to introduce a forward collision safety system to go beyond warning the driver to actively braking the vehicle. This feature, called the collision mitigation braking system (CMBS), provides several levels of driver warning and activates hard braking at the last moment to mitigate a collision. This is seen as a way of balancing deference to the driver’s judgment on one hand, with active intervention on the other hand, in those cases where the driver does not respond and the collision probability approaches 100%. In 2004, Honda again scored a world’s first by introducing intelligent night vision to the Japanese market on its new Legend sedan. Based on far infrared sensing, the system detects pedestrians in the forward path and highlights their presence on the in-vehicle night vision display screen. These systems are further described in Chapter 7.

Additional development activities focus on an adaptive frontlighting system, which swivels an in-board headlight as the vehicle enters a curve based on the driver’s steering inputs.

Within Japan’s ASV project, Honda is investigating intervehicle communication between cars and motorcycles so as to provide warnings of relevant vehicle movements that may be hazardous, especially at blind intersections and other situations where the driver’s vision is obscured. Honda is also a member of AHSRA and participates in SmartCruise R&D.

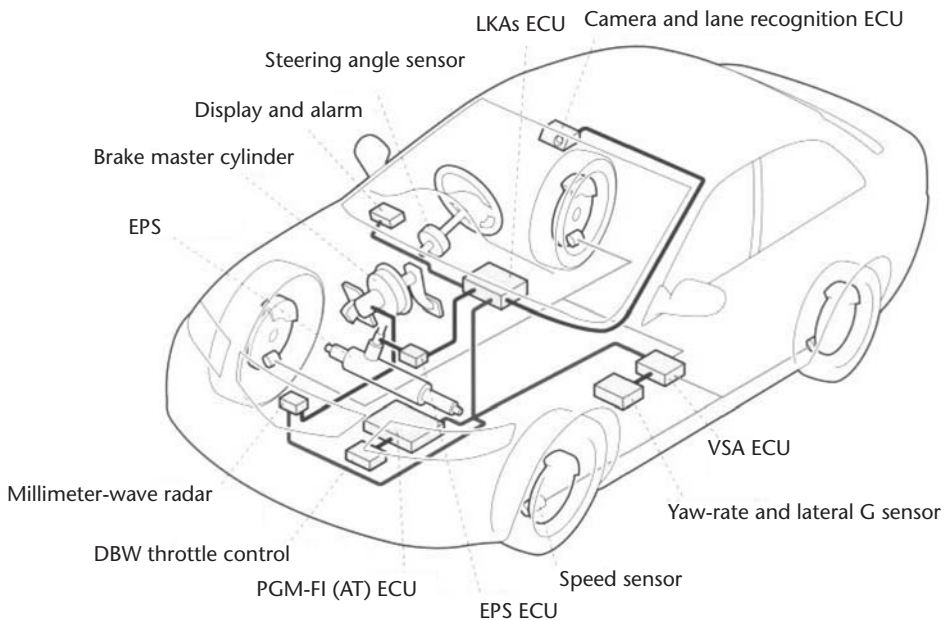


Figure 5.1 Honda intelligent driver support system components. (Source: Honda.)

In the United States, Honda participates in the CVHAS pooled-fund study. The company was a key participant in the NAHSC Demo '97, as well.

5.1.7 Mitsubishi [15]

Similar to other Japanese manufacturers, Mitsubishi Motors has introduced a wide variety of driver-support functions to the Japanese market and participates in AHSRA and ASV. Mitsubishi has also participated in joint research with its strategic partner DaimlerChrysler. This includes vehicle-vehicle communications technology development in the FleetNet project as well as an innovative approach to lane departure warning using the camera integrated in commercially available personal digital assistants.

5.1.8 Nissan [16–18]

Nissan's vision focuses on "a society free of crashes," as well as environmentally sustainable vehicle operations and optimizing the convenience and comfort of driving. Nissan's driver assistance philosophy spans the full breadth of the safety spectrum: advance information to prevent crash situations from developing, emergency vehicle control in the moments just prior to a possible crash, occupant protection measures prior to and during a crash, and automatic crash notification for emergency assistance after a crash.

Nissan has introduced a wide range of driver-support systems and pioneered several innovations. In 1988, it introduced the Traffic Guide forward collision warning system based on lidar for professional truckers in Japan, which transitioned to the car market in the 1990s. Infrared laser-based ACC is currently available worldwide on Nissan models, as is preview braking assist. In 2002, Nissan was the first OEM worldwide to introduce the lane-keeping function (Japanese market) and was also the first to introduce a LDWS for the North American car market on model year 2005 Infiniti vehicles. In 2004, Nissan was also one of the first to offer low-speed ACC in the Japanese market. Collision mitigation braking, side blind spot monitoring, and adaptive frontlighting systems are also available on Nissan vehicles in Japan.

In the research arena, Nissan was one of the first to investigate driver drowsiness detection techniques and an active program in this area continues. Other topics of research are side obstacle warning, active brake control for emergency maneuvering, information exchange systems for intersection safety, and infrared-based sensing of pedestrians and animals to the rear of the vehicle. This IR-based sensing approach also drives the pointing of adaptive headlights so as to better illuminate pedestrians or wildlife.

An effective and user-centered human-machine interface that integrates multiple driver support functions is an area of particular emphasis.

Nissan is an active participant in the Japanese ASV program and functions developed in initial ASV phases have led to current products. It also participates actively with AHSRA projects. One area of particular interest is the Guidelight concept, the cooperative road-vehicle illumination system described in Chapter 4.

In the United States, Nissan participates in several activities, including the CAMP driver workload research, DSRC evaluations within the VSCC project, and VII.

5.1.9 PSA Peugeot Citroën [19–21]

In 2004, PSA was the first to introduce lane departure warning on passenger cars in Europe, and it is in advanced development stages for a multimode adaptive frontlighting system.

Extensive research work has also been conducted in night vision systems. In addition to the typical passive IR system approach, PSA has experimented with an active system that illuminates the forward scene with IR light and detects reflections. It is also studying ways to analyze the image to alert the driver to specific hazards, such as pedestrians.

PSA has participated in European 5FW projects focusing on topics such as precrash sensing and societal, policy, and legal issues. The company is a core member in the PREVENT 6FW integrated project, and participated in the joint French-German IVHW project. PSA is also a core member of the French ARCOS program.

5.1.10 Renault [22]

Renault takes a comprehensive approach to safety, based on the principle of “safety for all.” The aim is to guarantee all vehicle occupants the same level of safety, regardless of the size of the vehicle.

Renault’s concept of “integral safety” focuses on four main areas, described as follows:

- Prevention: Assist the driver in anticipating risks and determine factors that contribute to reducing the probability of a crash;
- Correction: Assist driving in difficult or emergency conditions and correct driver errors (being careful to retain the driver’s primary role in operating the vehicle);
- Protection: Ensure optimum protection for all occupants in the event of an accident;
- Education: Inform the public of its role in improving road safety.

Road-holding and braking are seen as fundamentals that underpin active safety. In this regard, Renault offers vehicles with ABS, traction control, emergency braking assistance (which boosts braking power when the brake pedal is rapidly depressed), and electronic stability control. For convenience, radar-based ACC is also offered on the company’s Vel Satis models.

Renault has participated in European 5FW projects focusing in areas such as policy and societal issues, ADAS communications architecture, sensor fusion, precrash sensing, and ADAS supported by digital maps. Renault participated in the joint French-German IVHW project and is a core member of the PREVENT 6FW integrated project. Renault is also a core member of the French ARCOS program.

5.1.11 Subaru [23]

Subaru vehicles are produced by Fuji Heavy Industries, Ltd. In 1999, Subaru was one of the earliest to introduce ACC and lane departure warning products on the Japanese market. Uniquely, it has used stereo vision technology for these systems, which provides both the visual image for processing as well as depth perception, enabling range to objects to be determined.

Developmental efforts focus on sensor fusion of stereo vision with radar, so that objects ahead can still be detected even when vision is obscured by such factors as weather. In addition, crash avoidance using automatic steering control is under development, as well as autonomous driving based on high-accuracy GPS.

5.1.12 Toyota [18, 24–28]

Toyota is the leader in car sales in Japan by a wide margin and maintains an extensive array of R&D activities. The Toyota Group consists of Toyota, Aisin Seiki, Aisin AW, Denso, Fujitsu Ten, Daihatsu Cars, and Hino Trucks. At the 2004 ITS World Congress in Nagoya, Japan, the Toyota Group offered a massive exhibit addressing its view of the future in terms of safety, environment, and comfort. The key idea is to maximize benefits and “zero-nize” negative impacts, including road crashes. In fact, Toyota’s stated long-term objective is zero deaths, zero injuries, and zero car crashes.

The company frames driver assistance in terms of sense assist, judgment assist, and operation assist. As shown in Figure 5.2, its timeline shows “car intelligence” steadily increasing in future years, with enhancements provided by road-vehicle communication coming in 2005 and vehicle-vehicle communication around 2010. The following decade is seen as the time when Smartway (extensive information exchange with surrounding traffic via wireless communication) and Smartcar (automated driving) will emerge.

At the product level, Toyota offers ACC and preview brake assist worldwide, and lane departure warning, LKA, night vision, collision mitigation braking, and automated steering to support parallel parking maneuvers on the Japanese market. Toyota was the first to introduce the “automated parallel parking” system described in Chapter 3. Its new generation of CMBS has recently been introduced, fusing machine vision with the original radar system to provide earlier collision prediction and higher injury-reduction performance. In 2004, Toyota was one of the first to offer low-speed ACC to the Japanese market.

Systems in development for Hino Trucks include precrash safety technology, as well as lane departure warning, left- and rearview assist camera, nighttime pedestrian monitoring, ACC, and driver-condition monitoring. Their driver drowsiness-monitoring approach uses video recognition to track facial features illuminated by infrared LEDs.

Within both the Japanese ASV program and internal research, Toyota investigations have included intervehicle communications, obstacle detection using stereo cameras, and pedestrian monitoring. As with Honda and Nissan, Toyota is a key participant in AHSRA activities. Toyota is also a core member of the Internet ITS Consortium, whose goal is to realize ubiquitous wireless connectivity for cars to

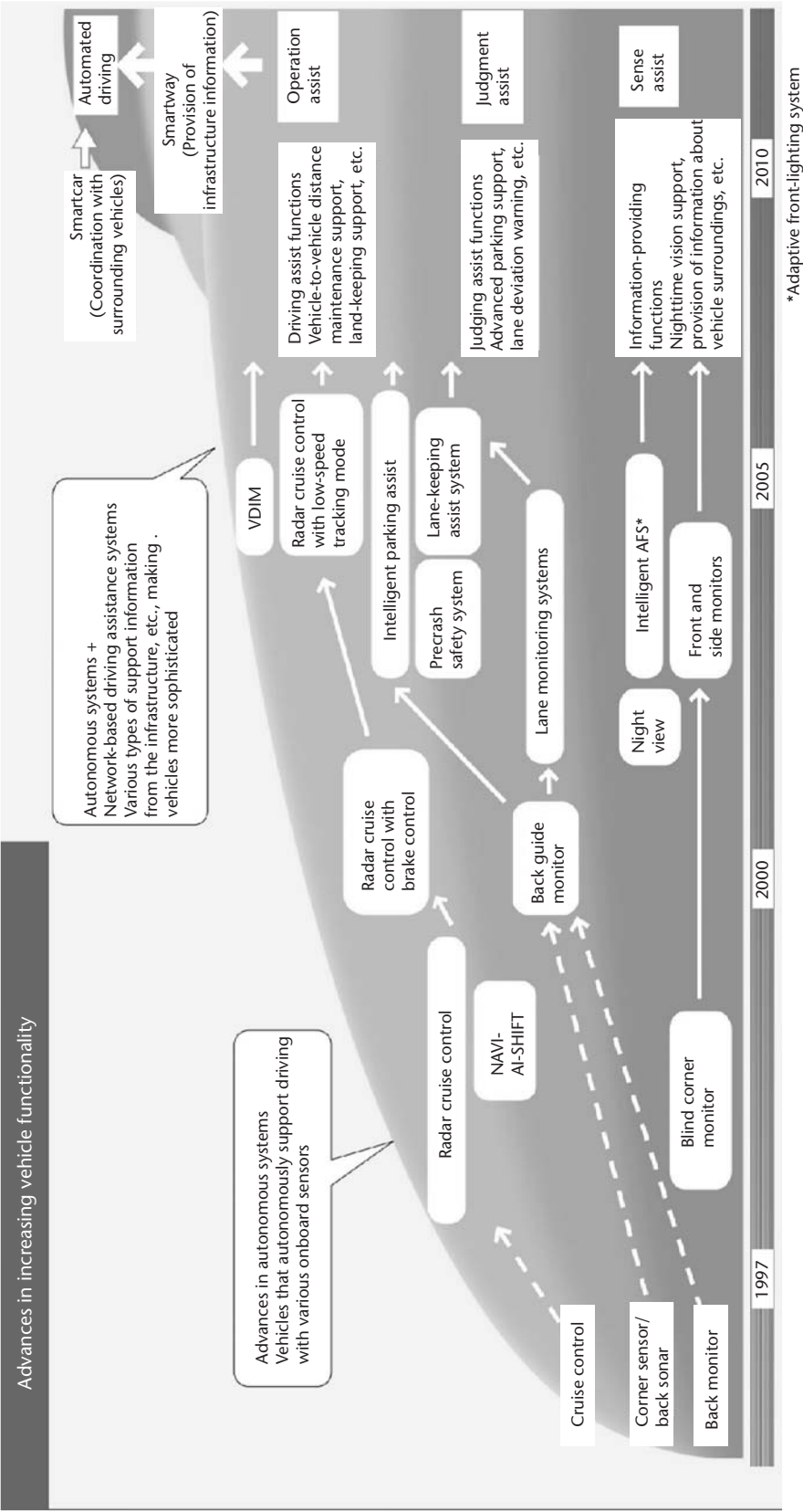


Figure 5.2 Toyota's timeline for IV highway systems. (Source: Toyota.)

provide commercial and safety services. Over 100 automotive and electronics companies within Japan are Internet ITS members.

Toyota also pioneered the introduction of vehicle automation on public transportation with the development of the Intelligent Multimode Transit System. This system provides automated platoon driving of buses serving the Awajishima Farm Park in Japan. Similar buses will operate at Expo 2005 in Nagoya. See Chapter 10 for more information.

In the United States, Toyota participates in the CAMP driver workload evaluation R&D, DSRC evaluations, ADAS applications enabled by digital maps, and VII. The company was a key participant in the NAHSC Demo '97, as well.

5.1.13 Volkswagen (VW) [29]

VW is one of the major automotive manufacturers worldwide. Its IV systems appear on both the VW and the Audi car lines, with ACC currently being sold in Europe and the United States.

VW's R&D focuses on the use of radar (short- and long-range), machine vision, laser scanners, and GPS techniques. Functions of interest include low-speed ACC, lane departure warning, and lane change assist, including development of later generation systems that go beyond isolated driver-assistance systems to networked systems based on sensor fusion techniques.

VW participates in European 5FW projects focusing on topics such as radar frequency allocations, legal issues, and pedestrian detection and avoidance. The company also participates in the 6FW PReVENT integrated project and is a participant in the German INVENT activities. In the United States, VW participates in DSRC evaluations and serves on the VII working group.

5.1.14 Volvo Global Trucks [4, 30]

AB Volvo encompasses the manufacturing of Mack, Renault, and Volvo trucks worldwide. Volvo seeks to ensure that "well-educated drivers have access to trucks with a growing IQ," (i.e., IV systems that help drivers maintain safety in all situations).

Forward collision warning, blind spot warning, ACC, and lane departure warning are already offered, and future systems of interest include rollover and drowsy driver countermeasures.

Volvo participated in the CHAUFFEUR II European 5FW project to implement electronic tow-bar capability between heavy trucks. The company is also involved in the French ARCOS research program. In the United States, both Mack and Volvo trucks have been involved in field operational testing of active safety systems within the USDOT IVI program.

5.2 Automotive Industry Suppliers

A significant amount of R&D for driver-assist systems is conducted by the tier one automotive suppliers. Generally, they must develop these systems at their own expense

and then seek to sell them to automotive OEMs for volume production to recoup their investment. Translating research capability into low-cost system designs for large-scale production is one of the prime challenges in this regard. Therefore, suppliers must be very selective in terms of the functions and systems they seek to develop.

As in the previous section, a sampling of suppliers and their involvements is provided in this section to provide a sense for key investment areas. Many of the large tier one suppliers are covered, as well as some of the smaller players bringing unique technology to the IV arena.

5.2.1 Aisin Group [31, 32]

Aisin is the second largest automotive supplier in Japan and consists of several subsidiaries, including Aisin Seiki Co. Ltd. and the IMRA R&D centers. A substantial portion of advanced driver-assist systems on Toyota vehicles is supplied by Aisin, including ACC, parking assist, and lane departure warning. Aisin offers a unique LDW approach that takes advantage of the rearview camera, installed for backup assist, to detect lane position at highway speeds.

Aisin envisions future systems such as front and side monitoring, more advanced parking assist, lane keeping assist, drowsy driver warning, and automated highway systems. Research topics include image processing and advanced signal processing.

5.2.2 Bosch [33]

With an annual research investment of 2.3 billion euro (2001), Bosch is clearly one of the world's preeminent automotive R&D houses. Using radar, vision, and other sensors, Bosch seeks to create a "virtual safety belt" around the vehicle.

For general driver support, it is developing blind spot monitors, low-speed ACC, full-speed range longitudinal support, lane change support, lane departure warning, LKA, semiautonomous parking assistance, and night vision optimization.

Bosch's long-range radar (77 GHz) for ACC is in production on the BMW 7 series and the Fiat Stilo. Its short-range radar (24 GHz), scheduled for production in 2005, will support blind spot monitoring and low-speed ACC. Custom sensor chips under development for video image processing are expected to be ready by 2005 for low-cost production for automotive products. In the works as well is full-speed range ACC based on both long- and short-distance radar sensing integrated with vision sensing. Bosch's semiautonomous parking assistant provides automatic steering using ultrasound sensing to guide the maneuver.

Bosch's predictive safety system (PSS) combines active and passive safety. The first generation PSS, expected to enter production in 2005, uses ACC sensors to recognize an impending crash and precharge the brakes for optimum braking force. The second generation system (2006) would also provide warnings to the driver, and the ultimate PSS (2009) would stop the vehicle automatically to avoid a crash.

The Bosch research agenda includes vision-based drowsy driver countermeasures, road sign recognition, "Car2Car" ad hoc vehicle-vehicle communication networks, pedestrian detection, and ICA. The company has noted that if longitudinal guidance is augmented by LKA, automatic driving is possible in principle.

Bosch's involvement in European projects during the 5FW was extensive and reflected the research topics above, as well as sensor fusion, night vision enhancement,

development of electronic tow-bar capability, establishment of radar frequency allocations, and examination of nontechnical issues in introducing ADAS to the market. It is a core member of the 6FW PReVENT integrated project and participates in the German INVENT and FleetNet projects. Figure 5.3 shows the full range of Bosch's focus in the comfort and safety arena, and Figure 5.4 shows its view of the total sensing package to provide these features.

5.2.3 Continental [34, 35]

Within the Continental Group, Continental Automotive Systems includes Continental Temic, supplier of both passive and active safety systems, as well as Continental Teves, one of the largest manufacturers of hydraulic and electronic brake, stability and chassis systems, as well as electronic air suspension systems. Automotive Distance Control Systems GmbH, a subsidiary of Continental Teves, provides the DISTRONIC ACC system for Mercedes Benz and other automakers.

Sensor technology and control electronics are core to Continental's goal of the total integration of key safety components. Its Active-Passive Integration Approach (APIA) concept is focused on the development of a single system providing optimal functionality for significantly more efficient crash avoidance and protection, by networking active and passive safety systems, and integrating environmental sensors (see Figure 5.5). Within APIA, a danger control unit detects traffic hazards and determines the probability of a crash for the current traffic situation and, if necessary, initiates a staged hazard response to protect the occupants and other road users. A key design goal is cost reduction through the common use of components.

A further stage is "electric steer-assisted steering" and rollover protection based on individual wheel braking to intervene in rollover dynamics, as well as lane-keeping support based on image processing. Continental researchers are also developing image processing techniques to classify road users; in combination with radar or lidar, this is expected to increase the reliability of analyzing the traffic situation. Combined steering and braking interventions will support the driver in avoiding crashes.

5.2.4 Delphi [36–38]

Delphi is another of the giants within the tier one electronics suppliers. In 1999, Delphi's radar-based ACC was the first to be introduced to the market on Jaguar models and is now being sold on Cadillac vehicles as well. Delphi has focused its IV activities within the concept of the integrated safety system (ISS), which employs extensive integration of sensors, data, and drive-by-wire. In the precrash domain, ISS includes adaptive restraints, head/torso/side curtain airbag systems, active knee bolster, seat belt pretensioners, and crash data recording. Employing radar, laser, vision, and GPS and map technologies, collision warning development is focused on forward collision warning, blind spot monitoring, lane change support, and lane/road departure warning. Prototype systems employ active braking for FCM. Delphi's state diagram for collision avoidance and mitigation is shown in Figure 5.6.

Delphi's forewarn backup aid dual beam radar, scheduled to reach the market in 2005, helps drivers detect pets, children, vehicles, and other objects when backing. A future version will integrate radar data with a video image of the rearward scene so that the driver can see the hazard.

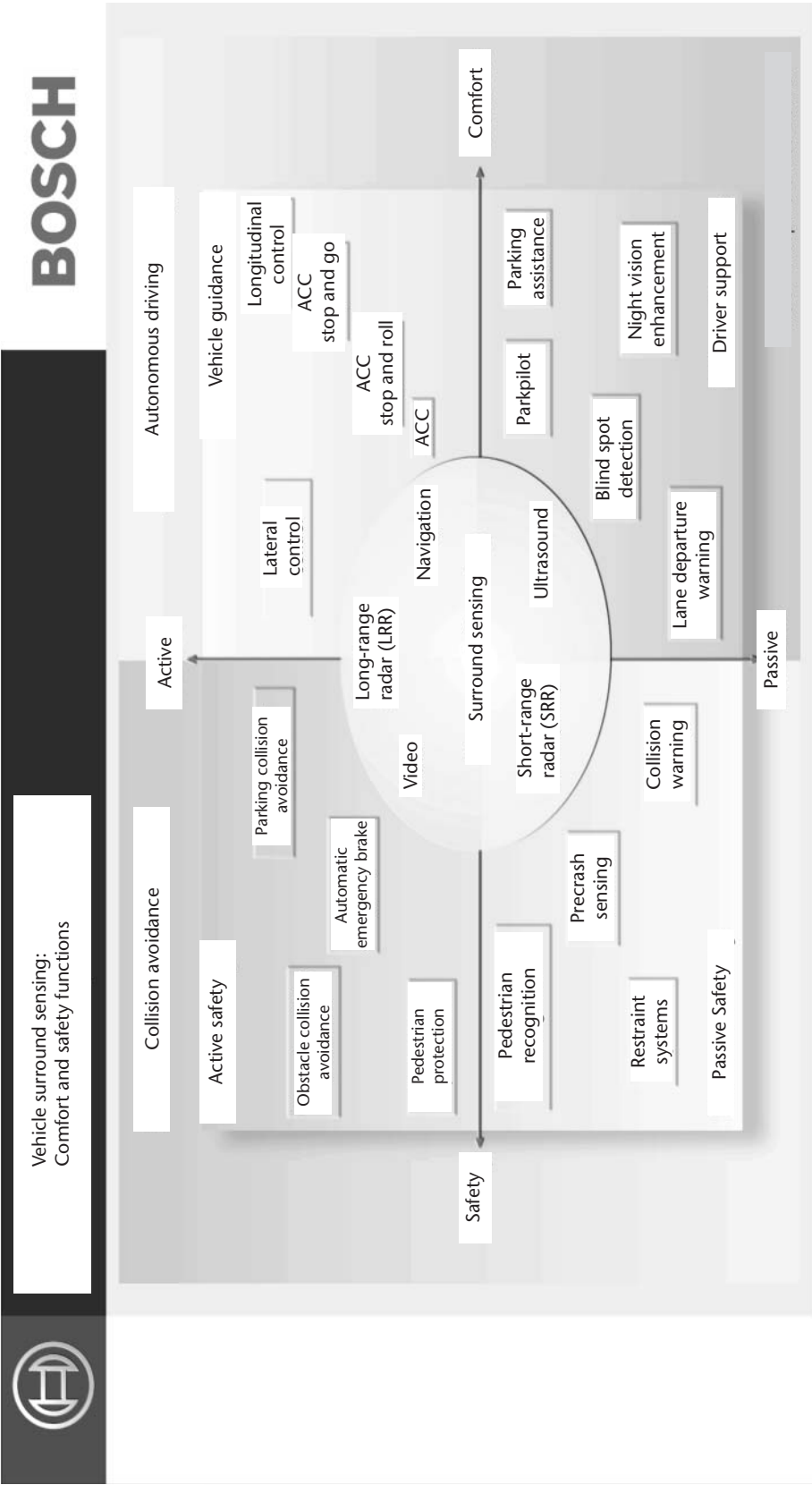


Figure 5.3 The Bosch spectrum and safety and comfort systems for driver assist. (Source: Bosch.)

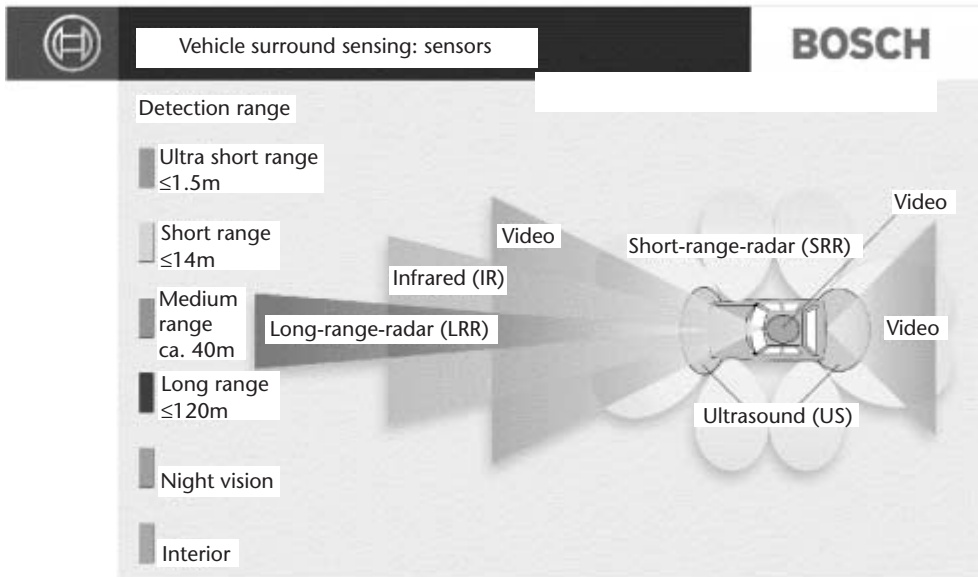


Figure 5.4 Bosch sensor suite for ADAS. (Source: Bosch.)

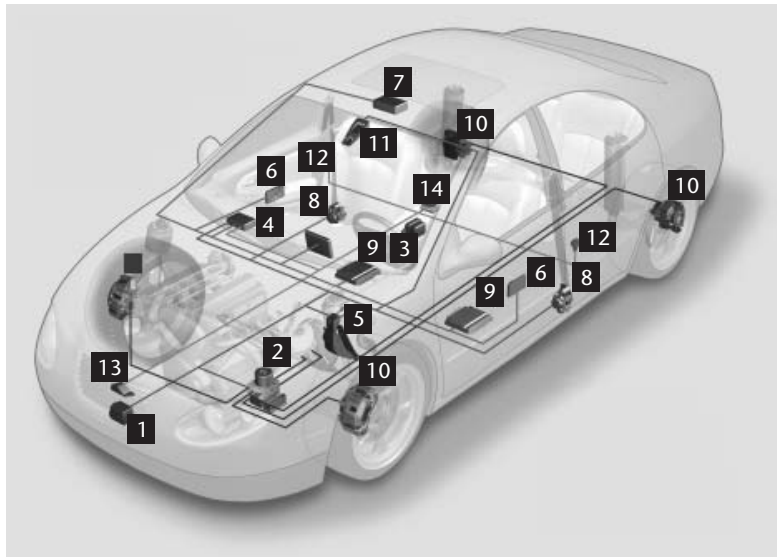


Figure 5.5 System components of Continental's APIA [1) ACC, 2) electronic brake system, 3) sensor cluster, 4) gateway data transmitter, 5) force feedback accelerator pedal, 6) door control unit, 7) sunroof control unit, 8) reversible seatbelt pretensioner, 9) seat control unit, 10) brakes, 11) closing velocity sensor, 12) side satellites, 13) upfront sensor, and 14) airbag control unit]. (Source: Continental Teves AG & Co.)

Dynamic Vehicle Safety Management Systems (DVSMS) enhance the vehicle's ability to respond to the driver's intentions and handle emergency situations. As one

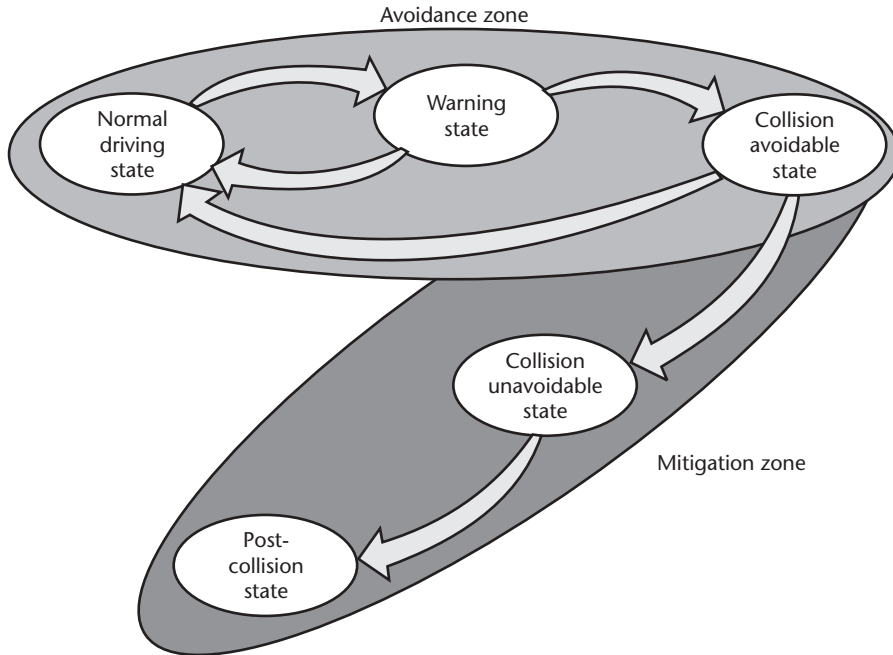


Figure 5.6 Delphi's state diagram for collision avoidance and mitigation. (Courtesy of Delphi Corporation).

aspect of DVSMS, collision avoidance systems employ Delphi's concept of unified chassis control to integrate controlled braking, suspension, and steering to avoid a crash. For example, steering and braking applied together in an emergency maneuver helps avoid excessive fishtailing and helps the driver bring the vehicle quickly under control.

Delphi is also a leader in the development of driver state monitoring systems. A combination of eye-tracking devices, biological sensors and vehicle steering all provide data on driver alertness or impairment, as well as information on whether the driver's gaze is focused on the road scene. Other sensors perform real-time evaluations of the environment, potential threats, and vehicle performance. With these data, the system can then detect a driver that is distracted, impaired, or inattentive. But then, how to get the driver back to a safe state? System feedback methods include lowering the radio volume, issuing a verbal warning, causing the seat to vibrate, or temporarily disabling in-vehicle devices such as the cell phone. If necessary, the system will enact appropriate safety measures. This system is scheduled for production as early as 2007.

Delphi is applying its driver state monitoring capability to the SAV-IT project in the United States. In Europe, Delphi participated in the 5FW activities focused on radar frequency allocations and is involved in the PReVENT 6FW integrated project.

5.2.5 Denso [39–41]

Denso is providing systems for both high- and low-speed ACC, which are on the market today. Denso is approaching improved vehicle safety through its enhanced safety and protection program. One result of this program is a precollision system

based on the ACC sensor and additional processing. Seatbelts are tightened and braking initiated in the moments just prior to an inevitable collision. Denso developed the system jointly with Toyota and introduced it in Japan in 2003 and in North America in 2004.

Denso offered an extensive review of its intelligent vehicle systems for safety, sustainability, and comfort under the banner of “Human First ITS” at the Nagoya ITS World Congress in 2004. A feature was the company’s intelligent warning system, which provides warnings of obstacles ahead with more or less urgency depending on the direction of the driver’s gaze. The sensing suite relies on the fusion of vision and radar or lidar. The system provides audible alarms and displays warning marks around the object on the windshield to focus the driver’s attention where it needs to be.

Other development areas are pedestrian detection, lane-keeping assist, driver monitoring, night vision, floating car data techniques, and low-speed following. Denso has also started a joint development program with Mobileye (see below) that focuses on image sensing and processing technology.

5.2.6 Hella [42]

Hella is developing a variety of driver-assist systems based on radar and optical technologies. Its ACC system uses a 16-beam lidar, for instance, and its LDWS based on machine vision will be ready for series production by 2006. The company envisions integrating the LDW camera, rain, and light sensors into one unit to minimize the overall space requirement and reduce costs. In addition, fusion of the LDW data with the data from an ACC system is currently under development; this will enhance ACC operation and support object recognition. In the night vision arena, Hella is developing an active system called ADILIS that illuminates the traffic scene with infrared light. The scene is then detected with an IR camera and displayed to the driver as a grey scale image. Also under development is a lane-change assistant that uses two 24-GHz radar sensors to recognize vehicles to the rear of the host vehicle in adjacent lanes, covering both the blind spot and an upstream range out to 50m. Hella envisions additional applications using 24-GHz radar technology including parking aids, low-speed ACC, precrash sensing, and collision mitigation. Its current 24-GHz radar unit is shown in Figure 5.7.

Hella participated in European 5FW projects focusing on night vision and radar frequency allocations and is a participant in the German INVENT program.

5.2.7 IBEO Automobile Sensor [43]

IBEO, a small technology firm, is leading the way in adapting laser scanner technology to the automotive sensing arena. Its ALASCA laser scanner can provide wide field-of-view obstacle detection in the short and medium range, with range information on the order of centimeters. Applications supported include low-speed ACC, precrash sensing, collision mitigation braking, lane departure warning, pedestrian recognition, and parking assist.

IBEO is cooperating with mirror systems supplier Lang Mekra for surveillance in near field around truck cabs for the commercial vehicle market. It has defined applications such as a turning assistant to detect objects immediately in front and to the side of a large truck tractor.

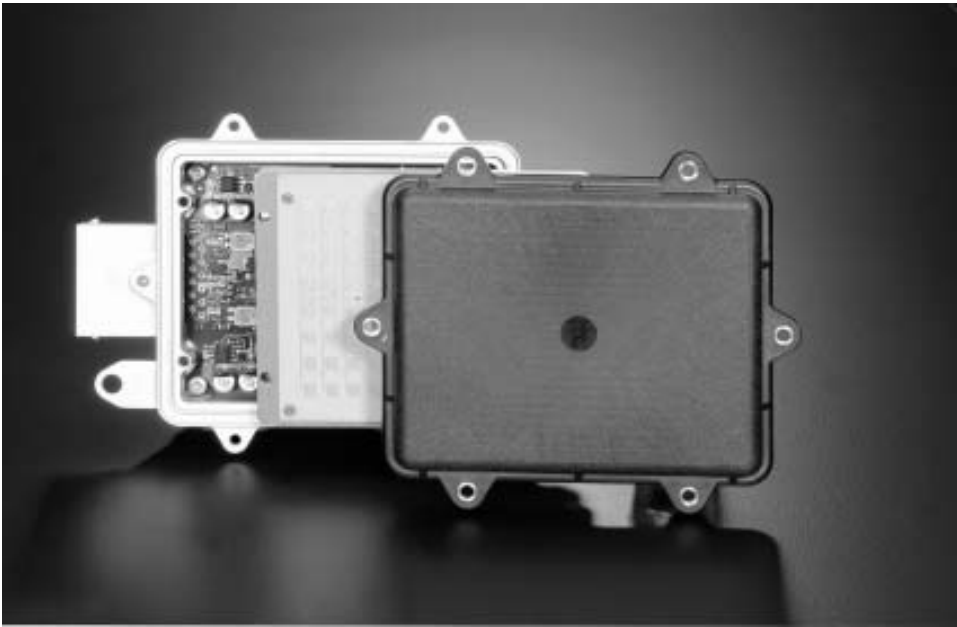


Figure 5.7 Hella 24-GHz radar sensor. (Source: Hella KGaA Hueck & Co.)

5.2.8 MobilEye [44]

While not a tier one supplier, MobilEye is notable, because it has pioneered monocular vision-based systems capable of providing range information. Compared to radar or lidar systems, this approach offers a low-cost means of implementing ACC and other forward-ranging applications. Further, the company is uniquely bringing warning-only applications to the automotive aftermarket. Image processing is performed on an application-specific IC developed by the company.

For OEM systems, applications supported include the following:

- Lane departure warning;
- Heading control;
- ACC;
- Low-speed ACC;
- Precrash active safety;
- Night vision;
- Pedestrian detection;
- Lane change aid/blind spot protection;
- Passenger detection and position.

Mobility's advance warning system (AWS) system for the after-market, which became available in 2004, incorporates lane departure warning, headway monitoring, and forward collision warning, which is also able to detect and warn of cut-in behavior by vehicles coming from an adjacent lane just forward of the host vehicle.

5.2.9 Siemens VDO Automotive [45–48]

Siemens VDO Automotive has a strong position in smart airbags and restraint electronics. It is pursuing the vision of a “seeing automobile” that recognizes crash hazards early on and reduces the consequences of crashes with adaptive restraint systems. The company seeks to develop IV systems that completely avoid road crashes.

Its ADAS R&D work includes radar, radar networking, image processing, sensor fusion, and intervehicle communications technologies. Applications of interest include lane departure warning, lane change support, pedestrian detection, drowsy driver countermeasures, urban obstacle detection, and driver assistance via digital maps and satellite positioning.

For lane change support, radar and video sensors are employed to continuously analyze the space behind the vehicle. The driver may be notified via slight steering wheel counterpressure when initiating a lane change in a dangerous direction.

Siemens’ lane departure warning system is based on vision processing like others in the industry; additionally, however, radar data is also incorporated to more robustly recognize lane markings of different quality under various weather conditions. The radar sensors also do double duty to recognize obstacles on the road.

Siemens is also applying its experience in active restraints and occupant protection with external sensing to respond appropriately to different types of collisions. For pedestrians, for instance, future car hoods will lift when they contact a crash victim to create an additional crush zone, or external airbags will fire. Siemens is developing the necessary radar, video, and ultrasound sensors and software so that the system reacts differently to an impending crash with a lamppost, for instance, versus a pedestrian or bicyclist.

In the European 5FW research program, Siemens VDO Automotive led the RADARNET project to develop a low-cost multifunctional radar network. Other project involvements focused upon drowsy driver monitoring, intervehicle communications, ADAS enhanced by digital maps, pedestrian detection, and radar frequency allocations. Siemens is a core partner in the 6FW PREVENT integrated project and participates in the German INVENT and FleetNet projects as well.

5.2.10 TRW’s Three-Phase Roadmap [49, 50]

TRW Automotive has published a three-phase driver assistance roadmap. The first phase consists of ride and handling optimization in the form of enhanced cornering via integrated steering/braking. The next phase, called “highly reactive vehicle control,” uses by-wire technologies and sensor fusion to assist drivers in emergency maneuvers. The third phase focuses on predictive control for collision mitigation and avoidance. By 2008, TRW seeks to vastly improve system performance through video and radar sensor fusion, at the same point having reduced system costs considerably.

TRW’s 77-GHz radar ACC system is currently being sold on Volkswagen (including Audi) cars, as well as heavy trucks. Figure 5.8 shows their first generation radar assembly. The company envisions current ACC evolving to a follow/stop approach for low-speed operation, then evolving further to stop-and-go operation.

Based on TRW’s long history as a steering components supplier, the company introduced a LDWS for heavy trucks in 2004, and expects to be producing



Figure 5.8 TRW's AC10 77-GHz radar unit currently used in first generation ACC systems sold by Volkswagen. (Source: TRW Automotive.)

active-steering lane following systems within five years. Other applications under development include automatic emergency braking, steering assist for semiautomatic parking, and emergency steering support to avoid obstacles.

Within Europe, TRW was a partner in 5FW projects focusing on sensor fusion for low-speed urban driving and radar frequency allocations. The company participates in the PReVENT 6FW integrated project as well.

5.2.11 Valeo: Seeing and Being Seen [51–53]

Valeo supplies a broad range of products to the automotive industry and maintains R&D budgets in the range of \$750 million annually. In 2001, Valeo initiated a domains-based approach to its technology and marketing strategy to optimally align its R&D activities and systems expertise to anticipated future needs of customers. Driver assistance is addressed within its “seeing and being seen” domain.” The goal is to address the single consumer and carmaker need for enhanced all-round visibility, both from within and from outside the vehicle, in all weather and traffic conditions.

Valeo's traffic environment sensing radar detects, processes, and tracks objects around the vehicle. It is intended to support parking, backup, blind spot, ACC, low-speed ACC, precrash sensing, and collision avoidance applications.

Technology demonstrator vehicles have been produced that incorporate lane departure warning, parking slot measurement, reversing aid, infrared night vision, and steer-able headlights. To achieve 360-degree surveillance around the

vehicle, technologies employed include ultrasonic, infrared, radar, vision, and sensor fusion.

Valeo has established two key partnerships in the driver-assistance field. The company signed a joint development agreement with Iteris, producer of the AutoVUE lane detection/tracking system, to initially productize and market lane departure warning, with lane departure avoidance products to follow in later years. Based on the AutoVUE system, Valeo is now supplying Nissan with LDWS for the 2005 Infiniti FX sport wagon and 2006 M45 Infiniti sedan.

To draw on Raytheon's strengths in military radars, Valeo Raytheon Systems was formed in 2002 to create a scalable suite of optimized radar sensors, with an initial focus on short-range radar technology for a blind spot detection system (Figure 5.9). In 2004, the partnership won its first production contract for these systems from a major vehicle manufacturer. The system is expected to be introduced to the market in 2006.

Within the European 5FW program, Valeo participated in the SARA project focused on radar frequency allocations.

5.2.12 Visteon [54, 55]

Visteon is an \$18.4-billion diversified manufacturer of automotive components and systems. Visteon's driver-assistance systems development strategy is based on studies of consumer attitudes and technology trends. Its plans focus on a rapid, phased evolutionary rollout of features in three phases:

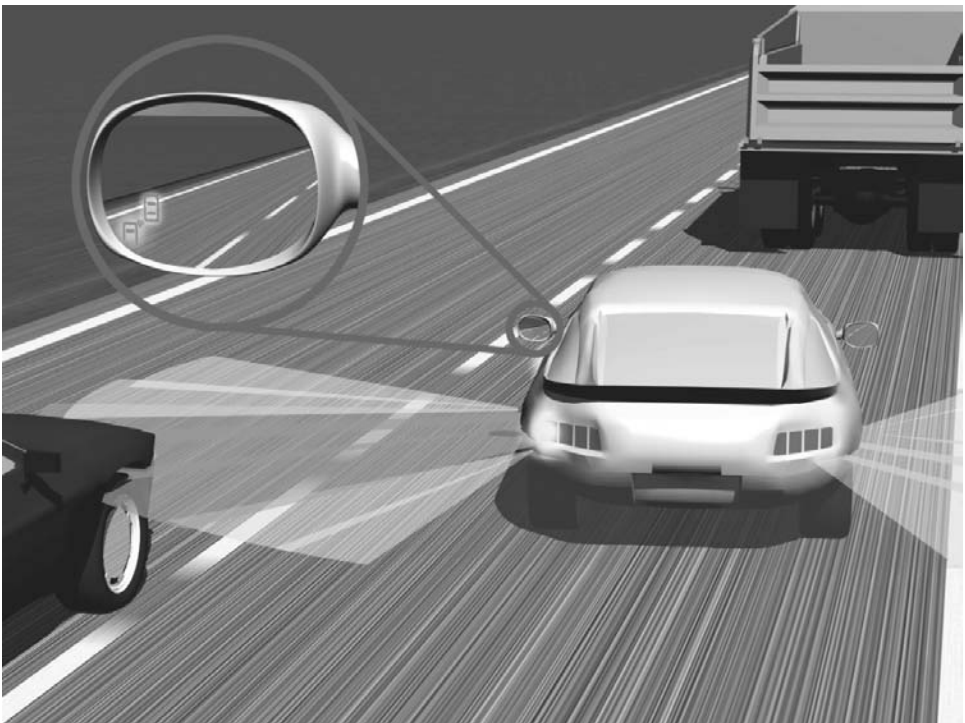


Figure 5.9 The Valeo blind spot sensor provides warning to the driver via an icon in the side view mirror. (Source: Valeo Raytheon.)

- First phase: Awareness—Enhancement of the driver’s awareness without taking active control of the vehicle, based on products providing obvious day-to-day utility;
- Second phase: Awareness + warning—Leveraging of existing systems to “bundle” additional features with low incremental system costs;
- Third phase: Awareness + warning + temporary control—Intervening temporarily in vehicle control to mitigate crashes and link sensor information to occupant-protection systems for crash management.

Visteon’s driver-assist systems include adaptive front lighting, described further in Chapter 7; driver vision at night, based on infrared technology; low-speed ACC; and lane/road departure warning. Radar-based side object awareness, to assist drivers in safe lane changing, is another area that has recently been the focus of major system development work. Visteon engineers have implemented a programmable alert zone that can be defined by auto manufacturers based on their perception of customer needs, or, as further described in Chapter 6, the zone can be modified dynamically based on the driving situation.

Visteon is the main automotive partner in the U.S. DOT-sponsored road departure prevention field operational test. In the European 5FW program, Visteon also participated in the SARA project to allocate radar spectrum.

5.3 Automotive Industry Summary

It is obvious that the automotive industry worldwide has a significant stake in introducing active safety systems and convenience features to the driving public. Estimates as to cumulative annual R&D investments range well over \$100 million. In addition to purely internal R&D, it is also apparent that the vehicle industry is actively participating in government-industry projects for next generation systems. This activity is summarized in Tables 4.1 and 4.2, depicting European and U.S. activity, respectively. A similar table is not shown for Japan, as essentially all OEMs and major suppliers are participating in the two major activities of AHSRA and ASV.

Looking at the industry activities overall, a clear picture emerges of “surround sensing” that supports and helps the driver in avoiding common crashes. Further, human-centered systems are a consistent focus, as car companies know that their customers have the final word on adoption of such systems. The need for everyday utility is a prime factor for long-term success of ADAS—applications such as ACC, adaptive front lighting, and side object awareness must provide frequent and obvious benefits to drivers for them to experience value for their money. More advanced systems can be introduced pending success in offering these types of basic driver-support systems.

ACC is well established as a market offering; lane departure warning and low-speed ACC have just entered the market; and global product availability of LDWS, low-speed ACC, and CMB is likely in the near term. Common themes for more advanced functions include lane change assist, lane-keeping support, driver monitoring, and pedestrian detection. Driver assist enabled by satellite positioning

and digital maps will also play an increasing role, as will vehicle-vehicle and vehicle-roadside communication.

The classic sensor suite that is emerging consists of short- and long-range radar combined with machine vision. Laser scanners will enhance the sensor suite if costs come down to a level consistent with automotive systems. The information horizon will be further extended as wireless data communications become commonplace on vehicles.

Japan is home to the most advanced systems on the market, and a trend is developing such that Japanese automakers may lead in IV technology introductions in the United States, the world's largest market. Some of the most advanced R&D worldwide is occurring in Europe (based on published information, at least). European automakers are rolling out new systems at a steady pace, although somewhat more conservatively than the Japanese approach.

Introductions of advanced products reflect company philosophies as well as the different customer bases in major regions of the world. The pacing factor is typically not the technology capability; rather it is in finding the intersection between that capability and the customer's perception of value. Key challenges for product introduction are in providing increasingly robust operation, exceptional user friendliness, and ever lower production costs.

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Lateral/Side Sensing and Control Systems

Here we begin the first of several chapters focusing on particular functions and services enabled by IV technology. No segmentation of these functions is perfect; however, for our purposes I have settled upon distinguishing between lateral/side sensing systems, longitudinally oriented systems, and then systems that integrate both for this and the next two chapters.

Referring to Chapter 3, we can extract applications relating to lateral control assistance as follows:

- Lane departure warning;
- Road departure warning;
- Curve over-speed countermeasures;
- Lane Keeping Assist (LKA);
- Parallel parking assist;
- Blind spot monitoring;
- Lane change assist;
- Rollover collision avoidance.

Lateral support systems rely on some knowledge of the lane boundaries or road trajectory. Lane detection relies almost exclusively on image processing to detect lane marking, and digital maps and satellite positioning can be used for knowledge on the road geometry ahead. Side sensing detects objects in an adjacent motorway lane, into which a driver may wish to move; either image processing or ranging sensors are used.

Rollover collision avoidance is geared to large trucks. These systems rely on the measurement of the physical forces that are the precursors to a truck rollover. These systems are useful to operators of cars, trucks, and buses, but the rationale and utility varies across them.

For drivers of passenger cars, features such as lane departure and curve over-speed warning refer directly back to the capabilities and awareness of the driver. This is not the case, for instance, with forward collision warning, in which an emergency situation may be invoked due to sudden braking by the vehicle ahead. Therefore, a bit of a ticklish situation is created when it comes to selling such a system to consumers, as the following (unlikely) interchange in automotive showroom illustrates:

Salesman: “Sir, are you a poor driver?”

Customer: “Why, yes I am!”

Salesman: “Well then! You may be interested in purchasing this optional lane departure warning system on your new car!”

On the other hand, these systems are indeed moving into the marketplace, more on the premise that none of us are perfect drivers all the time, and such systems provide an ever vigilant copilot during our momentary lapses of attention.

Moving into the control domain, LKA functions as the ACC of the lateral domain. Automobile drivers report greatly reduced stress and improved vigilance as a result of sharing the steering task with a supporting system on long drives.

When it comes to truck drivers, the sales equation is different. Truck drivers are operating a high-value piece of machinery carrying a high-value payload; here, it is simply good business sense to take precautions to avoid crashes. Further, given that lapses of attention are inevitable and the many hours truckers are on the road, the need for a copilot makes all the more sense. The same is true for motor coach drivers.

The operational mode is quite different when it comes to transit buses, as they operate typically at low speeds in cluttered urban environments. Here the impetus is on tracking very narrow lanes established exclusively for express bus service, a task that requires steering assistance to gain the full benefit of such lanes.

This chapter provides a review of these applications, their implementation, market status, and a sampling of ongoing R&D.

6.1 Lane Departure Warning System (LDWS)

Whether it be the driver lost in an animated cell phone conversation, the attention drawn by screaming children in the backseat, drowsiness at the end of a long day, or drunkenness at the end of a long night, cars do wander out of their lanes at times. Most of the time the lane departure is a benign event (even if the driver continues to be a hazard), resolved by a simple steering correction. However, about 20% of all crashes occur in these circumstances, and they are typically quite severe. For cases of driver impairment, there are driver-monitoring techniques to detect these conditions and warn the driver—these systems are addressed in Chapter 12. However, detecting the fitness of a human to drive a vehicle is much more complex than simply monitoring the vehicle’s lane-tracking performance. For this reason, LDWS will be the first to address this situation, appearing in the automotive marketplace sooner and proliferating more rapidly than driver monitoring systems.

System approaches to LDWS are covered here, both in terms of lane detection technologies and driver interfacing. Representative systems on the market are then described, followed by a brief review of on-road evaluations of LDWS.

6.1.1 LDWS Approaches [1]

Lane Detection To avoid run-off-road and sideswipe crashes and to support the driver in lane-keeping, IV systems must extract knowledge of the lane/road boundaries ahead of the vehicle and the vehicle’s position within the lane. Several techniques have been investigated for lane detection and tracking:

- Embedded magnetic markers in the roadway;
- Highly accurate GPS and digital maps;
- Image processing.

Specialized magnetic markers can be embedded in the road; these are then sensed by vehicle-based detectors. Clearly, this is a “rock solid” approach that enables direct detection of roadway-unique elements but suffers from the obvious challenge of equipping all roadways to be viable for market introduction.

Another approach is to combine highly accurate digital mapping of the roadway lanes with satellite positioning accuracies on the order of .5m or better. As an example, this technique is under evaluation in Minneapolis in the United States [2], in which transit buses use the roadway shoulder of a busy commuting corridor. While bus drivers have been authorized to use the 10-foot wide shoulder for some time, they are cautious: Their speeds are typically quite low due to the very small lateral clearances between their 9-foot-wide vehicle and the stopped or slow traffic just to their left side—only one foot away. The IV Lab at the University of Minnesota has come to the rescue by using differential GPS and highly accurate digital maps to determine lane position, with the system providing haptic feedback regarding lane edges to the driver. This cue is sufficient for the drivers to operate at much higher travel speeds, much to the delight of their passengers.

While the needed location accuracy for such systems will most likely evolve on its own due to market drivers unrelated to the vehicle industry, creating digital maps with submeter accuracy for all roadways will be a time-consuming and expensive proposition that the mapping industry is now evaluating—is the market for such detailed maps sufficient to justify the investment to create and maintain these maps?

Clearly, magnetic and GPS-based lane tracking techniques are viable in contained environments of limited extent, such as for bus lanes in an urban area. For the general road situation, however, detection of existing lane markings is preferred. Here, the predominant approach by far is the use of a monochrome video camera and image processing to extract the lane and road edge markings from the image—exactly what we do as drivers in visually processing the road scene. Dashed and solid lane markings of various widths and configurations are detected by the systems. It should be noted that there are also pitfalls to this approach, as the road markings are not always visible, due to deterioration of the markings, sun glare, obscuration (by snow or ice), or high pavement reflectivity after a rainstorm. However, each of these aspects can be addressed with ever better algorithms and cameras, and the performance of today’s systems is quite impressive. As shown in Figure 6.1, lane edges can be detected in virtually all environmental conditions and on all but the most poorly marked roadways.

When lane markings are not clear, for instance, some algorithms search for any longitudinally linear features that may indicate the lane path, such as discoloration of lane center due to vehicle oil drips onto the pavement over time, the boundary between the driving surface and the road shoulder, and even tracks left by other vehicles in snow. However, challenges in video-based lane detection will continue, given the wide variety of road marking techniques that exist. One particularly vexing situation is the “botts dots” used in California. These are raised reflective markers that are used instead of paint; they are sufficiently different from paint stripes

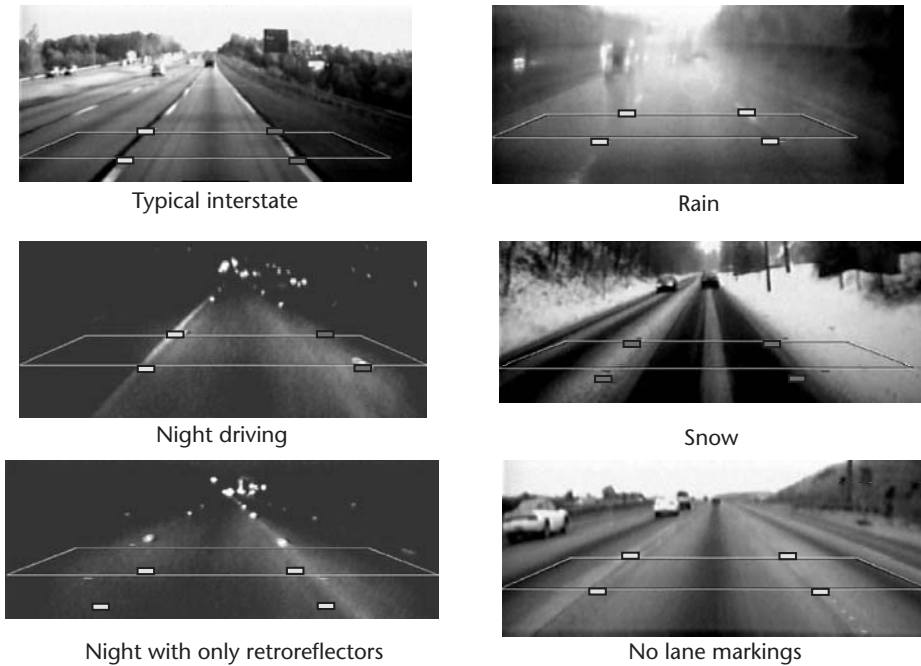


Figure 6.1 SafeTRAC system performing lane tracking under difficult conditions. (Source: AssistWare Technology.)

that specialized algorithms are needed to detect them. They are also a challenge because their conspicuity is lower, particularly in daytime on concrete roadways.

Here we return to the mapping issue, as next generation “lane level” digital maps can serve as an additional data source for situations in which image processing systems might become confused. However, when digital mapping is relied upon for purposes such as LDWS, their accuracy is paramount. Real-time updating of these maps was the focus of the European ActMAP project [3] (described in Chapter 9), in which several map-supported ADAS applications were implemented and tested, including the use of digital maps to improve lane detection performance for image processing systems. Map data performed the role of an additional sensor, enabling more robust identification of road elements such as bifurcations and exit ramps, and compensated for short-term dropouts of the vision sensor or the lane markings.

There is also a wealth of issues relating to camera technology for lane detection that is beyond the scope of this book. Fair quality performance can be obtained with off-the-shelf cameras at the quality level of a typical Web camera; however, camera bandwidth and dynamic range become important for products destined for automotive products. Dynamic range comes into play, for instance, when a vehicle enters or leaves a tunnel and lighting conditions change drastically and almost instantaneously; in these cases, lane tracking must nevertheless be maintained and the camera must adapt. More advanced LDWS use the vision sensor to detect that the vehicle is approaching a “lighting transition,” such as the end of a tunnel, and can proactively adjust camera parameters.

One additional approach to detection of existing road markings has been prototyped by carmaker PSA [4]. In this case, downward-looking infrared sensors,

located behind the vehicle's front protective molding at either side, detect the difference between reflectivity of lane markings versus bare pavement. This system has an advantage over forward-looking video sensors in that it is unaffected by poor visibility conditions and is a lower cost approach. However, it can only detect lane departures as the event is occurring, whereas the forward-looking video-based systems are able to detect potentially hazardous lane drift ahead of time and warn the driver prior to the lane departure.

While the obvious goal is to realize highly robust lane detection, it should also be noted that LDWS is not a system that must be available 100% of the time to offer a useful service to the driver. Systems that are detecting lane boundaries "most of the time" are seen as viable in the marketplace and can still play an important role in enhancing safety. In reality, lane detection rates on the order of 95% or better are typical on motorways.

Driver Interfacing for LDWS The driver interface for LDWS varies based on the intended user. For truckers, the system sensitivity (i.e., the alarm threshold relative to the lane boundary) may be adjustable by the driver or the fleet. Several warning modalities are available, from audible beeps, to simulated directional rumble strip sounds, to seat vibrations. The approach to any audible warnings must take into account the likelihood of a team driver sleeping in the rear of the cab while on the road and the need to avoid disturbing them.

LDWS for cars will likely have minimally adjustable features, if at all, and a low-key but effective warning modality, such as simulated rumble strips or seat vibrations. Here, per the introduction to this chapter, carmakers must take into account the desire for driver's not to be "exposed" to their passengers for their occasional lane-keeping lapses. This would argue for warnings via seat vibrations; this approach however, is more costly than generating rumble strip sounds through the existing stereo speakers in the vehicles. For initial offerings, the audible rumble strip approach is likely to predominate.

Obviously, alarms should not occur for intentional lane crossings: Warnings are therefore suppressed when the turn signal is activated. Also, most systems activate only at speeds above approximately 50 km/hr. This obviates the need for the system to deal with markings such as those found in parking lots and residential streets, which could confuse the lane detection algorithms, and focuses system operation on higher speed environments where lane departure warning is most useful.

6.1.2 LDWS on the Market

LDWS originally entered the heavy truck market in Europe in 2000, followed shortly thereafter by introductions in the United States. The systems became available to car drivers in Japan initially and were first introduced in Europe and the United States in 2004 on Infiniti and Citroën vehicles, respectively [5]. The systems described below are representative of the various products on the market.

AssistWare SafeTRAC System [6, 7] The SafeTRAC system is marketed to the North American heavy truck market, and the core technology has been licensed to Visteon for development and sales of automotive systems.

SafeTRAC uses a video camera to watch the road ahead, track the road and vehicle position in the lane, monitor for weaving and lane drifts, and alert the driver before a road or lane departure. The camera is mounted in a center position on the windshield interior. Lane detection software tracks both lane markings and subtle features such as the road edge and oil strips in the lane center area. Assistware has optimized the lane-tracking algorithms so that the system performs well in a wide variety of lighting, environmental, and pavement conditions.

SafeTRAC is unique in that the system provides a continuous indication to the driver of vehicle position within the lane, via a simple graphical display. Per Figure 6.2, lane position is shown as a vertical “dash” character moving between two vertical “dash” lane boundary characters. An audible alarm is sounded if the vehicle begins to depart the road or cross into another lane without the turn signal activated. Seat vibrators can also be activated from the system output. Sensitivity is adjustable, and the system automatically disables when road features are inadequate for lane detection.

The system also continuously tracks the driver’s relative accuracy over time in maintaining lane position to provide an “alertness feedback score” (shown as “86” in Figure 6.2). In this way, erratic or degraded driving can be detected even if lane departures are not occurring. This feedback can help the driver realize his or her level of fatigue may be more than they thought, and data such as this can also be logged for fleet managers to review as an indication of needed driver training.

Iteris LDWS [8–10] The Iteris Autovue system, shown in Figure 6.3, is the market leader in LDWS. Originally introduced in Europe in 2000, over 8,000 units have since been sold there and sales are averaging 4,000 systems annually. Iteris estimates that the systems have logged one billion kilometers thus far in Europe alone. A modified system entered the European motorcoach market in 2004. In the United States, Autovue is now available as a factory option from several truckmakers and over 600 units have been sold. In the auto market, Iteris is also the supplier of the



Figure 6.2 SafeTRAC camera (left) and combination processing and driver interface unit (right). (Source: AssistWare Technology.)



Figure 6.3 Iteris's first generation LDWS. Used in the United States commercial market starting in 2002. (Source: Iteris, Inc.)

LDWS introduced by Infiniti and Citroën. Autovue is sold as an integrated system installed by the manufacturer.

Autovue detects lane boundaries through video-based image processing as well. The system works in full daylight and at night with headlights on, as well as any weather in which lane markings are visible. This includes heavy fog, as the viewing proximity is very close to the front of the vehicle. A “virtual rumble strip” warning is provided to the driver if a lane departure is imminent, using the left or right audio speakers to indicate the direction of the lane departure. An exception is the European motorcoach version, which provides directional warnings via seat vibration.

Iteris notes that the system promotes the use of turn signals when changing lanes and conditions drivers to have a keen sense of “lane position awareness” and remain in the lane center.

In surveys conducted with over 200 truck drivers in the United States and Europe who have used Autovue, 75% or more of the drivers drove regularly with the system enabled and believed the warnings came at the right time, the system was valuable even with occasional false alarms, and the system could prevent crashes.

MobilEye LDWS [11, 12] MobilEye has pioneered the development of application-specific integrated circuits for driver assistance with their EyeQ™ system-on-a-chip (SoC). The company's vision-sensing approach based on the EyeQ™ provides lane departure warning as well as forward collision warning (see Chapter 7). The system became available to automotive and truck fleets as an aftermarket product in 2004. The system also mimics the rumble strip sound as a way of alerting the driver to a lane departure.

MobilEye's algorithmic approach fits a three-parameter road model that accounts for lateral position, slope, and curvature. The curvature parameter is used for increasing the warning reliability on curved roads and for estimating time to lane crossing. In addition the system retains multiple lane models (such as urban roads, merging lanes, or exit lanes) so that it can switch between them

instantaneously to find the best match for the conditions. During heavy rain, the visual interference caused by raindrops and windshield wiper motion are processed so that lane detection is not impeded.

Toyota Rearview System [13, 14] The Toyota LDWS on the market in Japan takes an innovative approach in using the rearview camera for double duty. Rearview cameras are primarily intended to assist the driver by providing an image of the area behind the vehicle on the navigation screen during parking maneuvers. The Toyota system, developed cooperatively with supplier Aisin, uses the same camera to look at lane markings immediately behind the vehicle while on the highway to realize the LDWS function.

6.1.3 LDWS Evaluations

Researchers in Europe and the United States have conducted evaluations of the behavioral effects, driver acceptance, and overall safety effectiveness of LDWS for heavy truck operations. These types of field trials provide valuable insight into “real world” use of such systems—are they truly supporting the driver? Two projects are briefly reviewed here.

LDWS Evaluations Conducted by the Dutch Ministry of Transport [15] The Dutch Ministry of Transport sponsored field trials of LDWS during 2002 and 2003. The trials were conducted by a team of researchers led by TNO and focused on professional drivers operating heavy-duty trucks and long-distance buses.

The research was organized into six major work packages:

- Analysis of the driving task and the role of LDWS;
- Behavioral effects of LDWS;
- Expert opinion of traffic flow effects of lateral driver support systems;
- Acceptance of LDWS;
- Infrastructural consequences of LDWS;
- Relation of LDWS to the use of narrow road lanes.

The test fleet consisted of 35 trucks and five motorcoaches. Five of the trucks had data recorders to collect detailed information. Several different LDWS, typical of those offered commercially, were used.

Overall, the effects of LDWS on traffic safety were seen to be positive. The results indicated that, with all trucks in the Netherlands equipped, approximately 10% of injury crashes involving heavy vehicles could be prevented. With respect to traffic flow, LDWS are not expected to have either a positive or negative influence, other than the reduction in congestion due to fewer truck crashes.

The Dutch government has investigated reconfiguring existing roadways into narrower lanes to create additional lanes as a way of reducing congestion. Therefore, LDWS were evaluated for their ability to help drivers maintain correct lane position in narrow lanes. Truck driving simulator experiments were conducted in which the lane widths on the virtual road varied from 3.5m down to 2.9m. A distraction task was intentionally introduced to stress the lane-keeping task of the

driver. The study results showed that the LDWS system improved lane-keeping, particularly for the narrower lane widths. At the same time, however, drivers reported driving to require more effort when using the LDWS.

LDWS enjoyed a high degree of user acceptance among drivers who used the systems during the on-road evaluation. This was also the opinion of managers at the transport companies involved, a key point given that company management must see benefits to make decisions to buy such systems. A total of 75% of the drivers had positive opinions of LDWS, and over 50% stated that they would prefer to drive with such a system installed in their vehicle. However, 21% of drivers stated that they would prefer vehicles without LDWS.

On the positive side, drivers noted fewer “startle” reactions during lane departure events by using LDWS, as they were advised earlier in the event and therefore could respond more gracefully; similarly, reaction times to take corrective action were reduced. Interestingly, 60% of drivers concluded that the system caused them to pay more attention to the driving task. Increased comfort levels were noted, as well.

On the down side, 20% of the drivers felt that the system could cause a startle response that might be worse than crossing the lane line; this factor was seen as potentially being related to the loudness of the audible warning. Further, drivers perceived 25% of the warnings as needless (i.e., false alarms). Obviously, this would argue for the provision of sensitivity and volume adjustments being available to the user, at the level of either the fleet or individual driver.

Mack Trucks/U.S. DOT LDWS Field Operational Test [16] The U.S. DOT Federal Motor Carrier Safety Administration, as part of the IVI program, partnered with Mack Trucks and McKenzie Tank Lines to evaluate the SafeTRAC LDWS on a fleet of approximately 20 tractor-tankers. The test, which is ongoing, involves extensive data collection on each of the trucks. To provide a basis for comparison, lane detection and data collection is active on all trucks, but the driver warning is disabled for a subset of the fleet. For the trucks with activated driver interfaces, driver acceptance is being evaluated through the use of surveys.

The onboard measurement system provides the following critical information:

- Vehicle state;
- Driving behavior;
- Roadway alignment and lane markings;
- Presence of precipitation;
- LDWS operational status;
- LDWS alerts;
- Lateral velocity and lateral acceleration during lane departure events;
- Surrounding traffic;
- Location.

When a lane departure event occurs, data from the previous 30 seconds and the following 30 seconds is captured in one-second intervals. The data acquisition system logs several different types of lane departures: less than 10 inches, 10–18 inches,

and greater than 18 inches. When the field testing is completed in 2005, over one million miles will have been logged by the test fleet. The data will be analyzed to assess the overall safety benefit of the system, as well as any negative impacts.

6.2 Road Departure Warning Systems (RDWS)

As one might expect, RDWS are similar to LDWS in providing lane tracking. However, there are some important differences and specialized applications in RDWS that are reviewed here.

6.2.1 Curve Speed Warning

Curve speed warning systems advise drivers when their speed is too high for an upcoming curve. These systems are currently in developmental stages and have not yet been introduced commercially; however, this application is expected to be brought to market in the near term.

The Digital Map Approach [3, 17] Here, the premise is simple: Digital maps produced for use in onboard navigation systems could contain sufficient road geometry information to enable a safe speed estimate to be generated for upcoming curves in typical road conditions. When a vehicle is approaching such a curve, an onboard processor compares this estimate with the actual vehicle speed. If the threshold speed is exceeded, a warning is issued to the driver or speed is automatically reduced. While some road geometry is available in current digital maps, it is generally agreed that enhanced next generation maps are needed for curve speed warning to be sufficiently reliable.

Curve speed warning, as well as vehicle control techniques to reduce speed automatically, have been addressed by projects in the United States and Europe examining the application of digital maps to driver assistance in general. Ford and GM separately prototyped curve speed warning approaches for both warning and vehicle control in the United States EMap project, and BMW did the same within the European ActMAP project. BMW's approach provides a good example of an advanced system implementation. BMW uses an active accelerator to provide feedback to the driver in a manner that provides both warning and a form of control. Whenever the current speed is deemed too high for the road conditions, the accelerator pedal presents a slight but insistent feeling of resistance to indicate that the driver should slow down. Through its respective position, the active accelerator pedal also "suggests" the right speed to the driver. However, the system cannot be all-knowing, so this feedback always remains a suggestion for the driver to accept at his or her discretion. In this way, the driver remains in the loop and the amount of feedback is based on the deviation between expected and actual behavior.

In addition to curve radius and curve angle, a fully informed curve speed warning system would also incorporate parameters such as surface quality, street width, number of lanes, shoulders, visibility (daytime), weather (for determining friction), and driving style of the driver. As curve speed warning systems evolve, they can take advantage of such data from other sensor systems to enhance the safe speed calculation.

Infrastructure-Oriented Curve Speed Warning [18] In Japan, AHSRA has pursued an infrastructure-centered approach to a curve speed warning that focuses on particular road sections known to be hazardous. While static roadside signs can be placed to provide general warnings to all drivers, these are not deemed to be sufficiently effective—drivers who are going too fast for the curve need to receive a direct warning. Prior to the curve, therefore, speed detectors and road-vehicle communications equipment are installed so as to warn drivers if their speed is too high.

This system approach is being evaluated at several sites. On National Highway 25 in Naga Prefecture, the “Omega Curve” is infamous for its steep downgrade and length, which tends to cause vehicles to accelerate to unsafe speeds. Another site, National Road 246 in Kanagawa Prefecture, is a two-lane bidirectional road in which one section has two consecutive curves on a downslope, such that the second curve is not in view and tends to surprise drivers. Lane departures caused by excessive speed for the situation have resulted in serious head-on collisions in this section. Testing is also under way on the Tomei Expressway and at several metropolitan freeway interchanges with complex and sharp flyover ramps.

6.2.2 U.S. DOT Road Departure Warning Field Operational Testing [19–22]

In 2001, U.S. DOT partnered with the University of Michigan Transportation Research Institute, Visteon Corporation, Navteq, and Assistware in a field operational test project focused on RDWS. The project defines and evaluates a system which warns drivers when they are about to drift off the road and crash into an obstacle, as well as when they are traveling too fast for an upcoming curve. As shown in Figure 6.4, technologies include a vision- and radar-based

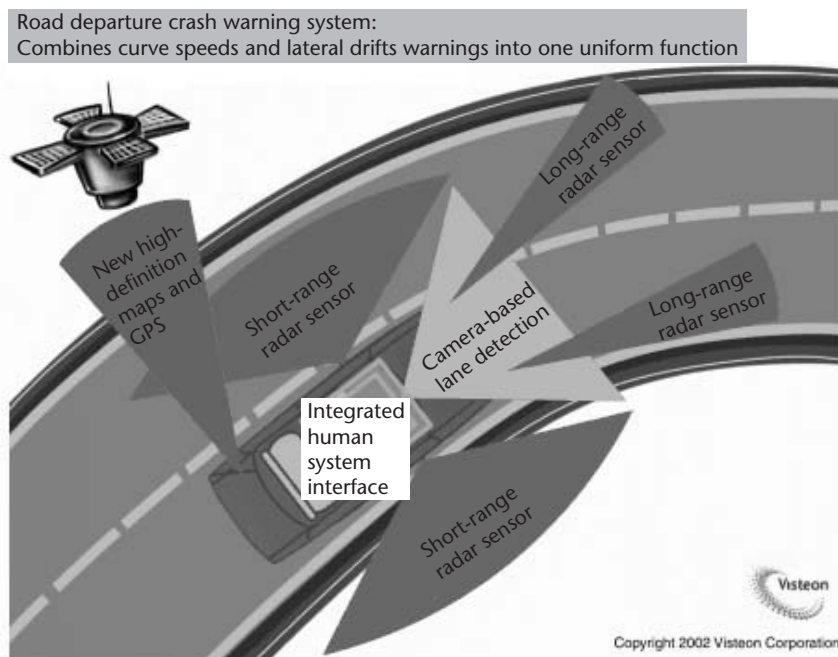


Figure 6.4 Road departure crash warning system under evaluation by the U.S. DOT.
(Source: Visteon.)

lateral drift warning system and a map-based curve speed warning system. A photo of the radar sensors, which are installed on each side of the vehicle, is shown in Figure 6.5.

The lateral drift warning subsystem takes road detection a step further than a typical LDWS. Using machine vision, it assesses the existence and width of the road shoulder. Furthermore, forward- and side-looking radar detects the presence of any obstacles on the shoulder (such as parked cars) or the roadside (such as poles or guardrails). Armed with this information, the driver warning modality can be more situation-aware. In the case of no shoulder or an obstructed shoulder, the warning would be at its most urgent level; conversely, when the shoulder is broad and unobstructed, the driver might only receive an advisory message. Audio, visual, and seat vibration warnings are used to present the various warning levels.

For the region ahead and nearby the vehicle, data collected includes the following:

- Upcoming road curvature;
- Lane width;
- Number of lanes;
- Paved shoulder width;
- Boundary marker types;
- Any temporary roadside objects (such as parked vehicles);
- Permanent roadside objects (such as bridge abutments).

At the heart of the system is a “situation awareness module,” which fuses data coming from the sensors to understand the situation and calculate available maneuvering room.



Figure 6.5 Side- and forward-looking radar units installed on a Nissan Altima for the road departure crash warning system. (Source: UMTRI; photo: Shekinah Errington.)

System development is complete and field data collection began with a test fleet of 14 Nissan Altima's in early 2004. Plans called for 78 people to drive the vehicles over a 10-month period. Data collection will be completed in early 2005.

6.3 Lane Keeping Assist Systems (LKA)

6.3.1 System Approaches

Lane-keeping systems are intended as convenience products by reducing the driver's need to make the frequent minute steering corrections that are a normal part of driving. The lane detection function is handled as described in section 6.1 and active steering input is added by the LKA system. For automotive products, the paradigm is one of shared control, whereas in specialty applications such as transit buses, full steering control is sometimes provided.

Automotive LKA Systems For automotive implementations of LKA, automatic steering torque is provided by a motor integrated with the vehicle steering system. Future systems will likely use steer-by-wire to “actuate” steering. Per Figure 6.6, torque increases as the vehicle nears a lane edge to create a “driving in a bathtub” type sensation for the driver. Surprisingly, the delivered torque to adjust vehicle direction at highway speeds is quite small. Therefore, the systems are easily override-able by even the weakest drivers—in fact, the systems were tested with specially selected “weak drivers” in Japan before being introduced to the market there!

Based on the shared control paradigm, automotive LKA require driver input to remain enabled. Approximately 80% of control is provided by the system and 20% by the driver, with the systems only operating on highways of rather modest curvature. If the curvature limits are exceeded, the system disables automatically [39].

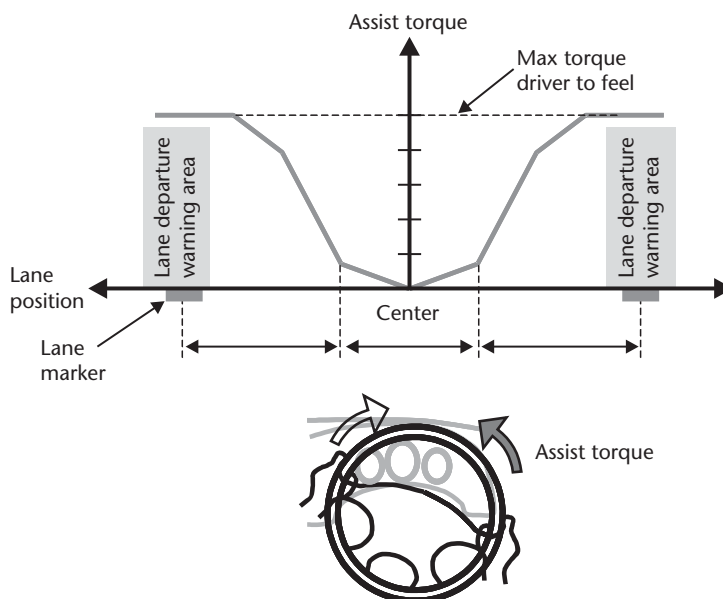


Figure 6.6 A relative indication of steering assist torque provided in steering assist systems. (Source: Honda.)

BMW's LKA system, called heading control, uses onboard sensors to analyze any crosswind, curves or ridges in the road, in addition to detecting lane edges [23]. It uses this information to calculate optimal steering behavior and define tolerance limits; should these be exceeded, the system applies force to the steering wheel to suggest corrections. Drivers then decide to accept the recommendation or initiate another action, such as overtaking. Heading control is currently under test by BMW and is expected to be introduced to the market soon.

Lane-keeping performance for LKA systems is typically better than human drivers can maintain. One study showed maximum lateral deviation within the lane at 0.2m for the automatic lane-keeping system, as compared to 0.4m for an experienced test driver.

When lane-keeping support systems are discussed, questions frequently arise as to the driver's ability to remain alert. Is the system providing too much assistance, such that the driver tunes out? This is one reason that system designers have adopted the 80/20 rule for first generation systems, so that driver input is required for the system to remain active. Research on this topic is discussed in Chapter 12.

Full Steering Support for Transit Bus Applications BRT systems rely on various methods to provide express service to travelers as compared to automobile travel, so as to attract greater bus ridership. One approach is to provide exclusive lanes for the buses. In many cities, the creation of such lanes is a major challenge given the existing development and already crowded streets. Real estate is at a premium, and even fractions of a meter in the width of a new lane can make or break the viability of new bus service of this type. When the pressure is on to make the lanes as narrow as possible (only centimeters wider than the width of the bus itself), automatic steering assistance is called for.

Given the limited lane-miles of such implementations, various approaches to lane-tracking can be used, including special infrastructure treatments. The CIVIS system, developed by Irisbus, uses image processing to detect distinctive lines painted on the road surface (Figure 6.7), and a guidance module synthesizes this and



Figure 6.7 Specialized pavement markings used by the CIVIS system for lane-tracking. (Source: Irisbus.)

other relevant inputs to generate steering commands (Figure 6.8). The Phileas system, developed by APTS, relies upon magnetic markers installed in the road surface.

6.3.2 LKA Systems on the Market

Automotive Systems LKA systems were introduced initially by Nissan in Japan in 2001 [24] and are now available from all major automakers there. The system philosophy is that steering assist is for the purpose of improved stability and reduced driver fatigue; it is not intended for autonomous driving. The systems on Japanese vehicles typically operate only over 65 km/hr on roads with a radius of curvature of 1,000m or more. However, the Honda system operates on road radii down to 230m, which essentially covers all Japanese highways.

An example of the Nissan LKA driver interface on the market is shown in Figure 6.9 [38]. This interface is placed within the instrument cluster and shows the activation of the LKS function by illuminating the “LANE” icon. When the system is actively tracking the lanes, an image is illuminated to iconically illustrate road lanes. In this image, a vehicle icon is also illuminated to indicate that the ACC system is tracking a vehicle ahead.

Similar systems are expected to be introduced on the European market within approximately three years, and North America not long afterwards. The market pull in North America is seen as particularly strong, given the long, monotonous intercity trips undertaken by Americans for business and vacation travel on the nation’s interstate highway system.

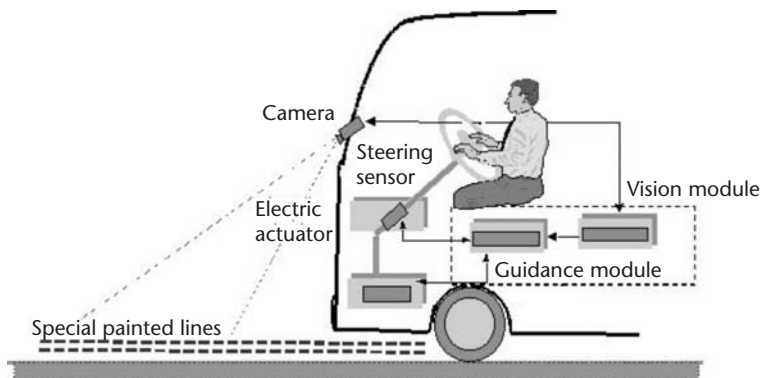


Figure 6.8 CIVIS lateral guidance approach. (Source: Irisbus.)



Figure 6.9 Nissan LKS driver interface integrated into instrument panel. (Source: Nissan.)

Bus Transit Systems Automated and semiautomated bus systems are now in operation in various parts of the world. The first CIVIS systems were installed in France in 2001 and are now operational in the French cities of Clermont-Ferrand and Rouen. CIVIS was also the first semiautomated bus system installed in the United States, with service initiated in Las Vegas in 2004 [25]. As shown in Figure 6.10, CIVIS buses are highly stylized so as to reflect the high-technology nature of the system.

CIVIS provides lateral control only. The Phileas system in the Netherlands and the Intelligent Multimode Transit System in Japan incorporate both lateral and longitudinal control and are further discussed in Chapter 10.

6.4 Parallel Parking Assist [14, 26, 27]

In 2003, Toyota surprised the IV world by introducing yet another system based on their rearview camera. Keying on the great challenges encountered in parking in Japan, a semiautomated parallel parking assistant called Intelligent Parking Assist (IPA) was introduced on its Prius hybrid. The system relies upon the rearview camera and image processing for sensing and provides automated steering. It frees the driver from the tedious, and sometimes unsuccessful, precision maneuvering needed to parallel park their vehicle successfully. The system is designed so that throttle and braking is still under driver control. Developed by supplier Aisin Seiki Co. in cooperation with Toyota, IPA builds upon an earlier parking assist system that performed the same sensing computations but provided only voice prompts, not steering, to guide the driver.

Toyota demonstrated the system at the ITS World Congress in Madrid in November 2003. After a brief demonstration by a helpful Toyota engineer, your intrepid author was allowed at the controls. The system has a brief learning curve, during which he was coached in using touch-sensitive arrows on the display screen to position a green rectangle over the empty parking spot, which could be seen in the video display sourced from the rear-mounted camera. Once properly indicated, the “set” button was pressed. A message was displayed that reminded me that, as driver,



Figure 6.10 CIVIS Vehicle in operation in Las Vegas. (Source: Irisbus.)

I remain fully responsible for the operation of the vehicle, and the proper acknowledgment key was clicked to indicate my assent and understanding. At this point, I was in charge of the throttle and accelerator and the car was poised to handle the precise steering necessary to adroitly move into the targeted parking space. From a driver perspective, it was simply a matter of watching the steering wheel and the scenery as the Prius glided into the designated spot. It was then my job as driver to place the vehicle in forward gear and finish the positioning process for a perfect parallel parking job.

Even though the functions implemented in IPA are only basic aspects of the driving experience for the average automobile customer, the significance of this type of product should not be lost. Toyota's automated parking assist provides a superb testbed for engineers to understand the performance of their automated steering in the real world, in the hands of real customers. Refinements stemming from this type of product will likely contribute to the future introduction of fully automated steering systems for all types of driving.

6.5 Side Sensing: Blind Spot Monitoring and Lane Change Assistance (LCA)

Side sensing supports drivers in detecting vehicles within the proverbial “blind spot” to the rear left of their own vehicle, to facilitate safe lane changes on motorways. LCA incorporates basic blind spot monitoring, which is fundamentally a short-range sensing mode, with longer range sensing to detect vehicles in adjacent lanes, which may be rapidly approaching and could also pose a hazard in a lane change maneuver.

Being a simpler problem, blind spot monitoring systems are more mature and basic systems are on the market. The primary sensing modality is short-range radar, typically operating at 24 GHz. Vision-based systems for both blind spot monitoring and LCA have also been implemented. Ultrasonics can be used for low-speed applications in urban operations. Additionally, a lidar system is being tested by the ITS Institute at the University of Minnesota to assist bus drivers with merging assist and blind zone reduction [2]. LCA based on laser scanners has also been developed to sense approaching traffic at a range of up to 200m [28]. The following sections review some representative systems.

6.5.1 Radar-Based Systems [29–31]

The “granddaddy” in blind spot monitoring is the Eaton VORAD system, which was introduced to the heavy-truck market in the early 1990s, combined with forward collision warning. The VORAD system uses range-gated Doppler radar at 24 GHz to help drivers detect vehicles in the right-side blind spot of the typical large truck. The sensor is pointed at a right angle to the truck and the active sensing zone is 2–10 feet to cover the adjacent lane. The VORAD system is further described in Chapter 7.

For the automotive market, the challenge is to offer radar-based sensing systems at a much lower cost than that the systems sold to truckers. Many suppliers have radar-based blind spot monitors in development, although their attributes differ. Here we provide a brief sketch of systems from Valeo Raytheon and Visteon.

The Valeo Raytheon system uses 24-GHz radar sensors to monitor the blind spot on both sides of the vehicle. If a vehicle is present in the blind spot, the system alerts the driver through a visible icon. The system range extends to 40m, with a 150-degree broad field of view. The radar is a multibeam system operating in a narrow bandwidth. Using several beams to recognize objects in the blind spot allows for high accuracy in determining the position and distance of the object as well as its relative speed. The sensors are integrated into the vehicle behind the rear plastic bumper. Valeo Raytheon expects its system to appear on production vehicles around 2006.

The Visteon system is a close-in blind spot monitor, covering a detection range of 6m, again using 24-GHz radar. Its driver interface approach uses an illuminated icon integrated into the side mirror. Per Figure 6.11, the alert zones are programmable, so that a customizable zone can be provided both laterally and longitudinally to fit specific product needs or regulations. As is key with all blind spot monitors, the system does not alarm on stopped objects, such as guardrails. Also, to avoid nuisance alerts, the system is designed to delay an alarm for what appears to be an overtaking vehicle that is likely not a threat. If the approaching vehicle does indeed pass the host vehicle, no alarm is sounded at all.

6.5.2 Vision-Based Systems [32]

MobilEye offers blind spot monitoring and LCA using a single camera solution. The system detects moving and stationary vehicles in adjacent lanes and determines the vehicle range, relative speed, lateral position and time to contact by monocular image processing. A warning is provided when vehicles in an adjacent lane do not permit a safe lane change maneuver.

The vision sensor is typically located on the vehicle's sideview mirrors and supports both right and left sides. Vehicles close to the subject vehicle are detected, even if the adjacent vehicles are only partly visible to the camera. It detects close-by vehicles based on visual motion analysis whereas vehicles farther away are detected

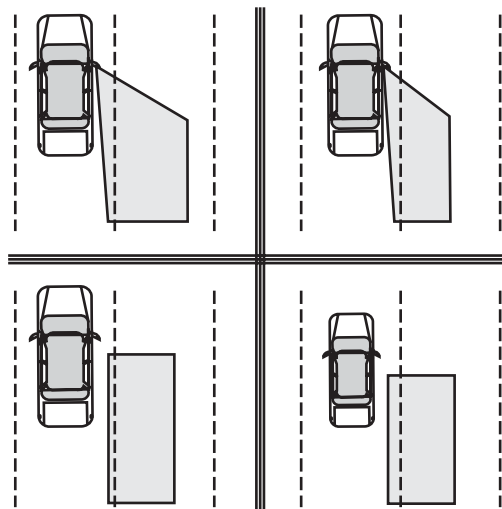


Figure 6.11 Programmable alert zones in side object detection enables customization. (Source: Visteon.)

using pattern recognition. The application discerns the lane position of all detected target vehicles so as to suppress warnings for vehicles that are in nonadjacent lanes and therefore not a hazard. If there are no lane markings at all, or the markings are not detectable, the warnings are determined based on the lateral distance of the approaching or passing vehicle.

6.5.3 Ultrasonic-Based Side Object Sensing For Transit Buses [33]

As described in Chapter 4, the U.S. Federal Transit Administration is developing performance specifications for several types of collision avoidance systems. The agency's work in side sensing was evaluated on 100 buses within the Port Authority of Allegheny County system in Pittsburgh, Pennsylvania.

Transit bus operations suffer from numerous property damage incidents resulting from maneuvering large buses in tight urban areas. Based on average property damage costs for the transit industry, a side object warning system costing \$3,000 would have a payback in less than three years. Taking into account other factors such as legal costs, these types of systems could potentially pay for themselves within a single year.

The approach with the Pittsburgh bus fleet was to integrate a number of ultrasonic sensors within a plastic strip running along each side of the buses. These buses were operated in regular service during 1999 and 2000. In a side-by-side comparison, a fleet of buses equipped with side object sensing had 100 such collisions in 2001, compared to almost 300 collisions for an equal number of unequipped buses over the same period. The system has subsequently been commercialized with a reduced set of sensors focusing on the vehicle areas most likely to be involved in potential collisions.

6.6 Comprehensive Lateral Control Assistance (LCA)

The systems discussed thus far can obviously be integrated into a more comprehensive suite of applications based on radar and vision sensing. Two such approaches are reviewed here.

6.6.1 INVENT: LCA [34]

The German INVENT R&D program includes LCA within the suite of applications addressed by the program subtasks Detection and Interpretation of the Driving Environment and Anticipatory Active Safety. This work is motivated by data that shows that 35% of fatal crashes in Germany in 2001 were due to road departure.

In the INVENT program, LCA is a comprehensive package of applications including lane departure warning, road departure warning, lane keeping assist, blind spot sensing, and lane change assist. Some LCA work is devoted specifically to support heavy truck drivers, to relieve them of the tiring tasks of driving "against" wind gusts, roadway banking, and road grooves, through automatic compensation in the steering mechanism.

Furthermore, the Predictive Control of Vehicle Dynamics program component takes a more comprehensive approach, addressing any situation in which vehicle speed and orientation are critical. The goal here is to avoid entering the hazardous

range of vehicle dynamics through active intervention. In the initial phase, targeted braking/steering interventions are implemented to support the driver when in danger of losing control in holding the lane or road. The second phase implements more significant preventive measures, via braking and steering to improve lane orientation. For instance, the orientation of the vehicle may be automatically adjusted when approaching a curve too rapidly.

6.6.2 PReVENT [35]

Within the European PReVENT integrated project, the lateral support and driver monitoring subtask is relevant here. The subtask includes the first European-level R&D in lane-keeping support, called SAFELANE. Also, lane change assistance and blind spot monitoring is being addressed in a subproject called LATERALSAFE. These applications are depicted in Figure 6.12. A particular project focus is to implement systems that support the driver in adverse or low visibility conditions. Driver monitoring systems are also integrated into these applications.

The work, which began in 2004, is expected to result in a lane-keeping support system for situations with poor road and environmental conditions, an integrated driver support system for handling critical driving situations, and lateral support in all traffic scenarios. For the demonstrations planned in 2006, two LATERALSAFE cars and one truck simulator will illustrate multiple system approaches and driving scenarios; also, two trucks and one car will demonstrate SAFELANE lane-keeping support.

6.7 Rollover Collision Avoidance (RCA) for Heavy Trucks [36, 37]

RCA does not involve external sensing and as such does not precisely fit the IV system definition in Chapter 1. However, the safety contribution of these systems is so significant, particularly for large trucks, as to merit some attention.

Electronically controlled stability systems have recently become available for automobiles and are seen as particularly important in preventing rollovers of sport

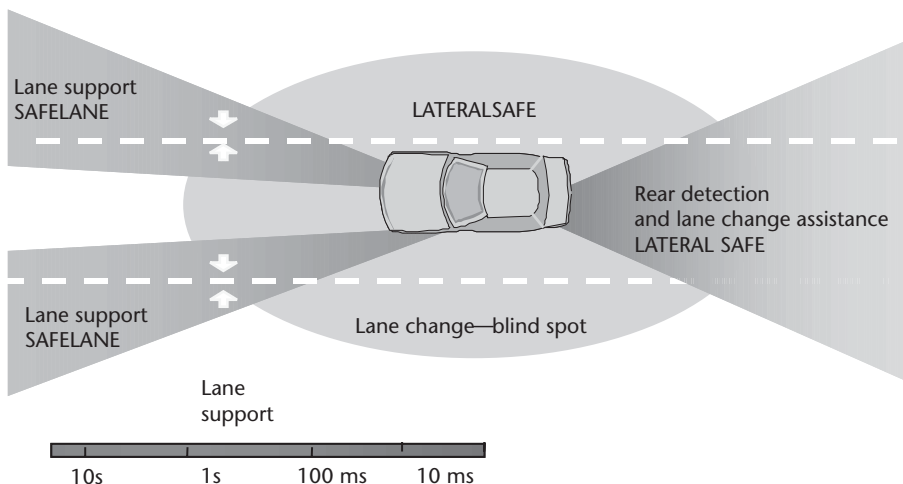


Figure 6.12 Lateral assist applications suite in the European PReVENT project. (Source: PReVENT.)

utility vehicles. These systems use complex algorithms to detect roll forces and activate differential wheel braking to compensate and prevent the roll event.

RCA for tractor-trailer truck configurations is a different case for several reasons. First, while the trucker has full braking control of both tractor and trailer, any specialized electronics must be limited to the tractor. This is because trailers are mated to tractors randomly in many trucking operations, and special interfaces and equipment on the trailer is therefore infeasible, particularly when the trailer is owned by a different company than the tractor owner, which is commonly the case. Also, the effects of a truck rollover go far beyond the individual vehicle. When a rollover blocks several lanes of traffic, thousands of hours of delay are incurred by other travelers. Further, tanker trucks, often carrying flammable materials such as gasoline, are more prone to rollovers due to “slosh” of their cargo. In the absolute worst cases, a massive fireball creates a major disaster site. We’ve all seen the news reports.

In the United States, rollovers comprise 6% of combination vehicle crashes, of which over 50% involve personal injury. The average cost of such a crash is in the range of \$120,000, but can be more than an order of magnitude greater when hazardous material spills occur.

In North America in particular, tractor-trailer combinations have a long wheelbase, and high centers of gravity (CG) are common due to the cargo. Both of these factors increase susceptibility to a rollover. Maneuvers promoting rollovers include the following:

- Excessive speed entering a curve;
- Maintaining a constant speed in a reducing radius curve;
- Accelerating in a curve;
- Sudden lane change.

A compounding factor is that drivers have difficulty sensing proximity to the critical vehicle rollover threshold. Amazingly, the trailer’s wheels can be lifting off the ground on one side and this action is undetectable within the tractor (see Figure 6.13).

Rollovers occur in situations of a high lateral coefficient of friction (i.e., dry pavement). When driving speeds exceed the threshold and surface friction is sufficient to resist sliding, the vehicle is prone to rollover. If the road surface is wet and friction low, then the trailer slides and a jackknife event is the result.

Rollover risk is calculated based on direct measurement of lateral acceleration and estimation of the vehicle CG. The CG is estimated using a load distribution model and calculated vehicle mass. The mass is calculated from comparing engine torque to the acceleration achieved, along with other factors such as tire size. The system intervenes through engine control or braking to reduce speed, which will in turn reduce the roll forces.

RCA accelerometers and the embedded computer system are typically incorporated in the same circuit boards used for antilock braking and traction control on the tractor body.

RCA systems have been developed by several truck suppliers, including Meritor WABCO and Bendix. The systems are available on Freightliner trucks and other truck OEMs are expected to follow suit very soon.



Figure 6.13 Photo of tractor-trailer on a test track invoking roll forces (note that the tractor is relatively stable while the trailer is in serious trouble). (*Photo courtesy of Meritor WABCO.*)

6.8 Summary

From this review of lateral and side sensing systems, we can see that there is a wealth of applications, most of which can be supported by range sensing (radar, lidar, laser scanner) or image processing. LDWS are quite mature and expected to proliferate fairly quickly, picking up momentum within the trucking industry and gradually being offered to more models on the car side. LDWS and blind spot and LCA systems offer a vital advantage in that drivers will perceive the presence and usefulness of the systems virtually every day—this way, they clearly see the value gained from purchasing the product. However, given the daily visibility of these systems, a potential downfall is the potential that the systems will sound too many false alarms and become a nuisance. Early indications from LDWS usage suggest that false alarms are at a reasonable level; this challenge remains for blind spot and LCA systems as they are brought to market.

Another advantage of LDWS is that they require no connection to the vehicle and can easily be mounted within the driver's compartment. Their simplicity allows for after-market sales and relatively easy integration into factory vehicles.

Lane-keeping assistance is an appealing idea to the average driver as another means of relieving the tedium of normal driving. However, human factors analysts are concerned that LKA combined with ACC gives drivers “too much” support. As we will see in Chapter 12, results so far are reassuring, but this will remain an area of debate for some time. Fortunately, having systems on the market in Japan provides solid user data against which to compare human factors laboratory experiments. For bus transit, LKA has become an enabling technology for exclusive lane operations, allowing transit operators to offer a light-rail type experience at a fraction of the cost.

ADAS supported by digital maps and satellite positioning are moving toward reality, and most likely curve speed warning will be one of the first embodiments of this concept.

What about automated parking assistance? No doubt it passes the “coolness” test, but how likely is it to be a market success? The key is customer pull—parallel parking is a common task for Europeans and Japanese, but fairly rare for Americans who are more likely to be pulling into the parking lots of shopping malls. As the United States is the largest market, automated parking assistance may not see huge sales but will certainly serve as a launching pad for other applications based on automatic steering.

As vision-based lateral support systems come into greater usage, vision sensing can also be used to enhance forward sensing systems, as we shall see in the next chapter.

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Longitudinal Sensing and Control Systems

Longitudinal sensing and control systems address situations pertaining to the forward and rearward movement of the vehicle. Drivers are assisted in perceiving and responding to obstacles, traffic, and road conditions to avoid crashes.

When parking, basic rear sensing systems help the driver avoid minor bumps and scratches, while more advanced systems are expected to have the perceptiveness to detect dangerous situations, such as small children out of view of the driver. On the open road, the driver's perception is enhanced through systems such as night vision and adaptive headlights. Beginning with ACC, forward sensing systems help drivers perceive the situation ahead of the vehicle to assist in following other traffic as well as in avoiding crashes.

In fact, forward sensing systems build upon one another. ACC constitutes the initial foray into forward sensing, which opens up the possibility of using the ACC sensor for forward collision warning and precharging of the brakes when a collision is imminent. Higher performance forward sensors support active braking to mitigate crashes, with the eventual possibility of avoiding most forward crashes altogether.

Forward collision countermeasures have actually been with us since the late 1980s, starting with systems on heavy trucks. Automotive systems for convenience (i.e., ACC) came along in 1997, with safety-focused systems being introduced only recently. There is also interest in equipping transit buses with these collision countermeasures. While the business case for transit buses may not be strong in general, just one tragedy in a city can spur equipping an entire fleet.

The net effect of the proliferation of these forward collision countermeasures is that severe crashes will decrease dramatically in coming years. Drivers will have an earlier awareness of a potential crash situation and can respond sooner. Forward crashes in general will decrease as well, but at a slower pace.

Another quite challenging and important area is the detection of pedestrians in the forward path of the vehicle. Pedestrian detection is challenging due to the complex road scene in urban areas and difficulty in predicting pedestrian movements that may be hazardous. Significant progress is being made in this field, however, and recent progress is described.

Examining the applications list in Chapter 3, we can extract quite a number of applications that rely upon longitudinal sensing. These are listed here, in the order in which they will be addressed in this chapter:

- Backup/parking assist;
- Night vision;
- Adaptive front lighting;
- ACC;
- Forward collision warning;
- Safe gap advisory;
- Rear impact countermeasures;
- Braking assist (precrash);
- Forward collision mitigation/avoidance;
- Pedestrian detection and warning.

Safe speed applications, such as ISA, are covered in Chapter 9 as they typically rely on cooperative system elements. Platooning, the ultimate form of longitudinal sensing and control, is addressed in Chapters 9 and 10.

For each application area above, a general introduction and descriptions of representative systems are provided. A discussion of market aspects is also provided in some cases, depending on the degree to which a particular application has entered the market. Evaluation projects and significant R&D relating to some of the key application areas are also described.

The chapter concludes with an overview of next generation longitudinal sensors and some observations by the author.

7.1 Rear Sensing for Parking

7.1.1 System Description [1, 2]

Parking consists of short, low-speed maneuvers that may be to the front, rear, or side. In Chapter 6 we saw that steering assist has been employed to assist drivers in the complex maneuvering used for parallel parking. Longitudinally, the maneuver is simple and the focus instead is on proximity sensing of nearby objects that are either not directly viewable by the driver or the clearance distance is not apparent.

The market pull is strong for such systems, as many drivers are at their most uncomfortable when operating their vehicle in a tight parking situation. While the risk to life and limb is almost nil, the risk to paint and good relations with the owners of neighboring vehicles is at a critical level! Further, drivers are aware of the risks and their own limitations in these situations and can easily understand the utility of parking-support sensors.

Back-up sensors based on ultrasonic sensing, consisting of miniature bumper-mounted sensors, have been in use for some time. These are first generation systems that are limited by a short detection range (only a few meters).

In recent years, parking-assist systems have progressed such that data from video, ultrasonics, and onboard processing are fused to provide sophisticated driver advisory systems. For instance, supplier Valeo has developed its ultrasonic park assist (UPA) system by integrating information from three previously separate sensing systems. When reversing, a rear-looking bumper-mounted wide-angle camera is activated. The video images are processed, any distortion is minimized, and the

image is presented to the driver on a dash-mounted LCD display. Data from a second source, the steering angle sensor, is interpreted to provide continuous information on the vehicle's trajectory as it reverses and is represented on the display by a series of colored "navigation" lines that the driver follows by turning the steering wheel in the appropriate direction. Information from a third data source, the UPA sensors, is accessed to provide closing distance to any obstacle to the rear of the vehicle. This information is also processed and superimposed on the driver's display, both as spatially correlated colored bars and as numerical data. The measurement ranges from 2m down to 25 centimeters. If this point is reached, the "stop" message is displayed. The intent of the UPA is to provide drivers an easy-to-use, real-time display of the essential data they need to successfully complete common parking maneuvers.

Use of short-range radar for rear sensing (and low-speed maneuvering in general) offers the advantages of greater accuracy in both the range and direction of obstacles, as well as extended range. At ranges of 5m, radar systems can provide obstacle detection with sufficient warning time to support speeds up to 7 mph. Therefore, whereas ultrasonic sensors are useful in close-in parking maneuvers, the extended range provided by radar supports drivers backing their vehicles in large parking lots and driveways.

As radar costs gradually come down, radar-based parking aids are expected to supplant ultrasonics to a large degree.

Parking-assist functions based on 24-GHz short-range radar were demonstrated at the 2003 ITS World Congress by the SARA Consortium. DaimlerChrysler and BMW both had vehicles on display that were equipped with arrays of four radars in each of the front and rear bumpers, allowing for comprehensive coverage ahead and behind the vehicle. Small vertical posts were positioned a short distance from the vehicle at heights that could not be seen by the driver once the vehicle was within a meter or so. An audible alert was sounded when encroaching upon obstacles ahead, and the brakes were applied when reversing towards obstacles behind, so as to make them impossible to collide with. Encouragingly, experts at the event noted that the radar units, even at this research stage, can be produced at a cost of approximately \$25. While a full suite of these sensors at this price would still be considered costly in automotive terms, the cost goals are seen as being within reach [3].

7.1.2 Market Aspects

Delphi is the market leader in first generation backup radars with over 300,000 units sold. Its Forewarn dual-beam radar back-up aid is scheduled to reach the market in model year 2006.

7.2 Night Vision

7.2.1 System Description [2, 4]

Night vision systems originally developed for military operations were adapted for the automotive market by General Motors during the 1990s. The first system was introduced on the company's Cadillac brand in the middle part of that decade.

The Cadillac and other first generation night vision systems employ an infrared camera operating in the far infrared region (over 1,000 nm). The forward range of this type of infrared sensing is on the order of 500m, which is far beyond the 150m range of typical headlights. Another approach, developed more recently, uses active illumination—near-IR energy is projected from the vehicle and the reflected energy is received and processed. Near-IR night vision provides a more natural-looking image to the driver than traditional thermal (far-IR) night vision and allows the driver to see “cold” objects such as trees and mailboxes. The near-IR light is not visible to humans, so oncoming drivers are not affected by the projected light. With active near-IR systems, the detection range is less, however—on the order of 100m.

The infrared image is typically displayed on a small screen near the driver’s forward view. Some systems employ a dedicated screen atop the console and others use a heads-up display. Infrared energy emanating or reflecting from pedestrians and animals is clearly seen on the display.

With night vision, the driver’s ability to perceive the forward path is enhanced immensely. Without night vision, the timing of a pedestrian coming within view of the headlights may give the driver very little response time if an avoidance maneuver is required, which could lead to a crash or loss of vehicle control. With night vision, a potential obstacle is made visible with plenty of time to gracefully respond to the situation. Depth perception is also enhanced. Further, night vision helps to detect pedestrians and roadside objects when the driver’s vision is affected by the glare of ongoing headlights.

7.2.2 Night Vision Systems

Some examples of night vision systems offered by automakers and suppliers are given here.

Visteon’s Driver Vision at Night [5] Visteon’s Driver Vision at Night uses a dedicated illumination source to cast near infrared light upon the road and an internally mounted, near-infrared sensor to capture the road scene ahead of the vehicle. This information is projected directly in front of the driver, thereby supporting drivers in keeping their eyes on the road.

PSA Night Vision [6] A system developed automaker PSA uses an integrated camera and emitter mounted inside the vehicle operating in the range of 700–1000 nm wavelength. IR energy at this wavelength is not affected by windshield glass. PSA has also developed a passive night vision system operating in the 8,000–12,000 nm wavelength range that must be mounted outside the windshield. The company is currently studying methods to analyze the infrared image to detect potential hazards (such as pedestrians) and alert the driver.

Bendix XVision [4] The Bendix XVision system was the first infrared night vision system designed for commercial vehicle applications. Their system, an adaptation of the Cadillac system, consists of an externally mounted, roof-top far infrared camera. This data is then transformed into a virtual image projected onto an in-cab heads-up display mounted just above the driver’s line of sight. The driver glances at the head-up display just like passenger car drivers glance at a rearview mirror. A 1:1

viewing ratio is employed so that images depicted on the in-cab display unit will be in identical proportion to the image as seen through the windshield.

When viewing the display unit, the driver sees a real-time, black and white, thermal image of the road in which warmer objects—such as people or animals—appear in shades of white, while cooler objects—like bridge abutments, guardrails, or trees—show in darker shades of gray or black.

7.2.3 Market Aspects

Night vision is sold as an option on Volvo and Hummer automobiles, in addition to Cadillac. Bendix is the only supplier of night vision systems to the heavy truck industry. A new night vision system that also incorporates pedestrian detection entered the Japanese market in 2004. This system, from Honda, is further described in Section 7.10.

7.3 Adaptive Front Lighting (AFS)

7.3.1 System Description

AFS systems illuminate areas ahead and to the side of the vehicle path in a manner intended to optimize nighttime visibility for the driver. Basic systems, already on the market, take into account the vehicle speed to make assumptions as to the desired illumination pattern. For instance, beam patterns adjust down and outward for low-speed driving, while light distribution is longer and narrower at high speeds to increase visibility at farther distances. More advanced systems also incorporate steering angle data to illuminate a fixed auxiliary beam. These concepts are illustrated in Figure 7.2.

Going one step further, advanced AFS systems use a swiveling lamp for the auxiliary beam. The lamp is controlled by a microcontroller linked to the vehicle's data

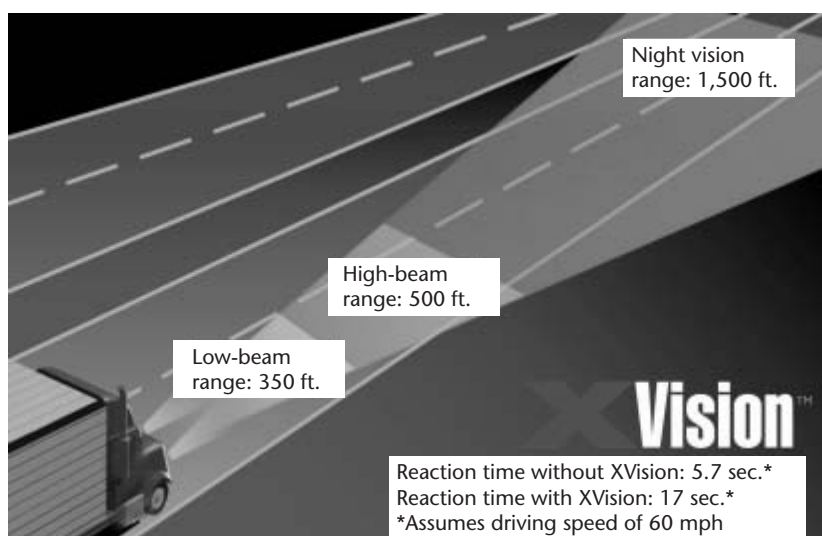


Figure 7.1 Sensing range of Bendix XVision night vision system is far beyond typical headlights. (Source: Bendix Commercial Vehicle Systems LLC.)

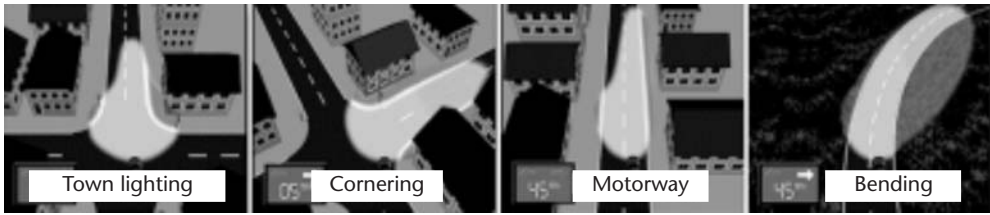


Figure 7.2 Adaptive front lighting optimizes illumination based on speed and steering. (Source: Visteon.)

network with real time inputs from both the steering angle and vehicle speed sensors. The system aims to automatically deliver a light beam of optimal intensity to maximize the illumination of oncoming road curves and bends.

The next generation of AFS systems will use satellite positioning and digital maps so as to have preview information on upcoming curves. Headlights are then aimed into the curve even before the vehicle reaches the curve, at just the right point in the maneuver. The net effect is that the driver is presented with a more consistent view of the road rather than unnecessary glimpses into the forest!

7.3.2 System Descriptions [1, 7]

Visteon's system controls the forward illumination pattern based on data from a steering wheel sensor, speed sensor, and axle sensors to direct the headlights in real time. In the case of a vehicle turning a corner, for example, the outer headlight maintains a straight beam pattern while the inner, auxiliary headlight beam illuminates the upcoming turn (Figure 7.3). The system responds to vehicle speed here as well.

Valeo's development of AFS, which is a part of its "Seeing and Being Seen" domain, provides another example. The company's base system adapts the direction and intensity of forward illumination to vehicle speed and road contours. In addition to the main and dipped beams, an additional light source is integrated into the headlamp at a fixed offset angle of around 35 degrees towards the nearside. This second light source provides automatic illumination of sharp road curves and intersections at low to medium speeds, again based on steering angle and speed data. Valeo asserts that such a system provides a 90% improvement in the driver's view of the peripheral area of the nearside lane.

7.3.3 Market Aspects [8]

These smart lighting systems have a market advantage relative to many IV safety systems which are "silent" unless a crash is imminent—drivers can experience the benefits of adaptive headlights every time they drive at night.

Market introduction of the advanced forms of adaptive headlights received an enabling boost in 2003 when regulatory changes allowed the specification of intelligent lighting systems on new vehicles throughout Europe [9].

In 2004, vehicles with AFS systems (15-degree swivel range) included Acura, Audi, BMW, Lexus, Mercedes-Benz, and Porsche. GM's AFS system swivels the lamp 20 degrees toward the outside and 5 degrees toward the center.



Figure 7.3 AFS improves roadside illumination on curving roads. (Source: Visteon.)

7.4 Adaptive Cruise Control (ACC)

ACC eases the stress of driving in dense traffic by acting as a “longitudinal control copilot.” As described in Chapter 3, ACC systems provide cruise control and also track vehicles in the lane ahead of the host vehicle and adjust speed as needed to maintain a safe, driver-selectable intervehicle gap. For reasons that will follow, ACC comes in various “flavors” including high-speed ACC, low speed ACC, and full-speed-range ACC.

This section begins with an overview of the sensing technologies and trade-offs for ACC systems, which generally apply to forward collision countermeasures as well. Individual system types, implementation approaches, and market aspects are then reviewed.

7.4.1 ACC Sensor Technologies and Trade-offs

ACC sensors must detect range and range rate to vehicles in the forward path of the host vehicle. To do this job, radar, lidar, and machine vision sensors are used. Their characteristics are described here at a high level.

In the ideal world, a suite of multiple, complementary sensors would be used to get the best performance, but this is currently cost-prohibitive. Therefore, tradeoffs between system types are also discussed.

Sensor technologies are described in relation to first generation high-speed ACC systems, which are at a more mature stage than low-speed or full-speed range ACC.

Radar-Based ACC [5, 10–13] Radar-based ACC systems are offered by several suppliers. Examples of ACC implementations are offered here, based on Bosch, Denso, Renault, TRW, and Visteon systems. Obviously, the parameters involved in such a system are numerous and only a few are covered here.

High-speed ACC systems operate within the 76–77 GHz frequency range and typically use FM Continuous Wave, frequency shift keying, or pulse modulation. Forward range of the Denso and Visteon designs is 150m, with others as short as 120m. An important range factor is also the minimum range, which affects the radar's utility at short distances. Visteon's system is specified at 1m minimum range, whereas the TRW system minimum range is zero. Range resolution is another key factor, which can be expressed in absolute terms (less than 3-m range resolution in the Visteon system, 5m for the Bosch radar) or as ranging precision (stated as 5% by TRW).

Beamwidths are generally in the range of ± 5 degrees. The beamwidth of the Bosch radar is ± 8 degrees, and Denso's radar is widest at ± 20 degrees. In some cases, the beam is designed to be wider (approximately 10 degrees) at short range (less than 40m) and narrower (approximately 8 degrees) at long ranges. This enables monitoring of near-distance "cut-ins" (vehicles in the adjacent lane suddenly moving into the host vehicle's lane) while at the same time rejecting targets in adjacent lanes in the far field.

Both mechanically scanned techniques and switched-sector beams are used to enable radar sensors to determine azimuth information for forward targets. The Delphi system used on Jaguar systems is a single mechanically scanned beam, for instance. For switched sector beams, the number of beams is another factor. The Visteon system uses two beams; Continental-Teves and TRW systems use three beams; Bosch uses four beams; and Honda's system uses five beams.

Elevation beamwidth is also important—too wide of an elevation beam will result in radar returns from overhead structures, complicating the process of rejecting false targets. Conversely, too narrow of a beam will degrade performance of the system in detecting forward vehicles on vertically sloping roadways. ± 2 degrees is typical.

Lidar-Based ACC [13, 14] Lidar systems emit and detect near-infrared light at wavelengths between 750 and 1,000 nm.

Switched-beam approaches are typically used for lidar. For example, Hella's ACC system uses a 16-beam lidar. Denso's lidar achieves a wide scanning range by using a rotating polygon mirror with various surface incline angles to achieve two-dimensional laser scanning at a horizontal angle of up to ± 18 degrees. Its laser diode produces power of 34 watts, which extends the range out to 100m. Using advanced time measurement circuitry, detection of forward objects can be accomplished with a range error of only a few centimeters at this range.

Vision-Based ACC [15] ACC systems based on monocular machine vision techniques have also been developed by Mobileye. While monocular vision systems do not perform direct measurements of the fundamental ACC parameters of range and range rate, this data can be extrapolated from the video images. The Mobileye

system uses a high dynamic range CMOS camera mounted on the inside of the windshield, with a field of view of 40 degrees horizontal by 30 degrees vertical. Detection range for vehicles ahead is 60m.

Auxiliary Measurements To track in-lane targets and filter out adjacent vehicles in other lanes, high-speed ACC systems also measure parameters such as the vehicle's longitudinal speed, yaw, and cornering rate.

Second generation radar and lidar systems will also use vision-based lane detection to get a better picture of road curvature, which can then be cross-correlated with forward sensing data to increase the confidence level as to which vehicles are in-lane and therefore relevant for tracking. The shape of the road up to 120m ahead can be determined by advanced image-processing systems. Vision-based forward sensing systems, of course, come with this capability "built in."

Eventually, ACC systems will also integrate digital map data into road/lane tracking algorithms to increase performance further.

Sensor Trade-offs [12, 14, 15] Cost/performance trade-offs exist between the sensing modalities of radar and lidar. Radar systems are more expensive to produce but offer robust performance in the presence of virtually all weather conditions encountered by drivers. In fact, radar wave propagation is less attenuated than human vision in poor weather conditions such as heavy rain or fog.

Lidar, by contrast, is cheaper to manufacture but degrades in precipitation and reduced visibility caused by fog or smoke. One lidar-based ACC system, for instance, automatically disables if the driver switches the windshield wipers beyond the "intermittent" setting, as this is an indication of precipitation potentially sufficient to degrade the system's performance. Vision-based systems offer a significant cost savings over both radar and lidar, but are also affected by visibility [15].

While customers may not want their lidar-based ACC to turn off in the rain, they can be happy with the price—lidar ACC systems are sold in the price range of \$800, compared to the typical \$2,000 cost of a radar-based ACC.

Later generations of lidar ACC are making headway in competing with radar systems while retaining the cost benefit. As shown in Figure 7.4, Hella's lidar unit is designed to successfully process reflected infrared laser energy from forward vehicles even in the presence of fog.

In terms of mounting and exposure trade-offs, ACC sensors are installed within or behind the front grill of the vehicle. In the harsh road environment, lidar is again more susceptible than radar to degradation by road dirt obscuring the sensor; however, the systems are nevertheless quite robust and disable only in conditions of almost complete obscuration of the sensor. Figure 7.5 shows a typical lidar unit mounting approach. Vision systems are installed on the inside of the windshield and are therefore protected from the elements.

7.4.2 High-Speed ACC

System Description [11] High-speed ACC allows a driver to set a desired speed as in normal cruise control; if a vehicle immediately ahead of the equipped vehicle is moving at a slower speed, then throttle and braking of the host vehicle is controlled to match the speed of the slower vehicle at a driver selectable time headway, or gap. The desired speed is automatically reattained when the way ahead is unobstructed,

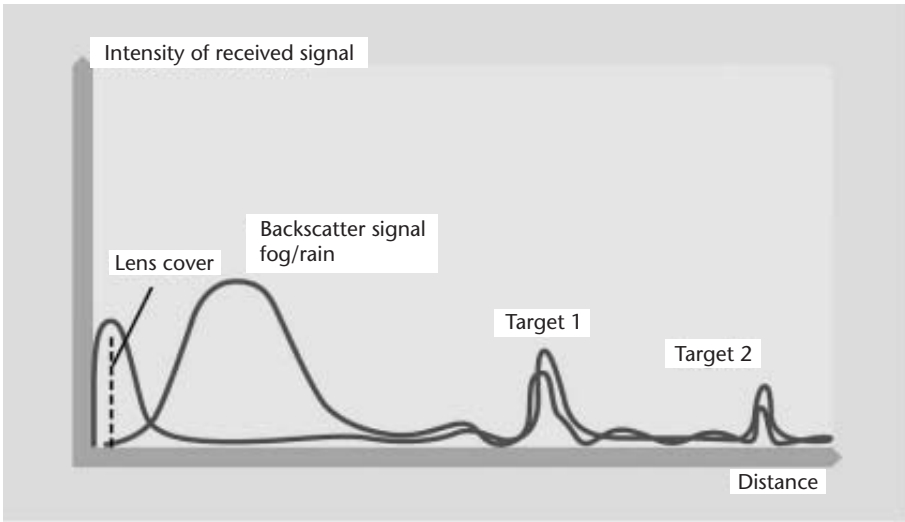


Figure 7.4 LIDAR system response within fog. (Source: Hella KGaA Hueck & Co.)

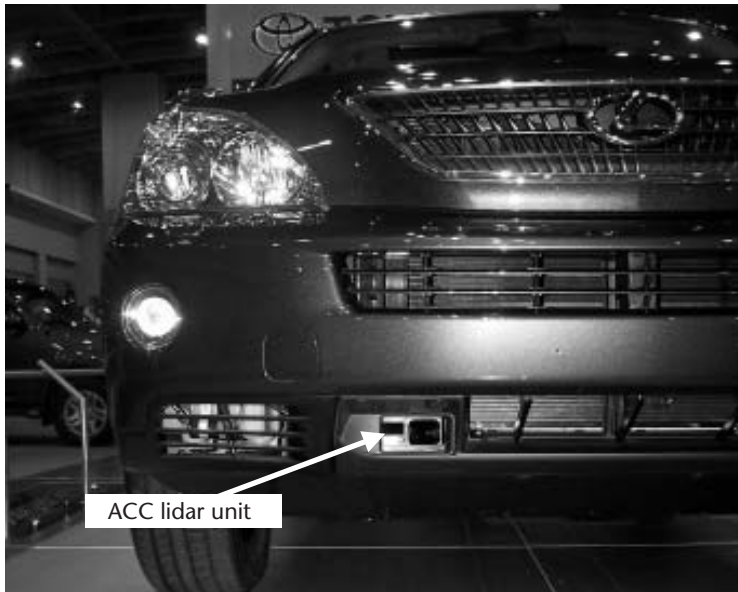


Figure 7.5 ACC Lidar unit mounted in front assembly of a Lexus vehicle. (Photo: K. Fowler.)

resulting from either the slower vehicle ahead leaving the lane or the driver of the host vehicle changing to an unobstructed lane.

The first ACC systems were designed to operate at moderate to high speeds, on the order of 40 km/hr and above. This is because it is much easier to discriminate bona fide targets (other vehicles) from nontargets (such as roadside clutter) at these speeds. Other vehicles traveling in the same direction will be at low relative velocities as sensed by the host vehicle system, whereas any stationary objects on the roadside are at high relative velocities and can thus be filtered out.

This speed range has expanded as system designs have proliferated, however. Most European systems operate from 30 kph and higher because this is a typical speed limit in city areas. The upper speed range goes as high as 200 kph.

ACC systems are designed to have limited braking authority, on the order of .25g (full braking in a typical car is 1.0g). In cases where the closing rate to the vehicle ahead is high and the braking authority of the host vehicle is insufficient to avoid a collision, audible alerts are sounded to compel the driver to intervene with additional braking. While automakers stress that ACC is not a safety system, most users nevertheless consider the system to have safety benefit, given that any automatic braking action is felt viscerally and alerts them to a situation ahead; the audible alerts compel their attention even more.

A typical ACC driver-vehicle interface is shown in Figure 7.6. The system is activated in the same way as normal cruise control, and the driver has a choice of three to four gap settings. Gaps are based on time headway, with selections ranging from typically 1.0 to 2.2 seconds. The set speed is indicated by a visual display and a car icon is used to indicate that the system is tracking a vehicle ahead.

It should be noted that regulations in Europe stipulate that, for regular driving, the following interval between vehicles recommended (or required, depending on the country) is 2 seconds. User experience thus far indicates that this is an unrealistically large gap, causing other vehicles to frequently cut in front of them. Automakers must tread a fine line between offering systems that do not get them into regulatory trouble while at the same time maximizing user acceptance. Therefore automakers offer shorter gap selections than those recommended by public authorities, with a default setting compliant with the recommendation. This is the case for the Renault ACC system, for instance, whose default setting is 2 seconds. If drivers then select a headway less than what is officially allowed, it is no different from maintaining such a headway under their own control and the responsibility is theirs alone.

Market Aspects [16, 17] High-speed ACC was introduced in Japan in 1995, followed by introductions in Europe in 1998 and the United States in 2000. Based on conversations with auto manufacturers, I estimate that close to 50,000 ACC-equipped vehicles have been sold to date worldwide. In monitoring consumer acceptance of ACC, automakers have generally found that customers highly value the system as a significant stress-reliever when driving in dense traffic and, as noted above, a safety enhancement as well.

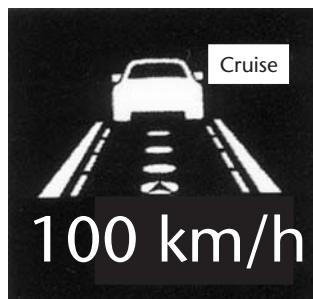


Figure 7.6 Dashboard indicator showing ACC enabled and tracking a vehicle ahead. (Source: Nissan.)

High-speed ACC is now available from Audi, BMW, DaimlerChrysler, Fiat, GM, Honda, Jaguar, Nissan, PSA, Renault, Saab, Toyota, and Volkswagen. Generally the systems are available only on the high-end vehicles, but ACC is beginning to come into the mid range, for instance on the Nissan Primera and VW Passat in Europe and the Sienna minivan in North America. However to get “dynamic laser-guided cruise control” on the Sienna, buyers must buy the top-of-the-line, fully loaded model [18].

What are the sensor choices in use? Some manufacturers use both radar and lidar, individually, on models in different parts of the world. However, generally speaking, radar systems are used by Audi, BMW, Cadillac, Honda, Jaguar, Mercedes, and Volkswagen, while lidar is used by Nissan and Toyota. ACC based on machine vision is under evaluation by automakers and has not been introduced to the market. However, machine vision is used to detect road geometry, and augment radar data in a new system introduced in Japan by Toyota in 2004.

In parallel with automotive product offerings, radar-based ACC was introduced to the heavy truck market in North America in the late nineties by Eaton VORAD. This system is an enhancement to its forward collision warning system operating at 24 GHz (see Section 7.6). The next generation system will transition to 77-GHz operation, which will then be in line with the automotive radar systems and likely reduce costs over the long term based on total sales of radar units for cars and trucks combined. ACC is also available on MAN and Mercedes trucks in Europe.

7.4.3 Low-Speed ACC

System Description In contrast to relatively free flowing highway traffic conditions, low-speed stop-and-go traffic is the bane of commuters and the cause of daily stress and fatigue. Low-speed ACC systems are meant to help relieve the tedium of driving in these conditions, even though the pace of travel may continue to be maddening.

Interesting issues arise, though, when an ACC system is introduced for low-speed operations. Although most useful on highways where traffic signals are not present, system designers must assume that drivers will use the systems on any type of road in any type of situation. Must the systems then detect more than vehicles ahead? Must they detect pedestrians entering the street in urban city centers? Or can the use of the system be restricted to use only on highways, through the use of satellite positioning and digital maps so as to enable or disable system availability based on road type?

Less intelligence is required to stop the vehicle for an obstacle compared to the intelligence required to assess the forward situation, judge that it is safe to proceed, and reinitiate forward motion. So, although the traffic may be stop-and-go, system designers appear to be opting for limited functionality initially, for example “stop-and-wait,” which leaves the restart decision to human perception. Another approach is ACC that operates down to a very low speed and disables below that level, simultaneously alerting the driver to take over control for both braking to a stop and restarting at the appropriate time.

Market Aspects [19, 20] In late 2004, low-speed ACC systems called “low-speed following” were introduced to the Japanese market by Nissan and Toyota. The systems operate quite differently and it is useful to take a look at each.

The Nissan system (Figure 7.7), operates seamlessly from highway speeds down to the low-speed following mode. The low-speed following mode can be activated from 10 to 40 kph and disengages at 5 kph. Below 5 kph, the driver is responsible for stopping the vehicle if necessary and receives an advisory warning from the system if there is an obstacle ahead. Functionally, the low-speed follower performs gap control, not speed control as is done with high-speed ACC. It can only be activated when there is a vehicle ahead and will disengage if the lead vehicle changes lanes. If while in following mode the driver sets a speed in the high-speed range, the system will seamlessly enter the high speed mode as the lead car accelerates to higher speeds. If the lead car then slows again to the low-speed range and reaccelerates to higher speeds, the system will stay engaged throughout.

The Toyota system operates in two separate modes: the regular highway-speed ACC, and a low-speed tracking mode. The appropriate mode must be activated by the driver when accelerating and decelerating between the speed ranges. The low-speed mode will operate down to zero speed—it warns the driver when the vehicle ahead is stopping and if there is no response the system will automatically halt the vehicle. This is only a temporary stop and the system will deactivate soon afterward.

In both cases, once the car stops, the driver must reinitiate motion and reengage the system.

Nissan demonstrated their a low-speed ACC system to the automotive media in late 2003. Drivers noted that the cut-off point of 5 kph is experientially very slow and observed that it is quite natural to resume control to halt the vehicle as the preceding car stops. They also noted that, while users may prefer a system that handles 100% of the stop-and-go traffic, a low-speed system such as this would provide assistance for a large portion of the time spent in a traffic jam. Compared to the alternative—no assistance at all—these types of partial solutions could be highly valued by consumers.

Other versions of low-speed ACC are expected to be introduced to the European market in 2005.

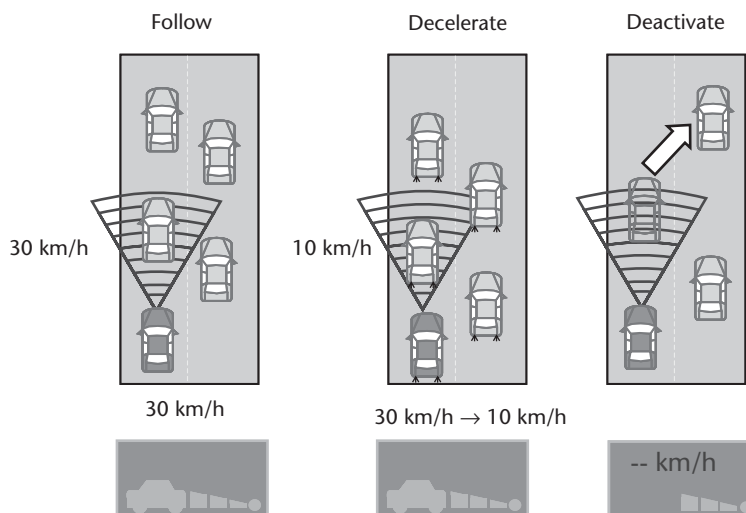


Figure 7.7 Operating modes of Nissan low-speed following system. (Source: Nissan.)

7.4.4 Full-Speed Range ACC

There is debate within the industry as to whether highway-speed ACC and low-speed ACC should remain separate in terms of driver activation, or instead be integrated into a “full-speed range” ACC, which would seamlessly transition between highway cruise and traffic congestion conditions. These differences appear in the two systems outlined in the previous section. The controversy hinges on the possibility that system functionality between the two speed domains could differ in minor but important ways, creating the potential for confusion on the part of the driver and improper system usage. At the same time, customers may perceive the high-speed and low-speed functions to be essentially the same and be irked by the need to switch from one to another as their speed increases or decreases.

These functional issues will most likely be addressed in an evolutionary manner as individual automakers introduce new products to the market, based on their best sense of customer utility and the customer’s ability to understand the systems. It will take some time for the issues to “shake out.”

7.5 Safe Gap Advisory

Given human perceptual limitations, it is difficult for many drivers to judge a safe intervehicle distance correctly. Safe gap advisory is intended as a noncontrol version of ACC to provide drivers with a continuous indication of their headway to the vehicle ahead. When the headway is deemed to be insufficient for safe stopping in the event of braking by the lead vehicle, the driver is alerted. Safe gap advisory systems can be viewed as a bridge between ACC and forward collision warning systems. Because no vehicle control is involved, the systems lend themselves to after-market sales in the same way LDWS does.

7.5.1 System Description

A safe gap advisory function is offered within Mobileye’s advance warning system (AWS), now sold in the automotive aftermarket. The vision-based system includes a compact camera located on the windshield behind the rearview mirror, a processing unit, a driver display, and audio speakers. As shown in Figure 7.8, the Mobileye headway display provides a visual indication when insufficient distance is being kept to the vehicle ahead, as well as a continuous numeric display (in seconds) as a cue to help the driver improve his or her car-following habits. In the figure, the upper image shows a safe situation, with the car icon (a green color in the actual unit) appearing to be more distant. The lower image shows an unsafe headway—the car icon is larger and appearing to be closer and the icon color is yellow.

7.5.2 Research and Evaluation

Belonitor [21] A pilot project called BELONITOR is under way within the innovation program of the Dutch Ministry of Transport. The purpose of the pilot is to investigate ways in which the driver’s behavior can be influenced, particularly with respect to headway and speed. The approach is innovative: to use rewards



Figure 7.8 Mobileye AWS display. (Courtesy of Mobileye N.V.)

toward behavioral goals, rather than the classic “punishment” approach of traffic tickets from police. The pilot aims to assess the degree to which rewards can improve drivers’ driving behavior. For the Dutch government, such a positive change in behavior relates to improved safety and traffic throughput.

The test concentrates on incentivizing drivers to maintain sufficient intervehicle distance and stay within the speed limit. During the test, leased-car drivers are rewarded for their positive driving behavior by accumulating “points.” The drivers’ behavior is registered by in-car equipment and constant real-time feedback is provided as well. They will be able to view the points they have accumulated each day on the project Web site, and can then exchange their points at their vehicle lease company to reduce leasing fees.

SASPENCE [22] SASPENCE is one of the subprojects within the European PReVENT Integrated Project. The goal is to develop and evaluate an innovative system able to provide safe speed and safe distance advice to drivers. The system incorporates data from onboard sensors, as well as information regarding the situation ahead (such as road condition, traffic, and weather) received via wireless communications.

7.6 Forward Collision Warning

FCW systems detect impending crash situations and provide a warning to the driver. Any crash avoidance response is the responsibility of the driver.

As with ACC, the sensing modes of radar, lidar, and machine vision are also candidates for FCW.

7.6.1 System Description

While FCW was seen as one of the earliest active safety systems for cars when “safety roadmaps” were discussed during the nineties, reality has been different.

While some FCW systems have been introduced, in essence the auto industry has “leapfrogged” directly to active braking systems (see Section 7.9). This can be seen as a combination of factors—the success and robustness of ACC, once in customer’s hands, resulted in increased confidence in active braking, even at the modest braking levels employed in ACC. Further, the time available for a driver to respond to an impending crash once a threat is reliably detected is minimal; if designers seek to increase the warning time, false alarms increase, raising the specter for automakers that their brand would be exposed to a system that “gets it wrong” frequently.

In at least one case, though, ACC sensing functionality has been extended to warn drivers of collision-critical closing rates even when the ACC function is turned off. This is the case for the Jaguar Forward Alert TM system.

The situation is different for professional drivers, such as those operating heavy trucks and buses, who are better trained and more able to respond appropriately to a warning. Furthermore, any false alarms are more tolerable if the system nevertheless contributes to the bottom line of the fleet operator by avoiding crash costs.

Nissan was the first to offer FCW worldwide with its Trafficguide system introduced in Japan in 1988, which used lidar for sensing. The Eaton VORAD radar-based system, described below, has been quite successful in the heavy truck market in the United States.

Japan has pioneered another approach to forward collision warning within the AHSRA research program. For certain high-crash highway sections that have blind curves, roadside sensors detect obstacles ahead and warn drivers upstream via electronic signs and/or in-vehicle alerts. This work is further described in Chapter 9.

7.6.2 Market Aspects

Two current FCW systems are described here as examples.

Eaton VORAD Collision Warning System [17, 23] Forward collision avoidance has been operating on heavy trucks in the United States since the early nineties. The Eaton VORAD system uses 24-GHz Doppler radar to monitor both the region ahead of the truck and the right-side blind spot. The forward sensing range is approximately 100m and data from an internal yaw rate sensor is incorporated so that radar signal processing can focus only on in-lane vehicles ahead, even on curved roads. The driver is alerted to hazards via a progressive visual display (green/yellow/red), combined with an audible warning when a critical closing rate threshold is reached. Figure 7.9 shows the placement of sensors and driver displays.

Fleets using the system, which sells in the range of \$2,000, have reported amazingly high crash reduction rates. For example, one fleet with 605 equipped trucks experienced a 92% reduction in forward crashes over 190 million miles traveled, compared to the equivalent mileage on unequipped trucks. The economic value of avoiding such forward collisions is huge to a truck fleet, as they are often self-insured and crash costs directly undermine profit. The costs of such collisions can sometimes exceed \$100,000, although there is wide variation depending on severity. It is interesting to note also that FCW systems on large trucks are more likely to save the lives of car occupants than truck occupants, due to the greater damage to the smaller vehicle in collisions.

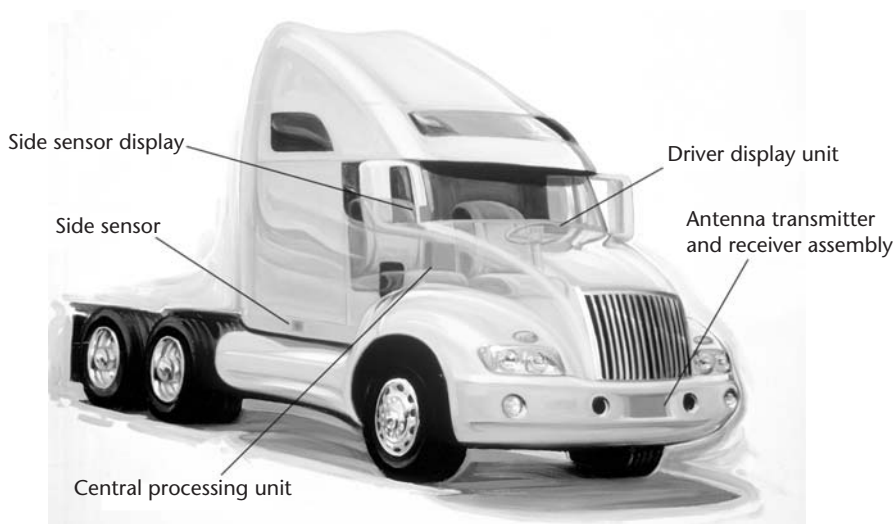


Figure 7.9 Sensors and display placement for the Eaton VORAD forward collision warning system. (Source: Eaton VORAD Technologies.)

Over 50,000 units have been sold to date, and the company is currently expanding into the European truck market, as well as large recreational vehicles, school buses, and transit buses. As noted above, the VORAD system is also sold with integrated ACC functionality using the same radar sensor.

Experiments have also been conducted with the VORAD system on transit buses. FCW for transit is a component of the Integrated Collision Warning System now under development by the U.S. Federal Transit Administration. This activity is reviewed in Chapter 8.

Mobileye FCW [15, 24] Mobileye's AWS system also includes FCW within its suite of functions. The vision system also allows for vehicle cut-in warnings. In this case, the system monitors the lateral motion of target vehicles and issues warnings when a vehicle is about to cut in front of the host vehicle's path.

7.6.3 Evaluation of FCW: The ACAS Field Operational Test [25, 26]

In one of the largest government-sponsored field trials of its kind, General Motors and a group of partners have enlisted Michigan drivers to test vehicles equipped with both FCW and ACC.

The U.S. DOT, GM, and Delphi Automotive fund the project, called the Advanced Collision Avoidance System field operational test (ACAS FOT). The test, involving 10 Buick LeSabre sedans, is the culmination of a five-year partnership formed in 1999 to develop and evaluate collision avoidance technologies. One of the test vehicles is shown in Figure 7.10.

U.S. DOT funding was motivated by a need to understand and assess the effects of such systems on safety, as well as a desire to further develop algorithms for robust forward collision warning. As an adjunct part of project, new test tools and methodologies to objectively evaluate performance have been developed that use surrogate vehicles, driving simulators, and test tracks.



Figure 7.10 One of 10 Buick LeSabre test vehicles used in the ACAS forward collision warning/adaptive cruise control field operational test. (Source: General Motors.)

The ACAS uses radar sensors, global positioning system (GPS) technology, and machine vision to detect hazardous situations ahead on the roadway. The system informs drivers of three types of rear-end crash scenarios:

- Tailgating advisory (triggered by following a preceding vehicle too closely);
- Cautionary closing alert;
- Imminent closing alert.

The warnings are intended to communicate to the driver that he or she may need to brake quickly or make an evasive maneuver to avoid a collision. Warnings are both audible and visual, with the visual warnings illuminated in front of the driver on a heads-up display on the windshield.

When the project was initiated in 1999, only ACC was in the marketplace; since then collision-mitigation systems have entered the market that basically surpass the capabilities of the ACAS systems. The unique value of the GM approach, however, is in the ability to quantitatively and thoroughly evaluate driver use and comprehension of FCW. Further, advanced forms of sensor fusion are employed, using both GPS/digital maps and vision to enhance radar-based target detection and tracking. The digital map and GPS receiver enable an indication of vehicle position and direction of travel on the map; this data, combined with image processing, is used to predict road geometry ahead. Additionally, radar tracking uses the trajectories of tracked vehicles ahead to determine if there is a pattern that may indicate the upcoming road geometry. For instance, if all forward vehicles are slightly turning to the right on a highway, it is likely that the road itself is curving to the right. Data fusion combines these estimates to determine the best overall prediction of road geometry ahead. From this, the proper targets for tracking are established and false alarms are reduced.

What are the key questions addressed by the test? Researchers are studying, among other things, if drivers using the systems actually experience fewer “close following” or “rapid-closing” driving situations that could lead to crashes, and if the performance of these systems meets consumer expectations. Some of the research questions being addressed are listed as follows:

- Do drivers experience fewer tailgating or “approaching too fast” driving situations, which can lead to rear-end crashes?
- Do drivers respond quickly and appropriately to visual and auditory warnings?
- How often do drivers experience useful warnings versus false alarms? Under what circumstances?
- Do drivers have an accurate mental model of the system?
- How do drivers feel about the crash alert timing and interface approach?
- What ACC headway and FCW alert timing settings do drivers prefer?
- Under what traffic conditions will drivers choose to use ACC?
- What implications do these results have on customer education approaches for ACC and FCW systems?
- Do drivers find ACC and FCW systems useful?
- Are customer expectations being met for ACC and FCW system performance (e.g., are drivers tolerant of false alarms?)

The data acquisition system, shown in Figure 7.11, records over 500 data channels, including the following:

- Circumstances surrounding crash alert occurrences;
- Roadway video;
- Driver video;
- Brake applications;
- Vehicle speeds;
- Traffic conditions;
- Driver-preferred system settings (including sensitivity settings for the FCW alerts).



Figure 7.11 ACAS data acquisition systems housed in the trunk of the test vehicles.
(Source: General Motors.)

Field data collection for the project was completed in early 2004. Ninety volunteer drivers participated and accumulated over 100,000 miles of travel. The data collected represents many gigabytes of both video and quantitative data, which must be analyzed to come to some conclusions on the questions above—a key challenge for U.S. DOT evaluators simply due to sheer volume of data. Data analysis is expected to be complete by the end of 2004.

Subjectively, preliminary feedback from drivers showed that almost all of them liked ACC. False positive warnings were considered a source of “mild annoyance.”

7.7 Rear Impact Countermeasures

For transit buses, in addition to forward collisions, rear impact countermeasures are needed. Rear impacts are a particular problem for transit buses, as the buses make passenger stops on busy city or suburban streets where other traffic would not normally stop. Therefore, they are susceptible to being struck from behind by following vehicles whose drivers are inattentive. Since the bus is most at risk, rear impact countermeasures rely upon sensing hardware on the rear of the bus to detect fast-closing vehicles. When this situation is detected, vivid warning flashers are activated to—hopefully—attract the driver’s attention in time to avoid a crash. In essence, then, this is an FCW system that is installed on the victim vehicle! The U.S. Federal Transit Administration has sponsored prototype development and evaluation of these types of systems under the U.S. DOT Intelligent Vehicle Initiative program [27].

7.8 Precrash Brake Assist

7.8.1 System Description

Another incremental step toward crash avoidance, without actually initiating braking, is the precrash brake assist function. Here, the ACC sensor is used to detect collision-critical closing rates and optimize braking performance to raise the driver’s chances of avoiding the crash. (Additionally, occupant protection systems are readied in case the collision is not avoided.)

The earliest form of brake assist, on the market for some years now, used the driver’s “foot action” to indicate an emergency situation. A quick switch from throttle to brake pedal activation is the telltale sign. The instant this condition is detected, the braking system pressure is increased so that the brake pads are moved as close as possible to the discs and the brake pedal “free travel” is minimized. (Free travel is the movement distance of the pedal before braking is actually engaged.)

Obviously, by adding information from the ACC sensor, this precharging action can be initiated even before a driver reacts to a dangerous situation. At 100 kph, with brake force activation occurring 100 msec sooner, stopping distance for the average sedan is reduced from 49m to 46m and the impact speed is reduced by 5 kph. Thus, these systems are effective in reducing crash severity if not avoiding the crash altogether.

7.8.2 Market Aspects

ACC-based brake-assist systems are now available in Japan from manufacturers such as Honda, Toyota, and Nissan. European manufacturers offering the system include Mercedes.

For the U.S. market, Toyota announced the availability of brake assist for the model year 2006 Lexus GS sport sedan at the 2004 North American International Auto Show. Its optional precollision system (PCS), developed jointly with Denso, uses the millimeter-wave radar ACC sensor to measure distance and relative speed to a target and integrates that data with vehicle speed, steering angle and yaw rate inputs to calculate whether a collision is unavoidable. The system then preemptively retracts front seat belts and precharges the brakes for increased braking force to help reduce collision speed, as discussed above [28, 29].

7.9 Forward Crash Mitigation (FCM) and Avoidance—Active Braking

7.9.1 System Description

The next step beyond forward collision warning and precrash brake assist is FCM, with the ultimate goal of course being forward collision avoidance (FCA). Each progressive stage in functionality represents a significant increase in required system performance, in areas such as target detection, robustness in the presence of clutter, and overall system reliability. Similarly, at each stage, the “stakes” get higher: The consequences of a FCW system misinterpreting a situation and sounding a false alarm is annoyance for the driver, whereas a false detection and unnecessary brake activation in a FCA system could potentially cause a collision from the rear.

FCM differs from FCA in terms of the braking activation protocol. FCM is the more conservative system, requiring the crash probability to be nearly 100% before initiating braking. When it comes to crash avoidance, however, things get interesting. To avoid a crash at high speeds, braking must be initiated at such an early point in the unfolding crash scenario that several key variables are in play. The driver is the main variable and may choose to steer out of the collision at the last moment. In such a case, it could both confuse the driver and interfere with an otherwise safe maneuver for hard braking to suddenly begin. This would be the case, for instance, in a multilane roadway in which the driver of the host vehicle must swerve out of the lane to avoid a forward crash and, to avoid secondary collisions with approaching vehicles in the adjacent lane, an appropriate speed must be maintained as that lane is entered by the host vehicle. These complex operational issues are expected to be worked out by system designers; at minimum, onboard system intelligence must possess a much broader view and understanding of the total traffic and road situation to implement such systems.

7.9.2 Market Aspects [30, 31]

FCM is therefore a much more tractable problem and was introduced into the market in Japan in the summer of 2003. This was a watershed event in intelligent vehicle safety systems, constituting the first ever market introduction of active vehicle control for the explicit purpose of increasing safety. System developers there were able

to benefit from several years of experience with production ACC systems to gain confidence in stepping into the active safety realm.

The introduction of FCM in Japan, as with all new car technology there, is managed by the Japanese MLIT. In 2003, the agency issued the following technical guidance for these systems:

- The system must alert a driver before activating deceleration by braking.
- System activation is limited to situations in which a driver cannot avoid a crash with 1.0G deceleration.
- Braking deceleration must be over 0.5G.

The major Japanese automakers responded by introducing very similar systems, as can be seen from Table 7.1. Sensing technologies employed—either radar or lidar—reflect the type of ACC sensing used by different OEMs. All three systems use audible alerts to initially get the driver’s attention to a forward crash situation, with Honda also employing “impulsive braking,” which is in essence a tapping of the brakes sufficient to be felt by the driver. If the driver does not brake the vehicle, the systems use the maximum braking force allowed by the government at the last moment to reduce the severity of the crash, while at the same time pretensioning seat belts.

The Honda CMBS provides a good example of how these FCM systems work. The system determines driving conditions using sensors that detect factors such as yaw rate, steering angle, wheel speed, and brake pressure, and the millimeter-wave radar detects vehicles ahead within a range of approximately 100m and a 16-degree arc. The system then calculates the distance between vehicles, relative vehicle speeds, and the anticipated vehicle path to determine the likelihood of a collision. Three levels of warning are employed in the Honda system:

- Primary warning—When there is a high closing rate to the vehicle ahead or if the distance between the vehicles has become dangerously short, an alarm sounds, and the message “BRAKE” appears on the information display in the instrument panel, prompting the driver to take preventative action.

Table 7.1 Forward Collision Mitigation Systems in Japan

<i>Manufacturer</i>	<i>Models</i>	<i>System name</i>	<i>Sensing technology</i>	<i>Driver alert mode</i>	<i>Braking force (g)</i>	<i>Occupant protection function</i>
Honda	Inspire	Collision mitigation braking system	Radar	Audible alert plus impulsive braking	.5	Pretensioning seatbelts
Nissan	Cima, President	Intelligent brake assist system	Lidar	Audible alert	.5	Pretensioning seatbelts
Toyota	Celsior	Preocrash brake system	Radar	Audible alert	.5	Pretensioning seatbelts

- Secondary warning—If the distance between the two vehicles continues to diminish, CMBS applies light braking and the seatbelt is retracted gently two or three times, providing the driver with a tactile warning. At this point, if the driver applies the brakes, the system interprets this action as emergency braking, and activates the brake assist function to reduce impact speed.
- Collision damage reduction—If the system determines that a collision is unavoidable, seatbelt pretensioning activates with enough force to compensate for seatbelt slack or baggy clothing. This provides even more effective driver retention than conventional seatbelt pretensioners, which only begin to operate once the collision has occurred. The CMBS also activates the brakes forcefully to reduce the speed of impact as much as possible.

The driver prewarnings are expected to be very effective and will likely result in drivers responding to the situation ahead with the best crash avoidance tool there is—the human brain. However, if they are incapacitated or completely distracted for some reason, the system can provide that last-second braking to reduce the consequences of the crash. This is good news not only for the driver of the host vehicle, but also for the occupants of the vehicle that is struck from behind. Although we have some control over our degree of personal safety by the way we choose to drive, we are fundamentally vulnerable to less vigilant drivers who share the roads with us. Therefore, these active braking systems spread the benefits to everyone on the road.

In essence, with FCM, severe crashes become moderate crashes, moderate crashes become fender benders, and so on. While too early to tell, the effects on crash fatalities in these types of crashes is expected to be quite significant, particularly when combined with the precrash activation of airbags and seat belt tensioners.

What about the heavy truck market, which has been an avid user of FCW in the United States? One would surmise that it would benefit immensely from implementing systems that take that next step into active braking. Indeed, such systems are currently under development and are expected to enter the marketplace by 2007.

7.9.3 FCM Research [22]

New work in forward collision countermeasures is being conducted within the European PREVENT project, which was introduced in Chapter 4. Work began in 2004 and is addressing a full range of crash avoidance modalities. In particular, the APALACI subproject is developing advanced precrash and collision mitigation applications including the development of systems with pedestrian classification ability.

7.9.4 Forward Collision Avoidance

Moving from FCM to FCA will progress gradually, on a continuum, as braking authority is increased and brake initiation happens earlier, based on sophisticated sensing. Next generation FCM systems that do exactly this are already under test by automakers in Japan.

7.10 Pedestrian Detection and Avoidance

7.10.1 System Description

Crashes between vehicles and pedestrians frequently result in dire consequences for the pedestrian, who has no protection from the impact. Pedestrian crashes are a particular priority in Europe and Japan, due to the greater concentrations of pedestrians there. For instance, European statistics show that vehicle-pedestrian collisions represent about 12% of all crashes and 15% of total road fatalities, or 9,000 deaths annually [32]. Japanese pedestrian fatalities are 30% of all road deaths, and the share is 10% in the United States.

A majority of pedestrian fatalities are the result of head injuries when a person strikes the vehicle's hood, windshield, and other rigid components. In the case of the hood, the lack of deformation space between the exterior sheet metal and the engine exacerbates the problem. New European regulations for pedestrian crash mitigation are driving design innovations, such as hood hinges that allow collapse under load and fenders with collapsible mounting brackets. Active measures such as "pop-up" hoods and external airbags to respond to imminent pedestrian impact are also under development [33].

However, the primary aim is of course, to avoid a pedestrian collision completely. Detection of pedestrians in the forward path of the vehicle is a challenge highly distinct from vehicle detection, due to the complex road scene in urban and suburban areas and difficulty in predicting pedestrian movements that may lead to a collision. A typical scene may consist of both parked and moving vehicles, narrow streets, and foot traffic on both sides. A nonhazard pedestrian may be walking at 5 kph only inches away from vehicles traveling ten times faster. In hazard situations, a pedestrian may emerge into the roadway from between two parked cars, requiring a very short recognition and reaction time.

The primary technique for pedestrian detection is sophisticated image processing of video or IR of the forward scene to detect and track pedestrians, including stereo vision. Laser scanners also lend themselves to pedestrian detection, as is further described in Section 7.11.

While pedestrian detection for say, surveillance purposes can be performed using relatively simple techniques such as background subtraction in the video image, pedestrian detection from a moving vehicle is much more complex, as all aspects of the image are in motion. More sophisticated techniques are called for. In addition, pedestrians with heavy clothing (which may distort their shape and IR signature) must be detected, and early detection also requires robust acquisition of "people parts," such as heads and torsos, when the total body outline is obscured. Systems must also maintain tracking when pedestrians pass behind obstacles, such as telephone poles. Even though this is a simple task for the human brain, to the computer processor, the "disappearance" and "reappearance" of pedestrians in such cases can be confusing and must be accounted for in software. Some of the R&D approaches to handling these thorny issues are described below.

7.10.2 Market Aspects [34]

Honda surprised the IV world in 2004 by introducing to the Japanese market intelligent night vision which also detects pedestrians.

Honda worked with Raytheon to develop the system, which uses two far-IR cameras mounted near the headlights. This stereo sensing approach enables the extraction of range information. Limitations are intentionally built into this first generation system so as to increase detection reliability. For instance, while the technology is capable of detecting heat-emitting objects up to 500m ahead of the vehicle, Honda's approach is to limit the active detection zone to between 30 and 90m. Their reasoning for the short-range limit is that any objects closer than 30m would be visible in the headlights and there is then no need to alert the driver. The limited functionality also includes a temperature threshold—the system only works below 30 degrees Celsius (86 degrees Fahrenheit). This is because there is not likely to be enough contrast between humans and the background when using heat-sensitive IR sensors above this temperature. Also, objects below three-feet-tall are not detected. Within the IR image, pedestrians are detected based on size and shape .

When a pedestrian is detected, a warning is sounded and an orange square is shown around the pedestrian in the image on the driver's display screen.

Selling at the equivalent of \$5,250, the system is expensive. However, Honda will benefit from experience with the system and less costly versions will doubtless follow if performance is acceptable and customers like it.

Sophisticated pedestrian detection systems for the general case are being readied for market for the 2007 timeframe. These types of systems are described in the following section.

7.10.3 Ongoing R&D

While the Honda system is a basic first step, a substantial amount of privately—and publicly—funded R&D is directed at more comprehensive pedestrian detection. Two projects within the 5FW research program, PROTECTOR and SAVE-U, have delved deeply into the pedestrian detection domain. Here we review these plus some other examples of such work.

Preventive Safety for Unprotected Road User (PROTECTOR) [35–37] PROTECTOR performed initial research on vision-based pedestrian protection and ran from 2000 to 2003. Major automotive participants were DaimlerChrysler, Fiat, and Siemens VDO. Within the project, DaimlerChrysler's stereo vision approach is outlined here.

The DCX system detects all obstacles in front of the vehicle and incorporates a module focused specifically on recognizing pedestrians. The system uses a statistical pattern recognition approach, based on “training” with thousands of video samples of pedestrians. Individual modules within the system are described as follows:

- Stereo preprocessing to detect obstacles and establish the initial area of interest;
- Shape-based pedestrian detection, based on matching within a hierarchy of pedestrian templates;
- Texture classification based on a neural network technique;
- Stereo verification to remove any false detections;
- Pedestrian tracking (which can also assist in removing false detections);
- Risk assessment based on pedestrian position and time to collision;
- Driver warning module.

The system's detection coverage is 10–25m in longitudinal range and up to 4m lateral range to either side of the vehicle. Processing rates are 7–15 Hz, allowing reliable detection for vehicle speeds up to 40 km/h. Figure 7.12 is a screen shot showing system data correlated to a pedestrian video. On the right, a top view of the situation, the sensor coverage area is shown, with the distance scale in meters. Open circles show the range history of the detected pedestrian, with his or her current position shown by the solid circle at 16.60m and relative velocity vectors by the white line segments. A computed risk level is shown by the bar at the center of the image, which displays in a “green-yellow-red” format.

Field tests of the system were conducted on both a test track and in urban traffic, which included an independent system validation.

On the test track, 29 separate traffic scenarios were performed, with a vehicle at 30 kph approaching either one or two pedestrians crossing the travel path laterally at various walking speeds. In some scenarios, roadside clutter was also present to stress the system. The results were deemed to be good, with overall object sensitivity of 80% or better and object precision, trajectory sensitivity, and trajectory precision all above 90%.

Urban traffic field tests conducted in Aachen, Germany, showed some very interesting results. Two runs through the same route were conducted in which 10 volunteer pedestrians were positioned. Each had instructions to perform actions such as standing near the road or crossing the road at various walking speeds. Regular pedestrians were of course also present. The vehicle was driven at 30 kph. Based

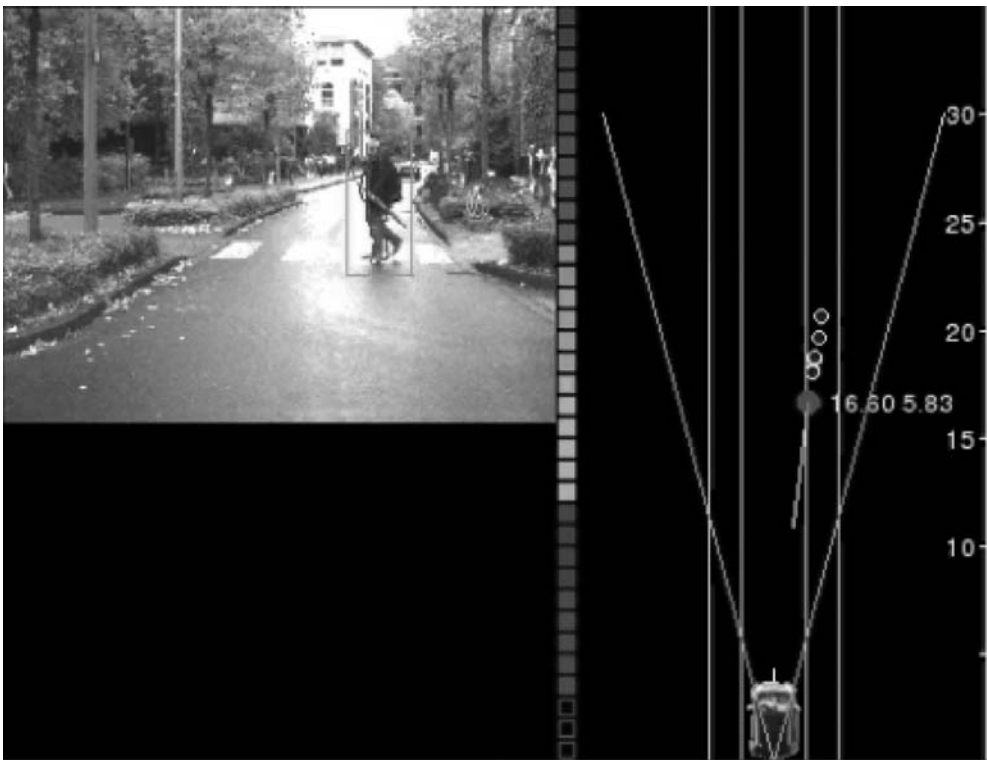


Figure 7.12 Data from the DaimlerChrysler PROTECTOR pedestrian detection system showing a pedestrian currently at a 16.6-m range. (Courtesy of Prof. D. M. Gavrila, DaimlerChrysler AG.)

on human analysis of the videotapes after the fact, a “ground truth” was created as to the real objects and pedestrians. For instance, of 71 pedestrians denoted by the ground truth analysis, the PROTECTOR system picked up 68 of these. Pedestrian sensitivity overall was in the range of 70–80%. Researchers concluded that more development was needed to improve object classification, particularly in distinguishing pedestrians from other relatively vertical objects.

The interior of the DCX PROTECTOR vehicle, showing the stereo camera and computer display, is shown in Figure 7.13.

Sensors and System Architecture for Vulnerable Road User Protection (SAVE-U) [35, 38–40] PROTECTOR’s successor, SAVE-U, runs through 2005. Major automotive participants are DaimlerChrysler, Volkswagen, and Siemens VDO. The main objective is to improve pedestrian detection performance by an order of magnitude with respect to false classifications, as well as to move from driver warning to automatic braking when a critical threat is detected. More broadly, the aim is to detect any type of vulnerable road users (VRUs), including cyclists as well as pedestrians.

To gain the improved performance, the SAVE-U sensor platform fuses data from radar, IR video, and color video. Five 24-GHz radar sensors are used as a single radar sensing network, and information from uncooled IR and video cameras complement one another to offer more reliable and precise detection in all weather conditions. In fact, this is one of the first ever integrations of passive IR and video for road environment sensing. Further, the radars and the IR camera used have been specially designed for VRU detection.



Figure 7.13 Stereo vision camera set up in the DaimlerChrysler PROTECTOR System. (Courtesy of Prof. D. M. Gavrila, DaimlerChrysler AG.)

Additionally, DaimlerChrysler has extended work done in PROTECTOR to combine their stereo vision system with the radar network.

To achieve the required levels of reliability, both low-level and high-level sensor fusion is performed. High-level data fusion relies upon individual sensors to identify objects and then merges object lists from different sensors. However, high-level data fusion alone is not seen as sufficient for VRU detection and tracking. Therefore, low-level data fusion techniques are being developed within SAVE-U, in which raw sensor data is exchanged between the image processing and radar processing modules within the sensor platform. This in particular helps to improve the detection rate versus the false alarm rate for objects. A system block diagram is shown in Figure 7.14.

SAVE-U researchers aim on going beyond basic techniques that detect VRUs based on single cues such as depth, motion, shape, and texture. The SAVE-U approach enhances current algorithms in the following manner:

1. Implementing hierarchical and probabilistic approaches to stereo, optical flow, and shape matching;
2. Implementing component-based approaches that are robust to the partial occlusion of pedestrians and other unprotected road users (e.g., pedestrian behind a parked car);
3. Identifying the most appropriate pattern classifier for pedestrian detection among candidates such as support vector machines, neural networks, radial basis functions, and polynom classifiers;
4. Implementing multicue detection algorithms.

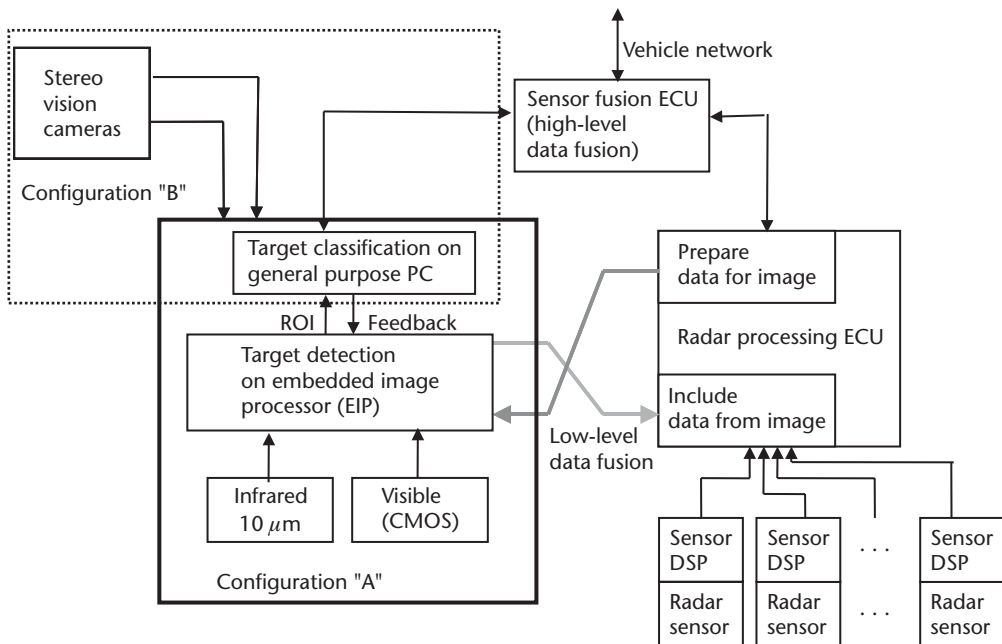


Figure 7.14 SAVE-U system block diagram (ROI: region of interest). [Courtesy of the SAVE-U Consortium (<http://www.save-u.org>).]

In the first phase of the project, SAVE-U team members conducted initial analyses to define relevant VRU scenarios in urban environments, as well as to analyze the reflectivity of the dressed human body for the sensing technologies employed. The VRU database can be considered unique worldwide due to its massive size: It contains more than 14,000 images and 180 sequences recorded with both IR and color video cameras. Additionally, the low-level and high-level sensor fusion techniques were developed in this phase.

The second phase of the project focuses on the development and implementation of the algorithms for data fusion, the integration of the entire sensor platform, equipping the experimental cars, and performance evaluations. The first fully integrated platform is expected to be complete by the end of 2004. Two experimental cars with different warning/control strategies for VRU protection are being developed for evaluation, consisting of a Mercedes E-Class and a Volkswagen Passat.

Mobileye Pedestrian Detection [41, 42] Mobileye's pedestrian protection application, in advanced development, uses images from a single camera and a real-time processing platform to assess pedestrian collision risk. The system measures target range, range rate, angular position, lateral velocity, and calculates the host vehicle path. With this data, all stationary or moving pedestrians in view are detected and the system determines if they are in or out of the vehicle path, or possibly entering into the vehicle path.

The application uses a combination of optical flow analysis together with pattern recognition techniques. Image inputs from the visible spectrum, far infrared, and near infrared can be processed. As further described in [42], this algorithmic approach uses an attention mechanism combined with a single-frame pattern recognition phase and a multiframe approval stage to achieve robust detection.

The image processing approach has been designed to function well in cluttered urban conditions. The software looks for walking and running pedestrians, as well as as distorted contours such as a person carrying packages and shopping bags, or when pushing a baby carriage. The system also has a special "crowd warning" signal, which detects groups of people or cases where many of the pedestrians are occluded by others. In complex cases, such as pedestrians crossing in opposite directions and occluding each other, the system tracks the individual targets continuously through the time of occlusion and maintains a correct path prediction.

The vision system compensates for turns by the host vehicle to predict the pedestrian path correctly. The system also relies on image processing-based vehicle detection capabilities and the ability to identify road versus nonroad regions and pedestrian crosswalks for enhanced performance and reducing false detections. Integration with vehicle systems allows access to data such as vehicle speed for improved estimation of time to contact.

The detection range depends on the camera design and field of view. Mobileye's current demonstration system detects pedestrians from 2 to 35m with 45 degrees horizontal field of view. With a progressive scan camera or a narrower field of view (25 degrees), 60-m range can be achieved.

Mobileye is currently working with automotive manufacturers to prepare very low cost systems for the market. Applications under development include the following:

- Vision-only;
- Fusion of vision with short-range-radar (SRR) for precrash;
- Fusion of vision with long-range radar for collision warning and mitigation;
- Vision-only with stereo option (dual camera) for very short range (pedestrians with feet occluded by the car hood).

Figure 7.15 illustrates the data provided by the Mobileye system. In the forward scene, each object (vehicle or pedestrian) is detected and range measured. The object is designated by a rectangle, with a black rectangle indicating in-path and a white rectangle indicating out-of-path pedestrians. In the image, lane edges and the vehicle's distance to each edge is also shown.

Mazda In 2003, Mazda Motor Corporation began public road trials of an advanced safety vehicle in Japan that includes a forward obstacle warning system capable of detecting pedestrians [40].

Pedestrian Protection in PreVENT In the European PreVENT Integrated Project, two subprojects apply to pedestrian protection. APALACI addresses advanced precrash and collision mitigation applications including the development of systems with pedestrian classification ability. COMPOSE focuses on the development and evaluation of collision mitigation and vulnerable road user protection systems for trucks and cars.

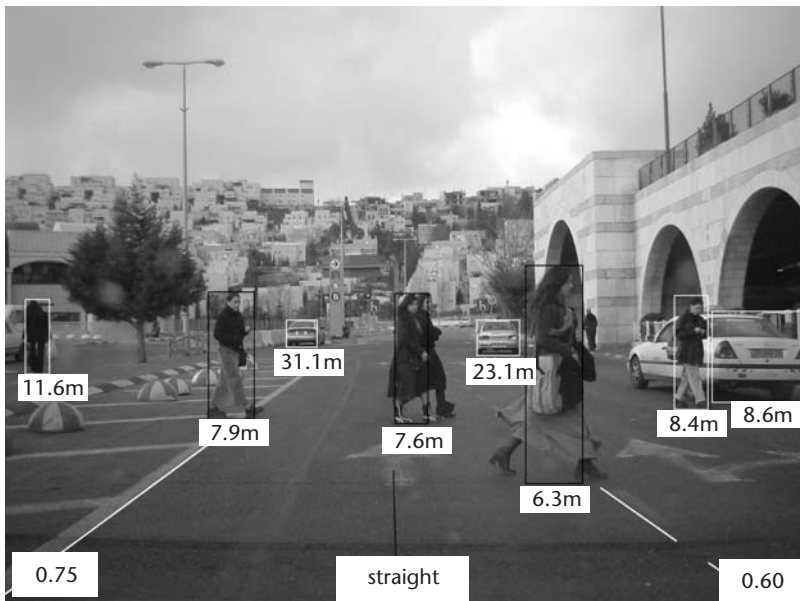


Figure 7.15 Detection of pedestrians using Mobileye technology. (Courtesy of Mobileye N.V.)

7.11 Next Generation Sensors

From the preceding discussion it is clear that an impressive degree of sensing and perception capability has been developed thus far. Further challenges exist in terms of reducing system cost, gaining advantages through integration, and enhancing performance further. This section reviews some key development activities in the radar and laser scanner arenas.

7.11.1 Next Generation Sensors—Radar

DENSETRAFFIC Second Generation ACC Sensor [43, 44] New radar technology being developed in the European DENSETRAFFIC project illustrates the challenges of sensing other traffic in the stop-and-go environment. DENSETRAFFIC's goal is to develop a forward sensor system for both stop-and-go ACC and detection of situations in which vehicles in an adjacent lane cut-in to the host vehicle's lane. These cut-in maneuvers can create a sudden close headway condition that may require immediate and urgent system response; therefore early detection of cut-ins improves overall system performance. A second objective is to demonstrate the feasibility of a low-cost, high-volume production design that will allow the product to be mass produced.

DENSETRAFFIC runs from 2001 to 2004 and is led by Groeneveld Groep B.V. and RoadEye Ltd.

Intended as a second generation stop-and-go ACC sensor, the DENSETRAFFIC system consists of a single sensor with a seven-beam antenna and multichannel RF transceiver so as to provide the increased angular coverage needed for low-speed ACC modes on highways and the early acquisition of new targets in cut-in situations. As shown in Figure 7.16, two “general” short-range beams look to the left and right of the vehicle (GL and GR); at a medium range, far right and far left beam-widths of 12 degrees focus on the cut-in region (LL and RR), and the three 4-degree beams are employed for long range forward target acquisition and tracking (L, C, R). The total coverage area is ± 20 degrees.

In addition, high-range resolution (less than 1m) allows target tracking at close distances. Key to the design are algorithms for adaptive waveform generation and multiple target tracking.

The sensor construction uses MMIC technology. Low-cost RF circuitry and magnesium antenna technologies have been implemented for manufacturability. The complete assembly is shown in Figure 7.17.

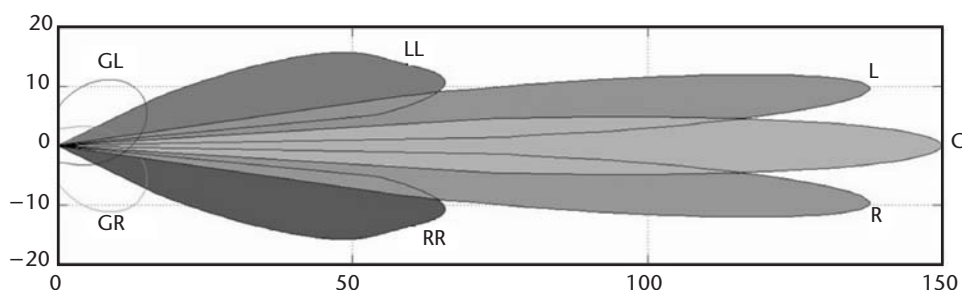


Figure 7.16 Two-dimensional coverage of the seven beams in DENSETRAFFIC radar. (Source: DENSETRAFFIC <http://www.densetraffic.org>.)

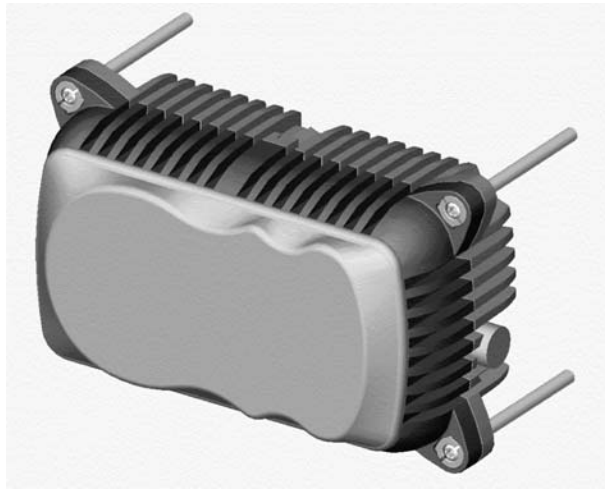


Figure 7.17 DENSETRAFFIC radar unit. (Source: DENSETRAFFIC <http://www.densetraffic.org>.)

The system hardware and software is being validated by road testing in demonstration vehicles (both trucks and cars).

RADARNET Multifunctional Automotive Radar Network [45] Led by Siemens AG during 2000–2003, RADARNET’s goal was to develop a multifunctional automotive radar network, intended as a new type of low-cost radar network for automotive applications such as parking aid, low-speed ACC, precrash warning, and collision avoidance. The premise is that a multifunctional radar network can significantly reduce production costs, facilitate fast system development and reduce time-to-market.

The research focused on the following:

- Development of a new 77-GHz monolithic microwave integrated circuit (MMIC) chipset;
- Development of new 77-GHz near and far distance sensors;
- Development of the radar network (four synchronized short-range and one long-range sensor);
- Development and validation of new vehicle applications using the radar network.

In contrast to short-range radar solutions using 24-GHz technology and long-range systems operating at 77 GHz, the RadarNet innovation keyed on the fact that both near- and far-distance sensors were realized using one integrated 77-GHz MMIC technology. One advantage of operation at 77 GHz is that sensor dimensions can be reduced significantly, which eases integration into the body of the vehicle. Costs are reduced in that all components of the radar network can be produced with only one manufacturing technology.

Using newly developed MMIC chipset and transmit/receive modules, the radar network consists of four near-distance radar sensors (25-m range), equidistantly distributed behind the bumper, together with a single far-distance radar sensor (180-m

range) implemented in the middle of the bumper. Precise time synchronization of the individually positioned near-distance sensors is performed so that their output signals can be coherently processed. Target information with high resolution in range, Doppler frequency, and azimuth angle is achieved this way. A system block diagram is shown in Figure 7.18.

RadarNet activities included definition of sensor requirements and systems architecture, design and implementation of the MMIC chipsets, component testing, and system testing, culminating with validation testing. For the validation phase, each of the five car manufacturers in the consortium developed strategies and algorithms for a particular automotive application of interest. Radar network prototypes were built and integrated into experimental cars, and the systems were evaluated in critical situations, both on test tracks and in real traffic.

7.11.2 Next Generation Sensors—Laser Scanners [46]

Laser scanners have been used in scientific research for several years, and have recently been applied in the active safety systems arena. Initially, researchers were forced to rely upon very expensive scientific-grade laser scanners. Recently, though, laser scanners optimized for automotive applications have become available. At a cost of \$20,000 or more, though, they are still far from an acceptable price range.

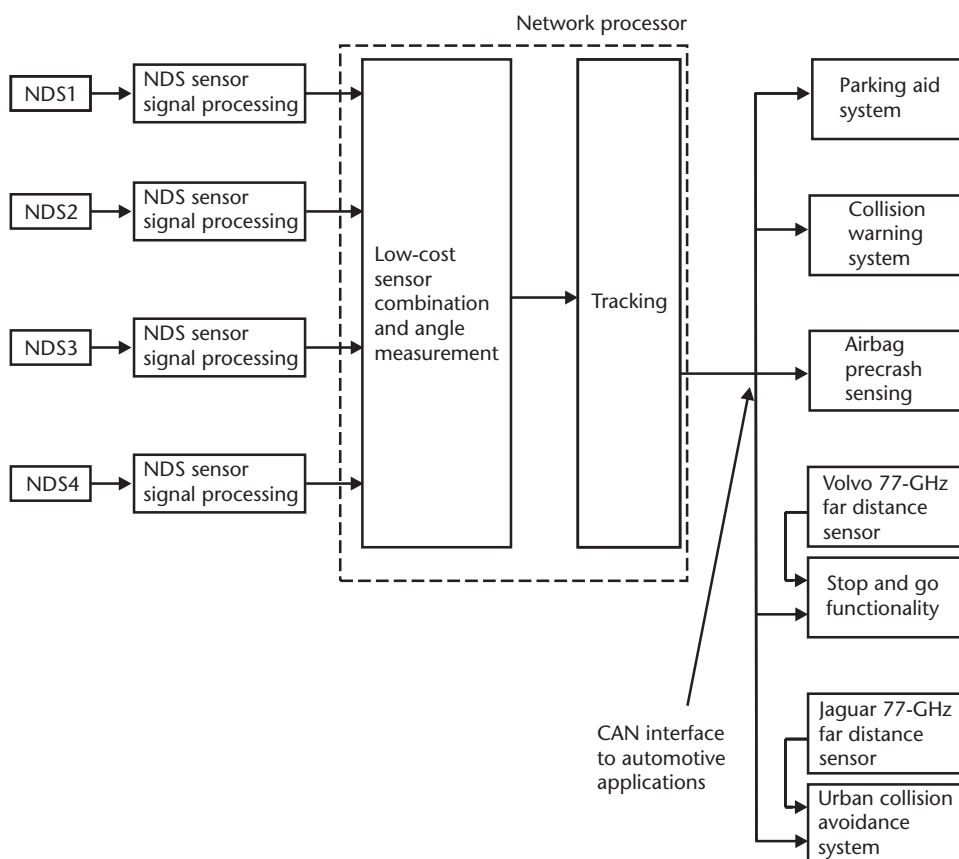


Figure 7.18 RadarNet block diagram. (Source: RadarNet, EC IST-1999-1A-14301.)

Attention is currently focused on proving the performance of laser scanners for driver assistance systems and assessing the degree to which they offer unique capabilities over and above the classic radar/lidar and vision combination. Advocates of these sensors contend that, if laser scanners are integrated into driver-assist systems for high-volume production, costs could come within an acceptable range.

One such system is the ALASCA® sensor, introduced by Ibeo Automotive Sensor GmbH in 2004. The basis of the ALASCA® sensor is a rotating infrared (IR) light beam. With the aid of this beam, the time-of-flight measurement is used to detect the contours of objects in the vicinity of the vehicle. From the resulting data, objects are extracted and classified, along with distance, direction, speed, and acceleration.

How does the scanner work? As shown in Figure 7.19, a laser transmitter diode generates a short light pulse (IR in this case), and a rotating mirror transfers and projects the beam. The target object reflects the beam and a photoelectric diode on the unit receives the reflected beam. The time-of-flight measurement provides information on the distance to the object and the angle encoder on the mirror drive supplies the angle resolution. Based on this data, object speed and acceleration can be calculated.

The sensor can track multiple targets and automatically compensates for any vehicle pitch. Although an optically based system, it has been designed to perform well in poor weather, with road spray and dirt accumulation on the housing. Further work is under way to enable the sensor both to detect and to take measurements in fog, so that drivers can be warned of masked obstacles ahead.

The sensor field of view is up to 270 degrees, with a scanning frequency up to 40 Hz. Measurement range is from .3–256 m, with object tracking within 50m. Due to the optical properties of the laser, distance resolution is an amazing 4 mm. High-performance versions of the scanner are built with four scanning planes; the automotive version uses one scan plane. The unit has been optimized for compactness so that it can be relatively easily integrated into a vehicle chassis.

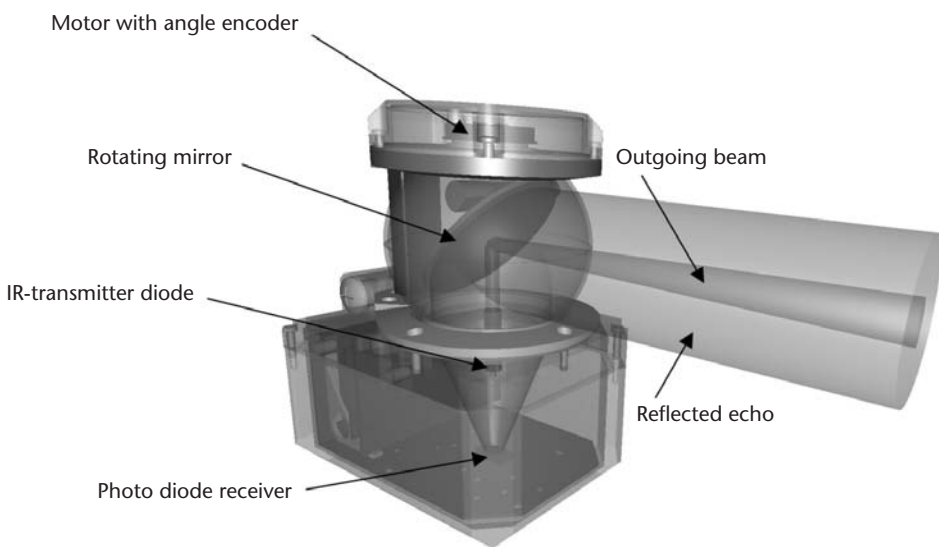


Figure 7.19 ALASCA® Automotive Laser Scanner. (Courtesy of IBEO Automobile Sensor GmbH, <http://www.ibeo-as.com>.)

ALASCA® is aimed at the implementation of applications such as low-speed ACC, forward collision mitigation, and pedestrian detection. When mounted in the front corners of a vehicle, laser scanners can be very effective in detecting vehicle cut-ins to support low-speed ACC, for instance. The technology can detect typical human contour outlines very accurately to enhance pedestrian detection. ALASCA® developers assert that pedestrian collisions can be detected with certainty up to 250 ms ahead of impact, providing time to activate braking and deploy pedestrian protection measures such as external airbags [46].

Ibeo expects that the first applications using laser scanners could be introduced on vehicles as early as 2008.

7.12 Summary and Observations

It can be seen from this rather long chapter that systems have gradually evolved from a self-monitoring mode to an environmental sensing mode. Sensing steering wheel movements enable headlights to be steered in early systems, and digital mapping techniques bring in a look-ahead capability so that illumination is even more smartly applied. Similarly, early precrash brake-assist systems monitored foot pedal action, whereas forward sensors now enable a variety of preparations and optimizations to be made prior to a potential crash.

It is also interesting to note that, for the most part, FCW has not been chosen as a stand-alone system by automakers, even though it is quite effective for commercial vehicle drivers. Instead, a more sophisticated and blended approach is used, with various warnings provided to drivers as a potential crash situation is developing and emergency braking applied at the very last moment. This is a lesson for prognosticators (the author included), as an example of an elegant system approach that was not foreseen when collision warning was initially envisioned in the 1990's.

Due to the large number of forward collisions, FCM in particular is expected to offer substantial benefits to society. If every new car sold worldwide were to be equipped with the FCM products on the market starting today, we would likely see corresponding reductions in crash fatalities within a short time. Unfortunately, the market behaves like a market—the systems, since they are relatively expensive, must prove themselves on high-end cars before being released on lower cost models. So, full dissemination in the vehicle fleet will take quite some time. Government incentives for purchase of such systems, which are under discussion in the United States and Europe, could play a major role in rapidly increasing market penetration, if enacted. Regionally, there are also challenges in introducing active braking in a litigious society such as the United States. Incentives, legal issues, and other challenges to market introduction are discussed further in Chapter 13.

But what if drivers were so well informed about conditions ahead that emergency situations never occurred? As we will see in later chapters, extending the “information horizon” so that drivers have ample advance notice of slower traffic and other hazards ahead could put FCM out of a job in all but the most extreme cases. Until that day comes, however, these longitudinal sensing and control systems will play a crucial role.

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Integrated Lateral and Longitudinal Control and Sensing Systems

We have heretofore reviewed IV systems focused separately on lateral and longitudinal driver support. It is logical for these systems to converge into integrated systems so that “surround sensing” and more robust driver support is accomplished.

Inevitably, 360-degree sensing will evolve as part of the total crash avoidance package of the future. Surround sensing is obviously superior to human sensing, since we only have two eyes and they are only on one side of our head—with even the best peripheral vision, our total view is less than 180 degrees. Imagine an obstacle, such as a disabled vehicle, stopped in the middle lane at a point on a high-speed motorway in which you are traveling. As you approach this point while driving your vehicle in traffic, you cannot see it because the vehicle just ahead of you is large enough to block the forward view. The large-vehicle driver sees the obstacle and swerves to another lane, suddenly presenting you with a dead-stopped vehicle just a few meters ahead. What do you do? Stop? Swerve? If you swerve to another lane, is it clear? In the miniscule time you have available for the decision, there is no time to check all of your options, and you hope your choice is a good one.

With surround sensing, it’s a different story. The vicinity around your vehicle is constantly being monitored. In the scenario above, not only will the object ahead be detected, but the best avoidance maneuver can be indicated to guide your response. More futuristic systems may even take care of the avoidance maneuver for you. Support will also be provided for less critical situations, such as lane changes in busy traffic.

Integration of lateral and longitudinal sensing basically boils down to sensor fusion, particularly with respect to machine vision and range sensing. Sensor fusion is a technical specialty all its own, and the implementation details quickly become proprietary. Our approach in this chapter is to discuss some fundamental approaches to sensor fusion as a background technology that can then be applied to a variety of applications. Several examples of these types of applications are then covered.

Such integrated systems are in R&D stages and will not be introduced to the market for several years. But precursors are out there now. In Japan, one can buy a vehicle equipped with both ACC and LKA, for instance. And, second generation ACC systems are becoming available that integrate lane detection with forward ranging so as to more accurately track relevant targets.

8.1 Sensor Fusion

Sensor data fusion merges the information provided by different sensors to get a better picture of the environment in front of the vehicle. Multiple sensors, apart from providing different coverage, can detect the same object, but with differing accuracy of the parameters describing that object. For instance, range accuracy of a laser scanner is much higher than that of range derived from vision sensors. Information from the various sensing modes is generally complementary and independent to some degree—RF noise that might affect radar data will typically not interfere with vision sensing. Further, certain sensors may see information “invisible” to other sensors, such as the ability to locate road markings with image processing but not with radar. The result is measurements of higher integrity, accuracy, and confidence.

Approaches to sensor fusion are described here to give the reader an understanding of the issues and challenges involved. The recently completed CARSENSE project and ongoing work in the German INVENT program are reviewed. Within the European PReVENT integrated project, initial results are available from the ProFusion subproject, which are briefly covered as well.

8.1.1 CARSENSE for Urban Environments [1]

CARSENSE, which was completed in late 2002, was a European project that focused on detection of objects at low speed in urban environments through sensor fusion. The CARSENSE project was considered to be an important step on the way to high-performance perception systems in future ADAS.

One prime objective for CARSENSE was the improvement of existing ACC systems in slow-speed applications. As a reference point for urban motorways, researchers used the Paris “*Periphérique*” or the large arterial roads parallel to the *Periphérique* as typical application environments. Traffic on such roads is characterized by the following:

- Traffic jams with stopped or slow driving vehicles;
- High numbers of motorcycles, crossing and weaving through traffic;
- Mixture of motorized traffic with bicycles and pedestrians;
- Difficult road configurations with curves, bridges, short-tunnels, and work zones.

CARSENSE researchers defined a set of scenarios to represent these situations in system testing. The scenarios defined covered the following types of complex situations:

- Following in dense traffic;
- Cut in and cut out of host vehicle’s lane;
- Lane change maneuvers with two or more objects involved;
- Single stationary obstacle, moving host vehicle;
- Multiple stationary obstacles, moving host vehicle;

- Variety of obstacles (size, shape, color of different objects);
- Obstacle transitioning from stationary to moving;
- Maneuvering in the presence of oncoming traffic (i.e., two-way travel).

Overall performance of obstacle detection, in terms of sensor systems as well as data fusion algorithms, was the primary focus within CARSENSE. The sensors involved are described below, along with data fusion approaches.

Radar Sensor Prototype radar sensors employed gallium arsenide-based MMIC technology, which lends itself to low-cost production. The basic technical characteristics of the radar were similar to those described in Chapter 7. Within the project, this radar sensor was improved on two fronts:

- Widened field of view in the short-range area ($\pm 35^\circ$ out to approximately 40m) by use of a new optical “lens” for the radar antenna;
- Improved detection of fixed targets by use of a digital FM radar waveform that combined the advantages of frequency shift keying with the advantages of FM continuous wave modulation. This waveform offered very high-speed discrimination, fixed object detection (as compared to Doppler radar), no distance or speed ambiguity, and low sensitivity to interference.

Laser Sensor An earlier version of the IBEO automotive laser scanner previously described was used. The main characteristics of the unit were the following:

- Viewing angle: Up to 270 degrees;
- Angular beam separation: 0.25 degree;
- Beam divergence: 5 mrad (beam diameter: 50 cm at 100m);
- Scan frequency: 10 Hz;
- Distance range: 30 cm–60m;
- Standard deviation of a single shot measured distance: ± 5 cm (1 sigma).

Raw data profiles were created based on range and angle to surfaces that reflected the laser energy. The raw data were divided into segments, which were assigned to on-road or roadside objects. Relevant objects were tracked using Kalman filters. Object parameters such as position, size, and velocity were transmitted to the host computer via a vehicle data bus.

Some of the innovations accomplished within the project include parallel line scanning, compensation of pitching angle, road geometry recognition (based on boundaries and other objects), and classification of typical objects.

High Dynamic Range Video System A video sensing system consisted of multiple cameras and a dedicated embedded processing unit. The cameras used offered high resolution and a high dynamic range (120-dB logarithmic) to adjust to rapid changes in ambient lighting conditions. The processing unit enabled the image processing algorithms to run at a frame rate of 25 Hz (i.e., real time). The components were designed in a manner suitable for high-volume production.

The high performance processing platform included both a field-programmable gate array and digital signal processor that is capable of processing raw video at the required high data rate. A modular and stackable unit was designed so that multiple algorithms could be tested on additional processing boards. The objective was to demonstrate that complicated image processing algorithms could be implemented using a cost-effective embedded hardware solution.

Video Processing The vision task was split into the functions of lane marking detection and obstacle detection.

As stated previously, lane marking detection assists the forward ranging sensors in identifying whether obstacles are within the host vehicle's lane or not. Road boundary detection must at least provide, with high accuracy, estimates of the relative orientation and of the lateral position of the vehicle with respect to the road. Two approaches, based on different road model complexity, were tested. First, a real-time algorithm performed computation of the orientation and lateral pose of a vehicle with respect to the observed road. This approach provided robust measures when lane markings were dashed, partially missing, or perturbed by shadows, other vehicles or noise. The second approach was based on an efficient curve detector, which automatically handled occlusion caused by vehicles, signs, light spots, shadows, or low image contrast. Shapes in two-dimensional images were described by their boundaries, and represented by linearly parameterized curves. In this way, particular markings or road lighting conditions are not assumed, and lane discrimination is based only on geometrical considerations.

Vision-based obstacle detection focused on obstacles within 50m in front of the test vehicle. For CARSENSE, an obstacle was defined broadly as a vehicle (car, truck), a motorcycle, a bicycle, or a pedestrian cutting into the host vehicle's trajectory. A stereo vision and multisensor fusion approach was used to detect such objects. Matching of data from the stereo cameras made it possible, via triangulation, to detect objects located above the plane of the roadway and to locate them relative to the host vehicle. The matching process also used results obtained from other types of sensors (range-finders) to make reliable detection and increase the computational speed.

The goal was to develop vision algorithms to detect obstacles on the road and to produce the trajectories of the various objects within the scene (other vehicles as well as static obstacles). To achieve this goal, algorithms were based on motion analysis in which the dominant image motion component was defined and assumed to be due to the car motion. The principle of this algorithm was to determine the polynomial model that most closely described the image motion in a specified zone of the image by statistical multiresolution techniques. With the car motion well understood, detection of obstacles could then be done by noting differences between the apparent image motion and the computed dominant motion. The trajectories of these objects, as well as the time to collision, could then be computed and provided as input to the car system.

Data Fusion Processing The various CARSENSE sensor units delivered processed information about the road geometry and relevant objects detected in the vicinity

of the experimental vehicle, in the form of a list of objects. Each object was characterized by a set of attributes (such as position and velocity), with the quality of that data varying depending on the sensor and processing combination.

Other algorithms were developed that combined the outputs of the various sensors to improve performance and robustness. This technique involved creating and maintaining a map of the object locations in the front of the equipped vehicle in real time, which included relative speeds and an estimation of the confidence and precision of the detection.

How well did the sensor fusion techniques work? In validation studies, the fused obstacle detection rate was significantly better than any one sensor type acting alone, as shown in Table 8.1 [2].

Some of the CARSENSE results have since fed into development of some of the automotive products described in previous chapters.

8.1.2 Data Fusion Approach in INVENT [3, 4]

Automotive researchers within the German INVENT program are developing advanced sensor fusion systems. As shown in Figures 8.1 and 8.2, they are moving from first generation systems—in which, typically, the vision system supports lane

Table 8.1 Sensor Fusion Results in CARSENSE

<i>Sensor type</i>	<i>Obstacle detection rate</i>
Short-range radar	80.1%
Long-range radar	52.2%
Laser scanner	41.2%
Stereo vision plus lane marking detection	21%
Sensor fusion	94.1%

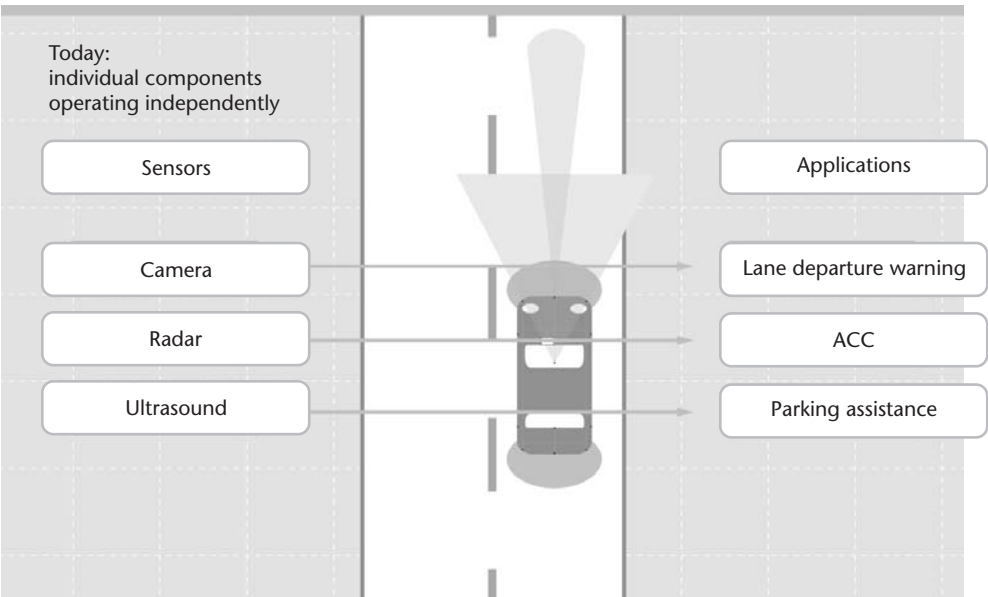


Figure 8.1 Application-specific sensing. (Courtesy of INVENT.)

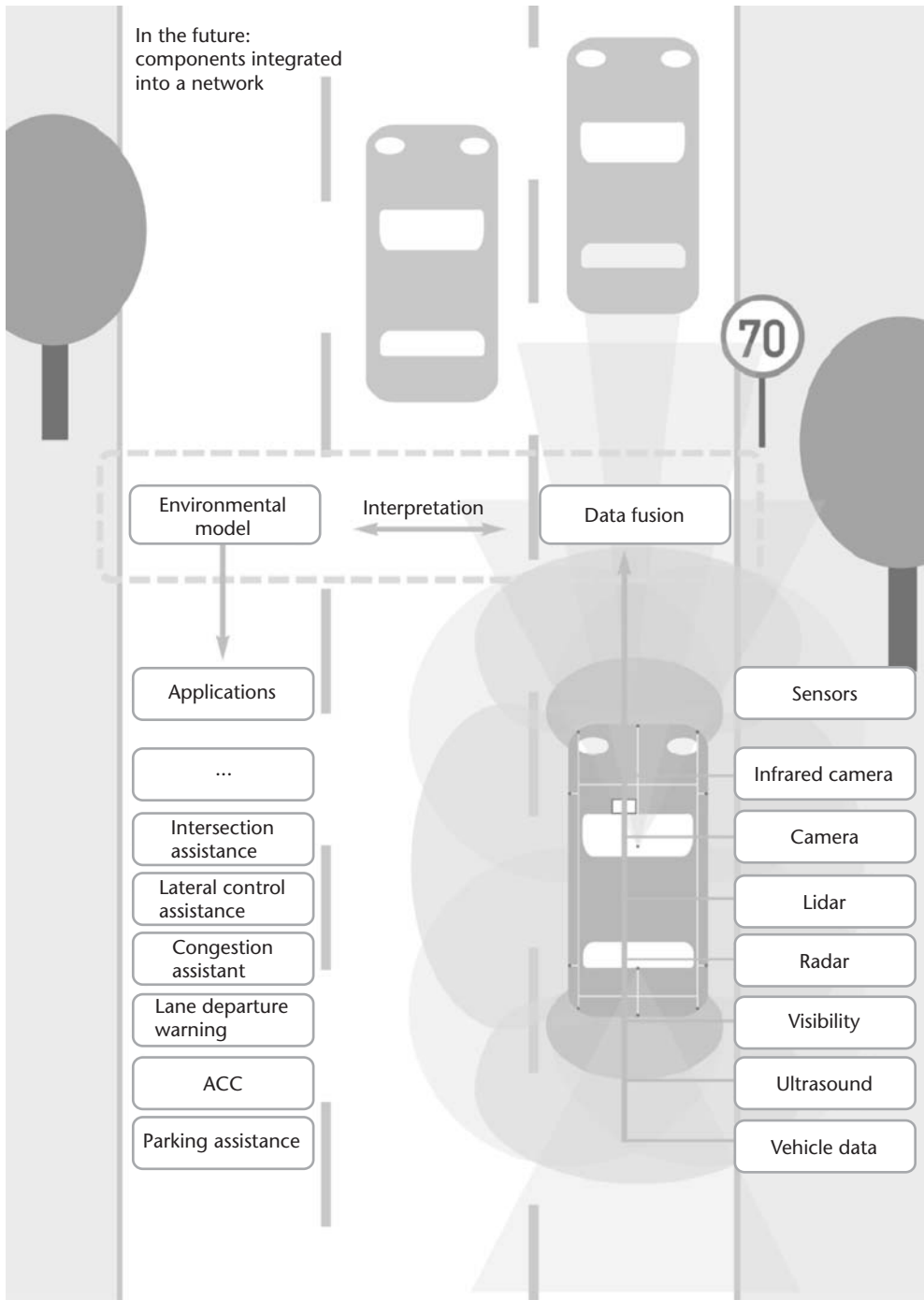


Figure 8.2 Sensor fusion to support multiple applications. (Courtesy of INVENT.)

detection, the radar supports ACC, and the ultrasound supports parking assist—to a data fusion approach in which the outputs of all sensors are fused to create an overall situational understanding (environmental model), which is then available to any applications running on the vehicle.

The INVENT researchers have identified the following complementary sensor technologies to assess object position, distance, speed, and size:

- Mono and stereo camera;
- Infrared cameras;
- Short- and long-range radar;
- Multibeam and scanning lidar;
- Ultrasound;
- Roadway condition detection;
- GPS & digital maps.

The key technical goal is to optimize perception through data fusion and interpretation. To accomplish this requires low-level fusion of sensor data; object identification, classification, and tracking; generation of environmental models; and situation analysis.

An example of the results of the perception process would be to classify a situation as “object vehicle in left lane is in the process of overtaking and passing a preceding vehicle.” While this can be perceived at a glance by a human driver, extensive machine intelligence is required to accomplish the same task.

For example, work performed by Siemens within INVENT focuses on the fusion of video, radar, and vehicle state data (odometer and inertial sensors) to support applications such as stop-and-go driving assistance. Initially, the perception steps of object detection, track initialization, tracking, and data association are performed. The system then fuses raw data of different sensor systems to generate object hypotheses. If needed, multiple targets are tracked simultaneously. The trackers produce uncertainty measurements of the state of tracked objects, which is important when weighing different sensor inputs that may conflict with each other. On the other hand, when the same object is detected by different sensors but with all sensors indicating a high uncertainty, this can be sufficient in some cases to confirm the reality of the object—a perfect example of the power of sensor fusion.

8.1.3 ProFusion [5–7]

The ProFusion subproject, as a horizontal activity within the European PReVENT integrated project, was meant as an early foray into requirements and issues regarding sensor data fusion, so as to benefit the overall set of PReVENT activities. As part of the PReVENT goal of achieving greatly improved “situation capture,” ProFusion is developing new techniques for robust and optimized scene perception.

The first phase of ProFusion work focused on examining the state-of-the-art in sensor fusion to identify needs and future R&D directions. Via questionnaires and workshops in the first half of 2004, contributions were provided by PReVENT partners, sensor suppliers, and experts from other European projects such as ARCOS, RADARNET, and SAVE-U.

Top priorities are seen as 1) the definition and prototyping of modular architectures for interoperability and sensor data fusion and 2) the definition, prototyping, and demonstration of a “framework for robust and reliable multisensor ADAS.” The modular architecture topic can be viewed as hardware-oriented, while the

framework for multisensor ADAS is more oriented toward algorithms and software in general.

Modular Architectures Creation of modular architectures for interoperability and sensor data fusion involves establishing interfaces between the different levels in the processing chain. The automakers are particularly motivated in this respect, because current sensor systems, and their computing resources, are focused on a single function. It is not uncommon for a data processing unit to be embedded into the sensor itself, for instance. Instead, it would be more effective to evolve the onboard electronic architectures so that sensors of the same type could be easily substituted for one another, with data exchange and processing performed downstream using shared computing resources.

An initial objective will be to create standardized platforms that include necessary hardware and software interfaces between the sensors and computing platforms, such as data formats and communication protocols; low-level software for interface and data management; and hardware interfaces such as connections for control, data, and power.

Long-term objectives seek the standardization necessary to achieve sensor exchangeability, even extending to different sensing modalities for the same function. For instance, researchers envision being able to exchange a long-range radar with a lidar for the ACC function.

Further, the mature platform architecture should possess high bandwidth and features necessary for real-time applications.

Framework for Multisensor ADAS Similar to the INVENT concept, the framework for robust and reliable multisensor ADAS would allow the use of various sensor technologies to construct a representation of the environment which is usable by a variety of ADAS applications. This would include the specification of a generic framework for sensor models, the specification of a generic environment model that can handle multitarget complex scenarios, capability to manage varying degrees of reliability within the sensor data, and the investigation and development of new algorithms and techniques to support the construction of the environment model.

The ultimate aim is to provide as many functions as possible with as few sensors as possible, while ensuring robust performance. The core sensor fusion and perception module is key here. This module must work with a large number of sensors and sensor types and provide information to serve a large number of applications.

Therefore, in this area ProFusion recommends focusing on the following activities:

- Defining a general framework, and the necessary techniques, for modeling sensors and sensor systems;
- Developing a standardized environment model allowing exchangeability at both the perception module and function level. Such a standardized interface would facilitate the use of a particular perception module for different functions and at the same time could allow the integration of several different perception solutions for the same application;
- Develop advanced algorithms and software tools for data fusion in multisensor systems to further enhance robustness and reliability.

In the medium term, steps would focus on specifying this generic framework. Researchers envision the framework as possessing the following qualities:

- Including information from “nonsensing” inputs such as maps and intervehicle or infrastructure-to-vehicle communication;
- Accommodating confidence data from various sensors and generating overall confidence estimations;
- Being capable of modeling sensor failures;
- Being compatible with the implementation of different strategies for sensor data fusion (i.e., low-level versus high-level);
- Being capable of redundant and complementary fusion;
- Allowing for progressive integration of new sensors and new technologies.

Further, a generic environment model should be specified, along with advanced algorithms as needed, which would be capable of multitarget tracking and obstacle classification, fault-tolerant representation and detection of inconsistencies between sensors, and management of contradictory information.

The researchers also noted the need for tools to visualize the computer-sensed environment. They propose a quite direct validation scheme for both the environment model and the visualization: “Is a human being able to drive knowing only this representation of the environment?”

8.2 Applications

There is plenty of momentum in moving toward integrated driver support systems, as is clear from the following discussion of projects in the United States and Europe.

One of the first forays into this domain occurred when the European CHAUFFEUR II project demonstrated both automated driving (see Chapter 10) as well as a more near-term application called Chauffeur Assist. This latter service consisted simply of simultaneous activation of ACC and full lane-keeping. Therefore, when activated, the driver was in a “machine supervisor” rather than a “machine operator” role. Chauffeur Assist relied upon a fusion of radar with stereo vision [8].

A less ambitious functionality exists on Japanese roads today. Although not integrated, vehicles can be purchased with both ACC and lane-keeping support. In this case, the driver must remain engaged in the steering task, as described in Chapter 6. Chapter 12 discusses the driver vigilance aspects of these two systems operating simultaneously.

Visteon has performed a relatively basic integration of forward and side sensing with its driver awareness system. Functionally, the company’s approach couples ACC with side object awareness. The broad beams of its forward-looking radar senses traffic directly ahead of the vehicle as well as to the sides. Side object awareness uses the broadest segment of the radar beamwidth to give an indication to the driver when an object, such as a bicyclist or another vehicle, is in the sensing zone [9].

More in-depth discussions of integrated lateral and longitudinal sensing are provided in the following sections.

8.2.1 Autonomous Intersection Collision Avoidance (ICA) [3, 10, 11]

ICA is generally seen as too great of a challenge for autonomous vehicle systems, such that most ICA R&D relies on a cooperative systems approach (see Chapter 9). However, DaimlerChrysler researchers have done some groundbreaking work using autonomous sensing for ICA.

First, they are using monocular vision systems to recognize traffic lights (and current red/yellow/green state) and stop signs that are relevant for the host vehicle. This is quite a challenge in a complex urban environment such as the one pictured in Figure 8.3. In the image, both the traffic signals and their state are detected, as indicated by the overlaid images.

The researchers believe that combining this type of video detection with digital maps showing intersection locations offers a high potential for alerting drivers to red traffic signals and warning them if they are not slowing appropriately.

With stop signs, these appear at a distance as nearly circular within image processing and the recognition is quite robust here also, based on algorithm testing to date.

Daimler researchers have also had good results using a single camera to detect any crossing obstacles in an intersection.

For full situation understanding of an intersection scene, Daimler worked with partners in the German INVENT program to experiment with active stereo cameras mounted together on a pan/tilt axis. This gaze control technique enables more



Figure 8.3 Traffic light detection and state detection by DaimlerChrysler's vision system. (Courtesy of Profs. U. Franke and F. Linder, DaimlerChrysler AG.)

nimble sensing but also required very precise calibration and fast rectification techniques to achieve acceptable performance. While such “look around” cameras are not necessarily practical for a vehicle product, it is expected that the vision techniques developed can eventually be applied to fixed hemispherical cameras, which might be mounted on the vehicle’s bumper.

Another application under examination within INVENT is in using map data to assist drivers as they approach a complex intersection. Information can be provided to help drivers understand the intersection layout, so that they may safely change to the correct lane for a turn, or to avoid a turn-only lane, for instance. Lack of awareness of an intersection layout can be responsible for sudden movements by drivers as they seek to “jump” to their desired lane, sometimes leading to crashes, and always leading to elevated heart rates.

8.2.2 Bus Transit Integrated Collision Warning System [12]

The U.S. Federal Transit Administration has sponsored a significant amount of research in collision avoidance for transit buses, under the U.S. DOT IVI. In fact, this work is unique worldwide, even though other parts of the world use many more buses. Research and testing conducted on various single-function systems has led to the development of the agency’s ICWS. As shown in the block diagram in Figure 8.4, ICWS focuses on both side and frontal collision warning. In addition to avoiding bus-car collisions, a key aspect of transit bus collision avoidance is to detect pedestrians, given their close proximity to buses. Also, transit operators seek to support less experienced drivers in avoiding sideswipes of street-side poles and signs when the bus is turning in tight urban areas.

As shown in Figure 8.5, one laser scanner and two video cameras on each side of the bus comprise the side sensors. The laser scanner scans in a horizontal plane to detect objects at about knee height, which is intended to cover detection of both adults and children. The cameras look down the sides of the bus. A curb sensor mounted behind the front bumper measures the location of the right-hand curb. For forward sensing, a laser scanner and radars are mounted in the front bumper and

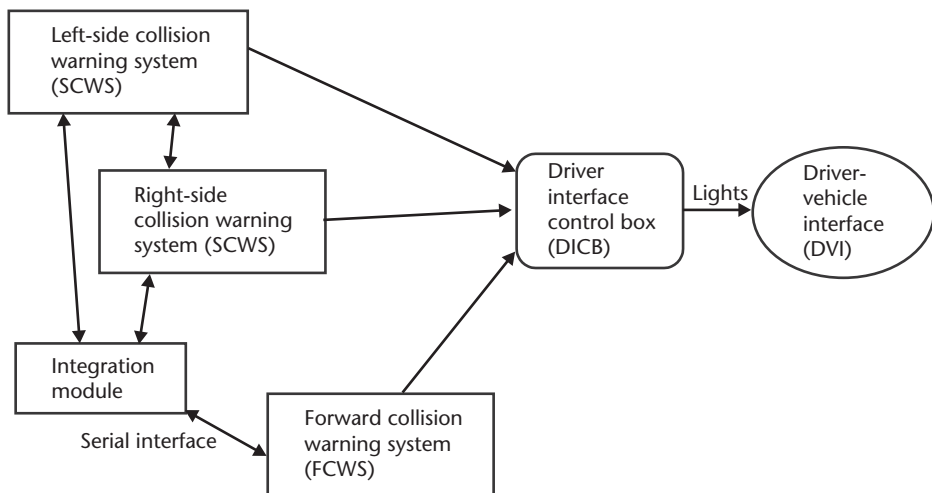


Figure 8.4 ICWS diagram. (Source: Carnegie Mellon University.)

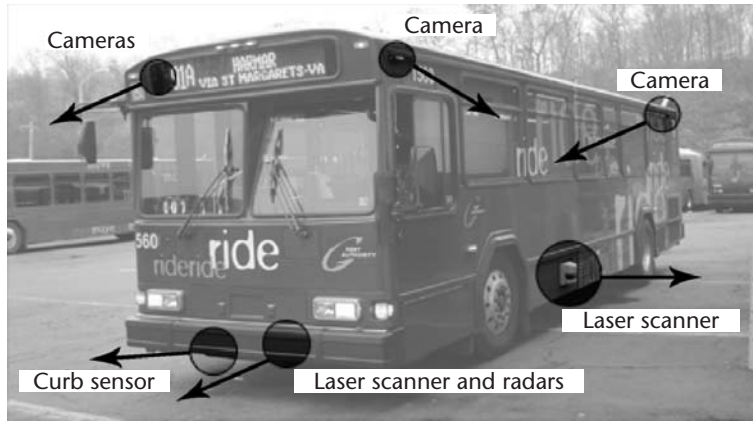


Figure 8.5 ICWS sensors installed on a Port Authority of Allegheny County Bus. (Source: Carnegie Mellon University.)

will detect objects at about the height of the bumper. Three forward-facing video cameras are mounted in the sign window on the upper front face of the bus. These sensors provide full coverage of the front and sides of the bus.

Driver warnings are displayed on two LED “bars” mounted on the left and middle window pillars.

The driver has control over the sensitivity of the system (to balance advance warning time with false alarms), as well as LED brightness and speaker volume. Researchers have noted several paradoxes in evaluating driver acceptance of these systems. Drivers would prefer the earliest possible warning so that they can avoid hard braking, but at the same time want to avoid the “nuisance effect” of frequent alerts. Also, the warning should be distinct enough to get the driver’s attention but ideally not be noticeable by passengers, to avoid unnecessarily alarming them.

Current work focuses on evaluating system performance, projecting benefits of widespread deployment, and addressing commercialization issues.

8.2.3 Integrated Vehicle-Based Safety System (IVBSS) Program [13]

In 2004, the U.S. DOT began the IVBSS program. The idea is to integrate crash warning systems for forward collisions, run-off-road, and lane change crashes, which together account for 48% of crashes in the United States. In fact, IVBSS is the first government-funded project worldwide aimed at fully integrating these crash countermeasures. The broader intent of the program is to accelerate the commercialization of these systems for light vehicles, heavy trucks, and transit buses. IVBSS is expected to be one of the major IV research programs of this decade.

Systems could of course be deployed to address these crash types separately, and this is clearly the case as we have seen in previous chapters. However, U.S. DOT officials believe that an integrated system will “increase safety benefits, improve overall system performance, reduce system cost, enhance consumer and fleet operator acceptance, and boost product marketability.”

The IVBSS program plan calls for a partnership with a private-sector consortium that would include vehicle manufacturers as key players. In this way, it seeks to create a strong link with commercialization and the real-world issues that must be resolved to

get there. Engineering activities call for the development of technology-independent performance specifications, building and testing prototype vehicles, and determining driver and fleet operator acceptance of these systems. Further work will address safety benefits and the development of objective test procedures. Objective test procedures are seen by U.S. DOT as a way to provide consumer information on these systems and to potentially create active safety “star ratings,” similar to those issued now by the National Highway Traffic Safety Administration for crashworthiness.

Figure 8.6 shows a more detailed view of the flow of program activities. Following industry and stakeholder input, system functional requirements based on target crashes and dynamic scenarios will be developed. Key questions must be addressed in this phase. For instance, should the functional scope be warning only or also include control intervention (such as active braking)? Further, should system development address both cost and performance goals, or performance goals only?

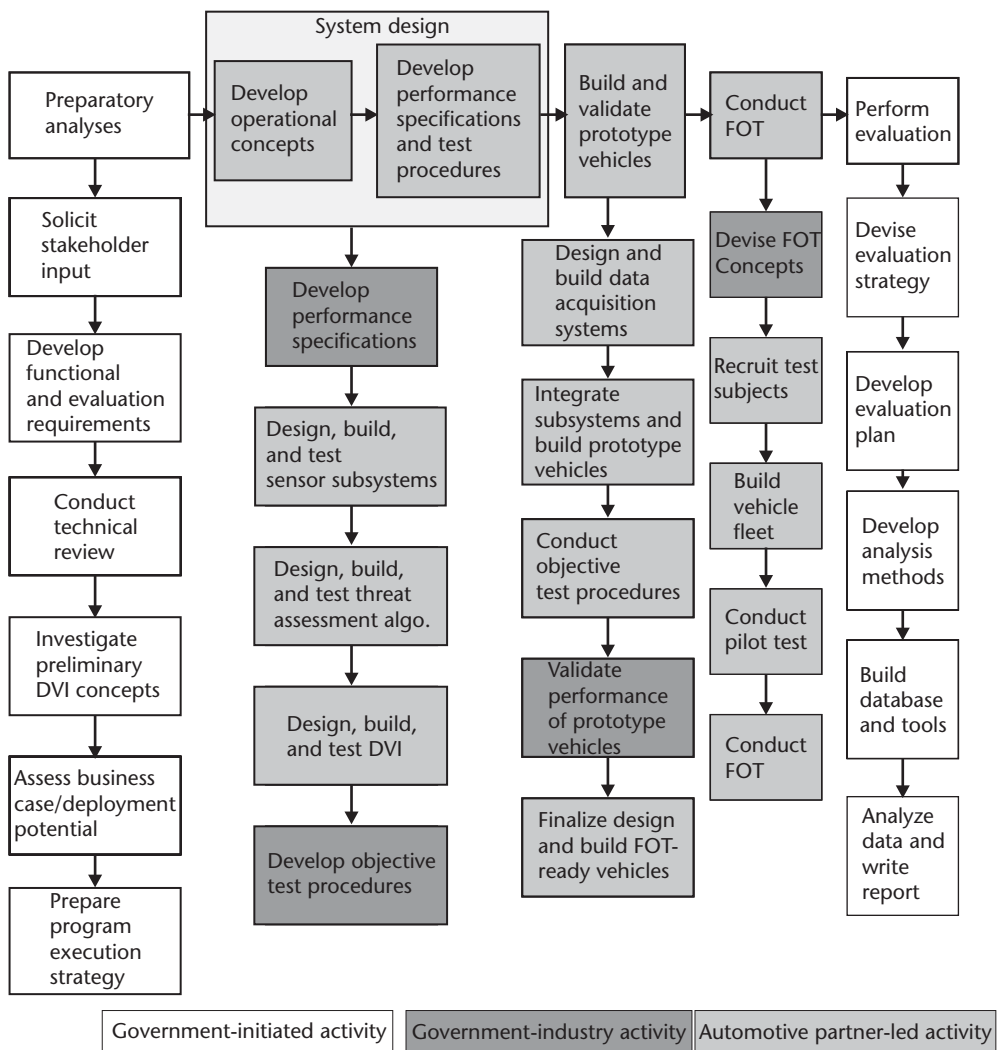


Figure 8.6 IVBSS program activities. (Source: U.S. DOT.)

Evaluation requirements will also be defined, including data needed to capture a visual image of the driving scene and the driver, as well as quantitative data needed to evaluate system performance and to identify and study crash conflict events. This is likely to be based on experience gained in the ADAS project outlined in Chapter 7.

Business cases and deployment potential will be addressed as well. Definitive cost-benefit analyses are particularly relevant for commercial trucks and transit bus operation as compared to cars sold to the general public.

In the system design phase, the industry partners will design, build, and test sensor subsystems; develop threat assessment algorithms; and design the driver interface. The intent is to deliver an integrated system that exceeds the performance of current single-function systems such as ACAS. Sensor fusion and sensor complementarity will play a key role here. Advanced technology subsystems such as enhanced digital maps, driver state identification, and vehicle-to-vehicle communications may also be employed if the vehicle industry partners deem these to be sufficiently mature and practical.

Research and definition of an effective driver-vehicle interface (DVI) is absolutely central to the IVBSS effort. Since crashes are rare events, it is quite likely that a driver will have never experienced the warnings prior to the critical moment. The DVI must be simple and intuitive enough that drivers are able to assimilate information almost instantly about a developing crash situation and respond appropriately.

Following system design, prototypes will be built and tested. A key parallel activity is the development of a data acquisition system to collect data required for performance validation. Validation tests are expected to comprise a series of controlled test scenarios and procedures on a test track or predefined on-road public routes. The IVBSS FOT approach is expected to be similar to previous U.S. DOT FOTs, in which fleets of 10–15 vehicles were deployed and several dozen drivers had use of the vehicles for several weeks or more in their everyday activities. Data will be gathered on driver performance with and without the assistance of the integrated safety system.

An independent evaluation will be performed to assess the safety benefits and driver acceptance of the system. A key challenge will be to create tools to effectively wade through the vast amount of multimedia data expected from the FOT.

The program plan calls for kickoff in the second half of 2005, with initiation of the FOT in 2007, and the program completed late in 2009. In the end, the government expects that the IVBSS program will produce performance specifications, objective test procedures, prototype vehicles, a database of driver performance with and without the assistance of integrated safety systems, and an evaluation report on benefits and user acceptance.

8.2.4 PReVENT Integrated Systems [14]

Conceptually, the European PReVENT integrated project provides a comprehensive vision of integrated lateral and longitudinal sensing systems, as vividly depicted in Figure 8.7. The project structure consists of parallel but coordinated subprojects separately addressing 1) safe speed and safe following; 2) lateral support, lane change support, and driver monitoring; 3) intersection collision avoidance; and 4) forward collision mitigation and pedestrian sensing. Several of the functions rely on advanced forms of sensor fusion, as described above.

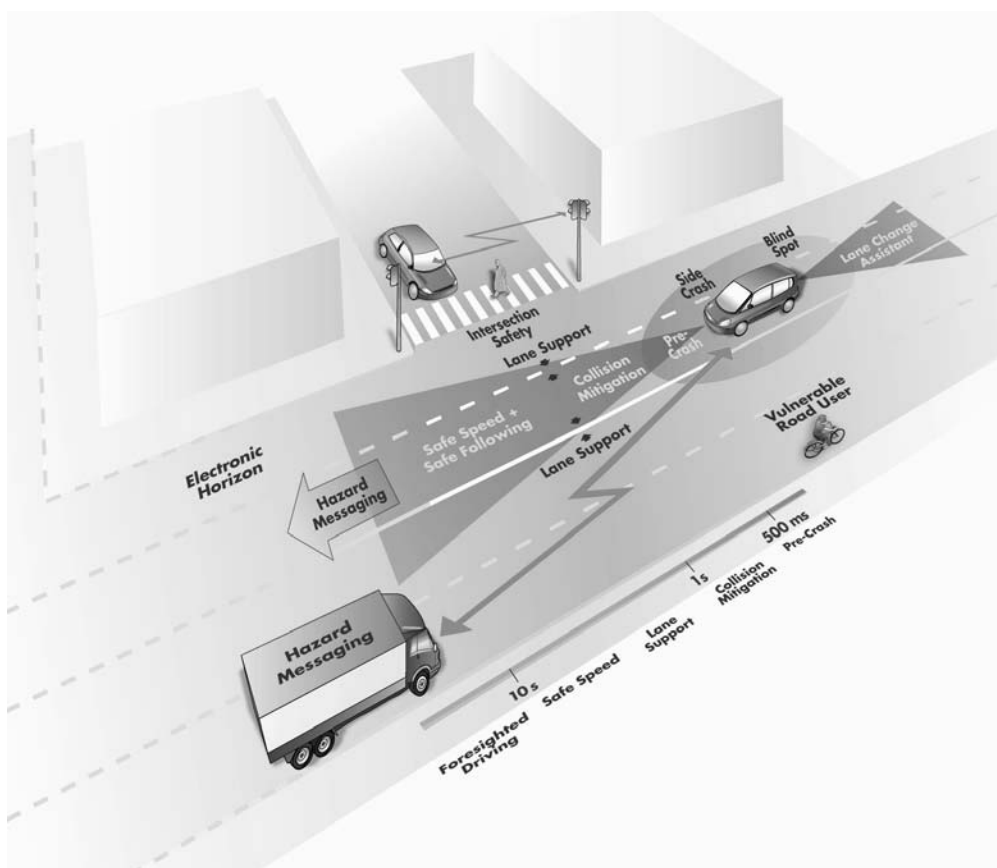


Figure 8.7 Integrated system concept in PREVENT. (Source: ERTICO—PREVENT Dissemination.)

However, the final demonstrations of PREVENT results do not include plans for integrated systems across lateral and longitudinal sensing. Instead, demonstration vehicles will be equipped separately for the four areas listed above.

8.3 User and Societal Assessments of Integrated Systems [15–17]

When considering the sophisticated functionality of integrated systems, questions arise as to how to best provide support to drivers. A joint venture by the Dutch TNO and University of Twente delves into these questions. The venture's Applications of Integrated Driving Assistance (AIDA) program runs from 2003 to 2007.

The researchers have defined a generic Integrated Driving Assistant (IDA), which would provide drivers with a wide range of support functions:

- Choosing and maintaining a safe speed, headway, and heading;
- Safe overtaking, merging, and turning;
- Monitoring traffic signals;
- Warning the driver of obstacles.

The researchers are investigating the impacts of such a system on driving performance, behavioral adaptation, and traffic (both safety and traffic throughput). Major research questions are listed as follows:

- What does the driver want in the way of driving support and can these desires be met by the technology? If the systems existed, would they purchase them?
- Does the behavior of drivers change when they use these systems? If so, how does this impact traffic safety, flow, and driver acceptance?
- Estimating effects: what effects do driver support systems have on travel, both objectively and subjectively as experienced by the driver?
- What effects do the support systems have on the traffic performance, in terms of flow, reliability, safety and the environment?

Major themes are the interaction between intelligent vehicles and intelligent infrastructure and the design of algorithms to support integrated functions and services.

Driver preferences are first assessed using an Internet-based survey—drivers are asked to what extent they have a need for certain types of assistance while driving. Emphasis is placed on the perception of driving (i.e., which tasks and situations are seen as easy or difficult) and on preferred combinations of driver support functions, so as to get a picture of the ideal driver support system from an end user's standpoint. Based on this input, an integrated driver support system will be conceptually defined. Next, impacts of the integrated driver support system on the driver, per the questions above, will be investigated using TNO's driving simulator.

Assessing the impacts of the integrated system on traffic flow and overall safety are done using traffic simulation.

8.4 Summary

This has been a brief look at integrated forms of the systems discussed in the previous two chapters, as well as an opportunity to examine sensor fusion techniques. As can be seen from the discussion, a large portion of future investment in ADAS development will relate to integrated systems and sensor fusion. The resulting challenges in terms of hardware, software, and data architectures are not trivial. In essence, we are at a crossroads—to transition to the next plateau in ADAS performance and marketability (translated: cost), the exchangeability of sensors and sophisticated sensor fusion techniques such as those discussed here must be both developed and broadly adopted by the automotive industry.

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Cooperative Vehicle-Highway Systems (CVHS)

In the preceding chapters, we covered lateral, longitudinal, and integrated systems. What can be accomplished, however, if the vehicles cooperate with each other and the highway as an integrated system? What if information concerning traffic ahead, obstacles, and road and weather conditions were flowing as freely between electronic subsystems on the vehicle as do land-side computers accessing the Internet? This is the fundamental premise for CVHS, which open the way for a “federated computing” approach to road-vehicle systems. Some applications, such as intersection collision avoidance, work better with CVHS, and others—such as traffic flow enhancement—are not possible at all without cooperation.

In fact, as the information horizon extends via the use of cooperative systems, the need for emergency braking is greatly reduced, as the “surprise factor” diminishes. So, tongue in cheek, one could even say that the aim of cooperative systems is to put crash avoidance systems out of business!

The prospect of employing vehicle-highway cooperation to gain vast improvements in the safety and efficiency of the road-vehicle system has been a part of the ITS program since the beginning. In fact, during the early years of ITS [then called Intelligent Vehicle highway system (IVHS)], the possibilities offered by a cooperative system approach were the central concept that gave momentum to the overall program. In those more visionary days, this cooperation was embodied in the idea of an AHS, whereby roadway elements and communications would interact with automated vehicles to increase road capacity. What is emerging now is a more gradual building-block approach.

Cooperative systems rely fundamentally on wireless communications to enable data exchange. Therefore, the first portion of this chapter is an overview of communications applied to this purpose. We then briefly cover maps and satellite positioning, which forms another pedestal on which CVHS rests.

Then we finally plunge into some CVHS functional areas thus far neglected: intelligent-speed adaption (ISA), intersection crash avoidance (ICA), and IV-based traffic flow improvements. Floating car data (FCD) techniques constitute a special case of a cooperative system, and these are covered separately in Chapter 11.

But what about deployment? CVHS comes with the perils of a chicken and egg dilemma. One car communicating cannot do much; it must have partners for data exchange. Therefore, CVHS require some level of fleet penetration to reach a “critical mass” of equipped vehicles. Fortunately, simulations performed to date indicate that fairly low (under 10%) fleet penetrations may be sufficient to achieve initial

benefits. Further, from a business perspective, it is critical that CVHS be defined to take advantage of existing trends in automotive electronics; CVHS concepts that require specialized hardware or dedicated communications paths are unlikely to succeed. To address some of these issues, we finish the chapter by examining some potential business models and deployment paths for CVHS systems.

9.1 Wireless Communications as a Foundation for Cooperative Systems

Wireless communications to support IV applications is a quite extensive topic, encompassing technical details, spectrum allocation, and a variety of commercial factors which may drive or impede deployment. A fundamental premise is that early users of such systems must have communications partners to gain value from their investment in communications equipment. In this section, we will provide an overview of the major approaches and trends in this domain.

Electronic toll collection, a very basic form of vehicle-roadside communications, has proven to be a “hit” all over the world by reducing wait times at toll collection points. These systems operate at a very short range and only require relatively low data rates. What type of expanded data services might vehicles use as they travel the roads in the future? Various applications call for image and video transfer, Internet access, infotainment (movies and music), vehicle status (for real-time diagnostics), traffic and road-relevant information (for traffic management), route guidance, car to car safety messaging, advertising, and “yellow page” services.

The primary modes of communications supporting CVHS can be distinguished as follows:

- Vehicle to/from roadside: requires the use of roadside transponders and supports both vehicle-specific data as well as locally relevant data broadcast to vehicles.
- Vehicle to/from external entity (not at roadside): using commercial wireless communications media to a central entity or the Internet via cellular or satellite-based data services.
- Vehicle to vehicle: Via ad hoc networking or command/response protocols. V-V modes include in-line communications with vehicles in same lane or communications with any neighboring vehicles (including those traveling in the opposite direction). Both point-to-point and broadcast may be employed.

In the following discussion, “vehicle to/from infrastructure” is a general term used to encompass both “vehicle to/from roadside” and “vehicle to/from external entity.” Three types of communications are supported:

- Command/response between a service provider and a service user;
- Broadcast to listener;
- Peer-to-peer, in which neither device is identified nor controls the actions of the other.

For CVHS to be viable, a wide range of applications is important to balance the costs of installing communications hardware in vehicles and on roadsides, so that the costs per application are lowered. An extensive set of applications based on vehicle communications has been conceptualized. A sampling encompassing cars, trucks, and transit bus applications is provided in Table 9.1, several of which are elaborated upon later in this chapter.

As an example of vehicle-vehicle safety applications, within Japan's ASV project Honda is investigating intervehicle communication between cars and motorcycles so as to provide warnings of relevant vehicle movements which may be hazardous, especially at blind intersections and other situations where driver's vision is obscured [1]. Motorcyclists are particularly vulnerable operating in such environments.

Data security is a key issue for vehicular communications. The system must ensure that the transmission comes from a trusted source and has not been tampered with since transmission. Certainly, security solutions have been developed for wired networks and two-way point-to-point communications, but trade-offs exist for developing a solution appropriate to the various vehicle applications. Threat assessments must be completed for the various vehicle safety applications to determine the appropriate level of security. This must be traded off against performance—if extensive security measures are required for safety critical applications, this could

Table 9.1 A Sampling of CVHS Applications

<i>Vehicle to/from infrastructure (for traveler information, convenience, productivity)</i>	<i>Infrastructure -to-vehicle safety applications</i>	<i>Vehicle-to-vehicle safety applications</i>
Electronic toll collection	Curve speed warning	Emergency braking of forward vehicle
Wireless diagnostics	Optimal speed advisory	Precrash warning
Software “flashing,” (i.e., updating vehicle software wirelessly)	Highway work zone warning	Driver advisories when making turns across traffic
Commercial driver log information	Highway/rail crossing collision avoidance	Lane change warning
Vehicles acting as data probes for traffic and road information	Traffic signal violation warning	Approaching emergency vehicle advisory
Real-time traffic updates	Low bridge warning	Stop sign movement assistance
Real-time map updates	Road condition warning	Road condition warning
Enhanced route planning and guidance		Cooperative adaptive cruise control
Drive-through payment (gas, parking, fast food)		Vehicle platooning
Wireless transfer of digital entertainment (games, music, video)		
Data exchange for border clearance		

create an excessive data overhead that could negatively impact latency and/or channel capacity. These are key challenges that must be worked out as R&D activities move toward commercial products.

Related to data security, personal privacy must also be assured for users. In most cases, data can be communicated on an anonymous or protected basis, which will be essential to user acceptance.

Applications based on vehicular communications have been discussed since the early 1990s. However, R&D activity has greatly accelerated in recent years. In the following sections, we review key activities and approaches in the following areas:

- Dedicated short-range communications;
- Ad hoc networking;
- Wireless Access Vehicular Environment;
- Continuous air interface long and medium range communications;
- Radar-based intervehicle communications;
- Interverhicle communications using millimeter-wave frequencies.

9.1.1 Dedicated Short Range Communications (DSRC) [2]

DSRC is intended to support traveler information, commercial applications (e.g., toll collection and parking fees), and safety applications (such as intersection crash avoidance). DSRC is relatively short range (up to 1,000m), line-of-sight, and based on a command-response control of communications between the roadside and passing vehicles. Although DSRC is a communications protocol, the term has also become identified with dedicated ITS spectrum allocations in various parts of the world. This spectrum allocation is in the 5.9-GHz region in the United States and in the 5.8-GHz region in Europe and Japan.

North American DSRC Analyses [3, 4] In 2003, the U.S. Federal Communications Commission (FCC) licensed 75 MHz of exclusive radio spectrum for DSRC in the 5.850–5.925 GHz band specifically for ITS safety applications. This culminated a process begun when the ITS industry petitioned the FCC in 1997. The exclusive spectrum is provided to avoid any interference from other users, given the safety criticality of the communications. Although individual safety messages are typically short, this broadband allocation is required to handle the communications loading of many vehicles sending these short messages frequently.

An extensive evaluation of this DSRC band for IV systems applications has been performed by the Vehicle Safety Communications Consortium (VSCC), a joint effort of the U.S. DOT and the automotive industry that was conducted from 2002 to 2004. Carmakers BMW, DaimlerChrysler, Ford, GM, Nissan, Toyota, and Volkswagen participated in the project.

VSCC objectives were the following:

- Estimate the potential benefits of communication-based vehicle safety applications;
- Define the communications requirements of selected applications;

- Identify and investigate specific technical issues that may affect the ability of DSRC to support these applications;
- Estimate the deployment feasibility of communications-based vehicle safety applications;
- Assess the ability of proposed DSRC communications protocol standards to meet the needs of safety applications.

The North American DSRC is seen as promising for vehicle safety applications because it offers the following:

- Very low latency;
- A broadcast capability;
- The option to allocate portions of the spectrum for high-availability access so that vehicles can exchange data almost instantaneously in imminent crash situations;
- An operating range deemed sufficient for most applications.

While the operating range is specified as 1,000m, at a practical level it is limited to approximately 200m in most conditions. At highway speeds, 200m is seen as an appropriate range to enable entities to transmit information about potential hazards and respond appropriately.

The low-latency aspect of DSRC is one of its most significant advantages. Latencies of less than 100 milliseconds appear to be possible with DSRC, and many of the vehicle safety application scenarios appear to have latency requirements in this range. Latencies in this range do not appear to be achievable with alternative wireless communications technologies; in fact, the potential DSRC latency is three orders of magnitude lower than other existing wireless technologies. This, plus the fact that broadcasting is possible with DSRC, creates a significant advantage over circuit switched, point-to-point wireless communications such as cellular.

Over 80 applications that could be enabled by DSRC were identified by the VSCC team. Communications parameters defined for each application included the following:

- Types of communications (one-way, two-way, point-to-point, point-to-multipoint);
- Transmission mode (event-driven, periodic);
- Update rate;
- Allowable latency (communication delay);
- Data to be transmitted and/or received (message content);
- Required range of communication.

Data packets to support most vehicle-to-vehicle communications were determined to be less than 100 bytes, with roadside-to-vehicle packets ranging up to 430 bytes.

Below, several of these applications are briefly described to illustrate aspects relevant to data communications.

Applications Based on Roadside-to-Vehicle Communications The applications shown in Table 9.2 can be implemented based on a fairly consistent set of communications parameters:

- One-way communication;
- Point-to-multipoint communication;
- Transmission mode: periodic;
- Minimum frequency (update rate): ~ 10 Hz;
- Allowable latency ~ 100 msec (consistent with typical automotive sensor update rates);
- Maximum required range of communication: 250–300m.

For intersection situations, the infrastructure system obtains information about approaching vehicles using sensors and/or DSRC, including parameters such as their position, velocity, acceleration, and turning status. Relevant data can then be transmitted to the host vehicle. Road surface and weather conditions can be transmitted to assist the vehicle system in optimally estimating braking distance. In these scenarios, either the roadside system or the vehicle system can estimate collision risk and takes appropriate action.

Applications Based on Vehicle-to-Vehicle Communications The V-V applications shown in Table 9.3 can be implemented based on the same communications parameters as

Table 9.2 Selected DSRC Applications Based on Roadside-to-Vehicle Communications

<i>Application</i>	<i>Function</i>	<i>Data communicated</i>
Traffic signal violation warning	Warns the driver to stop if a traffic signal is in the stop phase and the system predicts that the driver will be in violation, based on vehicle speed and braking status	Traffic signal status and timing Traffic signal stopping location Traffic signal directionality Road surface condition Weather condition
Stop sign violation warning	Warns the driver if the distance to the stop sign and the speed of the vehicle indicate that a high level of braking is required to properly stop	Stopping location Directionality Road surface condition Weather conditions
Stop sign movement assistance	Provides a warning to a vehicle entering an intersection after having stopped at a stop sign, to avoid a collision with traffic approaching the intersection	Vehicle position, velocity, and heading; Warning
Intersection collision warning	Warns drivers when a collision at an intersection is probable	Traffic signal status, timing, and directionality; Road shape Intersection layout; Vehicle position, velocity, and heading
Curve speed warning	Aids the driver in negotiating curves at appropriate speeds, by using information communicated from roadside beacons located ahead of approaching curves	Curve location Curve speed limits Curvature Super-elevation Road surface condition

Table 9.3 Selected DSRC Applications Based on Vehicle-to-Vehicle Communications

<i>Application</i>	<i>Function</i>	<i>Data communicated</i>	<i>Range (m)</i>
Cooperative forward collision warning	Aids the driver in mitigating or avoiding a forward collision; data received from the forward vehicle is used along with host vehicle information as to its own position, dynamics, and roadway information to estimate collision risk	<ul style="list-style-type: none"> – Position – velocity – heading – yaw rate – acceleration 	150
Emergency electronic brake light	When a forward vehicle brakes strongly, a message is sent to other vehicles following behind to provide advance notification even if the radar sensors or the driver's visibility is limited by weather or other vehicles	<ul style="list-style-type: none"> – Position – heading – velocity – deceleration 	300
Road condition warning	Marginal road conditions are detected using onboard systems and sensors and a road condition warning is transmitted to other vehicles via broadcast. This information enables the host vehicle to generate speed recommendations for the driver	<ul style="list-style-type: none"> – Position – heading – road condition – parameters 	~400
Lane change warning	Warns the driver if an intended lane change may cause a crash with a nearby vehicle by processing information sent from surrounding vehicles and estimating crash risk when the driver signals a lane change intention	<ul style="list-style-type: none"> – Position – heading – velocity – acceleration – turn signal – status 	~150

those above with the exception of range, which varies according to the application. Generally, the communications information is meant to augment, not replace, onboard vehicle sensors.

Preocrash Sensing For illustrative purposes, communications for preocrash sensing is examined in a bit more detail here. The required communication range is approximately 25m, with messaging in a broadcast mode for more basic systems. However, a cooperative preocrash sensing system can also be conceptualized in which two-way communications occurs once the radar sensor predicts the eventuality of a collision, in order to exchange data such as vehicle type. A generic block diagram for such a system, developed within the VSCC project, is shown in Figure 9.1.

In Figure 9.1, in-vehicle sensors refers to information that is available on the vehicle data-bus, such as speed, yaw rate, longitudinal acceleration, lateral acceleration, steering wheel angle, air bag crash sensors, and brakes and throttle status data. Static vehicle data refers to parameters such as vehicle ID, class, size, mass, and DSRC antenna location. The differential GPS (DGPS) unit provides vehicle position, heading, and time stamp. The DSRC onboard unit (OBU) provides messaging at 10 Hz in broadcast mode and 50 Hz for two-way communications. The radar unit measures target range, range rate and azimuth angle. The preocrash processor consists of a DSRC message processing unit and a radar processing unit to conduct the threat evaluation and confirmation based on the radar data, the host vehicle

The AHSRA approach employs a two-beacon system for information points. The “starting beacon” orients the vehicle with reference points and informs it that information is available. The “information beacon” provides the relevant information. In this way, the vehicle can judge the content and timing of services and provide information to the driver as appropriate. The combination of information from the two beacon types allows the vehicle to know the direction in which services are provided and judge whether to accept the services.

Data reliability has been a key focus. AHSRA established the concept of the safety integrity level (SIL), which encompasses both the accuracy of the information provided and the communications integrity. AHSRA assigned a share of 99.1% of the SIL to the road-to-vehicle communications link, given the many factors that can affect signal transmission—such as environmental conditions, radio wave leakage, code errors, shadowing, radio interference, crosstalk, equipment malfunction, and power failure. Extensive testing has been conducted, in particular for the characterization of code errors caused by multipath and shadowing. Via simulations, test course testing, and field operational testing, research has shown that the 99.1% figure is achievable.

Issues for future AHSRA work are expected to include the following:

- Addressing the occurrence of radio shadowing due to the variety of vehicle movements (particularly for intersections);
- Addressing deterioration of signal reception due to oblique reception when the onboard unit is installed on the interior of the vehicle;
- Integration of applications;
- Standardization of communications protocols.

9.1.2 Transceiver Development for North American DSRC [6]

In an effort to accelerate the potential availability of 5.9-GHz DSRC devices for safety applications, the U.S. DOT initiated a \$5 million project in 2004 to begin the process of building and testing prototypes. Communications technology company ARINC plus four transponder manufacturers that compose the DSRC Industry Consortium are designing and building the prototypes. The U.S. DOT sees this initiative as a necessary step toward commercialization of the new 5.9-GHz band, as a way of validating the emerging DSRC standard.

The project involves requirements development, design, construction, and testing phases. Initial prototype hardware and software that meets the DSRC standards is expected to be available by early 2005. The effort is on a fast track and is expected to be completed in late 2005, including testing conducted in concert with interested car manufacturers.

Design goals call for communication range and data rate to be increased by two orders of magnitude over previous systems. The upper limit for communication range at 5.9 GHz is targeted for 1 km, with a useable range of about 300m for critical safety applications. The “official base data rate” for this new 5.9-GHz system will be 6 Mbps. Once a link is established, the two systems will negotiate with one another to move to a higher data rate based on transmission conditions. That data rate can be as high as 27 Mbps.

9.1.3 Wireless Access Vehicular Environment (WAVE) [7]

WAVE can be considered to be a superset of DSRC as it supports the traditional characteristics of DSRC but supports longer operating ranges (over 1 km depending on environmental conditions) and higher data rates, as well as allowing peer-to-peer communications. WAVE is an adaptation of the IEEE 802.11a protocol and has received a tentative designation of 802.11p within this wireless interface standards family. In the United States in particular, industry activities are focused strongly on using the WAVE protocol within the dedicated DSRC spectrum. WAVE can be viewed as the means by which DSRC is brought into the IEEE wireless standards world.

9.1.4 Continuous Air-Interface for Long and Medium (CALM) Distance Communications

CALM is a framework that defines a common architecture, network protocols and air interface definitions for all types of current and (expected) future wireless communications—cellular second generation, cellular third generation, 5.x GHz (including WAVE), millimeter-wave (~63 GHz), and infrared communications. These air interfaces are designed to provide parameters and protocols for broadcast, point-point, vehicle-vehicle, and vehicle-point communications. CALM is currently the subject of a standards process within the International Standards Organization (ISO).

These standards are designed to enable quasicontinuous communications between vehicles and service providers, or between vehicles. In particular, for medium-and long-range high-speed roadside/vehicle transactions such as onboard Web access, broadcast and subscription services, entertainment, and “yellow pages” access, the functional characteristics of such systems require contact over a significantly longer distance than is feasible or desirable for DSRC, and often for significantly longer connection periods.

Some applications will have the need that communication sessions set up in an initial communications zone may be continued in following communication zones. CALM establishes the network protocols to support the handover of a session conducted between a landside station and a mobile station to another landside station using the same media or a different media, in whatever way is optimum for the application.

CALM also supports safety critical applications, such as those examined within VSCC. In such cases, a handoff between media is unlikely as the messages will be short and quick. However, the CALM architecture allows for messages to be sent simultaneously on several media to improve quality of service (via redundancy).

Many see CALM operating on microwave media in the 5-GHz region as a likely candidate for the next high-volume ITS communication medium. Typically, data rates of up to 54 Mbps and ranges up to 1 km would be supported. It is expected that CALM applications will begin appearing around 2008.

9.1.5 Intervehicle Communications Using Ad Hoc Network Techniques

In contrast to the DSRC command-response approach between communication partners, the CarTALK and Fleetnet projects in Europe have explored in depth the potential of ad hoc communication networking techniques for vehicle communications.

Using ad hoc networking, data transmissions are free—because the base stations and mobile switching infrastructure required by commercial wireless services are not needed. Both projects are based on exploiting the properties of “UTRA-TDD.”

UTRA-TDD [8, 9] Using the communications standard called the universal mobile telecommunications system (UMTS), a communications framework known as UMTS terrestrial radio access time division duplex (UTRA-TDD) has been selected as a highly promising candidate for intervehicle ad hoc communications. However, since UTRA-TDD was developed to operate in a cellular network structure, modifications are required that relate to the synchronization mechanisms to allow an ad hoc operation in high-velocity traffic, decentralized power (range) management, and providing channel access priority for safety-critical applications.

In an UTRA-TDD frame structure, transmission is organized in frames of 10 ms duration each. Each frame consists of 15 independent time slots. Because any time slot within a frame can be dynamically assigned to act as either an uplink or a downlink, UTRA-TDD is ideal for the asymmetrical communications traffic patterns likely to occur in intervehicle communications. UTRA-TDD also supports high mobility, (i.e., communication nodes with relative speeds of 400 km/hr or more (speeds that may be encountered in opposing traffic in settings such as the German Autobahn). It is robust in the presence of multipath and the estimated 2-Mbps data rate is seen as more than adequate. Acceptable communications performance over a range of 2,000m for highway situations, and 600m for urban situations, is seen as feasible.

For European use, license-free spectrum for UMTS is available from 2.01 to 2.02 GHz. Experts expect a large mass market for devices and applications based on the UMTS standard.

FleetNet-Internet on the Road Services and applications examined by FleetNet (described in Chapter 4) were the following:

- Cooperative driver-assistance applications for safety;
- Local FCD applications;
- User communication and information services.

The driver-assistance safety applications are based on short messages being passed from car to car in efficient ways so that drivers can get information on obstacles or traffic jams ahead, beyond the view of the driver's vision or the range of vehicle sensors.

FleetNet researchers were faced with no shortage of technical challenges, which included the following:

- Development of communication protocols for the organization of the ad hoc radio network;
- Development of routing algorithms for multihop data exchange, for forwarding between vehicles and between vehicles and stationary gateways;
- Access mechanisms for the radio channel that ensure good quality of service in terms of delay and error rates.

Satellite positioning systems played a key role in the FleetNet approach. Under the assumption that cars will in the future know their positions with within 10m by using GPS and digital maps, FleetNet uses this information to better organize the ad hoc radio network. Radio routing protocols use of the knowledge of the position of other cars within communications range, and a geo-addressing technique is used to connect with cars based on their positions. Position-based communications addressing is important, as the requirement is to communicate only with the car in front or behind in longitudinal emergency braking scenarios, for instance.

FleetNet prototypes implementing these services were successfully demonstrated at the DaimlerChrysler research center in 2003.

CarTALK [10–14] CarTALK, a European-wide project that included many of the FleetNet organizations, also focused on mobile ad hoc networks for intervehicle communications, with an emphasis on cooperative driver assistance safety applications. The project, led by DaimlerChrysler, ran from 2001 to 2004. Other partners included Fiat, Bosch, Siemens, TNO, and several universities.

CarTALK explored both direct and multihop intervehicle communications. Direct communications provides benefit in extending the information horizon through upstream communications with following vehicles, but the coverage range may be limited by topology as well as vehicle densities. This is overcome with a multihop approach in which opposing traffic “grabs” the signal and travels onward for some distance before transferring it back over to the lane of interest, (i.e., the traffic actually approaching the hazard). CarTALK techniques use position awareness and spatial awareness to perform these data transfers efficiently.

Application clusters selected for analysis and prototyping within CarTALK were the following:

- Information and warning functions (IWFs);
 - Basic broadcast warning of a roadway hazard ahead;
 - Extended blind spot assistance when merging with traffic;
 - Intersection warning in vehicle crossing-path situations;
- Communication-based longitudinal control (CBLC) functions;
 - Distance-keeping in a stop and go traffic mode;
 - Early braking, in which a car performing hard braking transmits a signal which can be received by several following vehicles, (i.e., three or four vehicles upstream, so that the braking response of following vehicles is smoother). (This could be an automatic braking feature implemented as an extension to ACC.)
- Cooperative driver-assistance functions;
 - Automatic coordination of traffic merging on a motorway in a fully autonomous driving mode.

CarTALK demonstrated selected applications in six test vehicles.

Because of its simplicity and low cost, IWF is seen as promising for early market introduction. But how long will it take for early users to reliably encounter communications partners? CarTALK researchers analyzed the equipped vehicle penetration rates needed for IWF. For a light traffic scenario on a motorway with two lanes each way, the analysis showed that having 6% of all vehicles on the road equipped was

adequate, with only 3% needed if the motorway is four lanes each way. In a heavy traffic scenario, 3% vehicle equipage was determined to be adequate for the two-lane situation, or only 1.5% for the four-lane. An analysis was performed based on these rates as well as the number of new vehicles sold each year and assumed rates of equipped vehicles within these new car sales (ranging from 6% in year one and rising to 30% by year five). Under these conditions, after five years the overall vehicle equipage rate was estimated at 7.5%, well over that needed for the scenarios above. The team recommended that emphasis be placed on infrastructure-based beacons in the early years to provide benefits to first purchasers.

A benefits assessment conducted for the IWF basic warning and the CBLC early braking showed crash reductions of 3.6% and 12.6%, respectively, for passenger cars on motorways in Europe, assuming 100% market penetration. Benefits were roughly proportional for lower levels of penetration. Based on their assumptions for crash and personal injury costs, basic warning showed a cost/benefit ratio of 1.51 and emergency braking showed a cost/benefit ratio of 3.5.

9.1.6 Radar-Based Intervehicle Communications [2, 15]

Given that ACC radars are generating radio signals for forward sensing, why not add a communications channel and get dual use out of the same hardware? This added-value concept is driving ongoing work by researchers in Germany, Japan, and the United Kingdom. Such an approach allows for simultaneous sensing and information relay, such that information sensed by a preceding car may be passed on to following cars, for instance. The available data rate is relatively high due to the bandwidth used by the radar systems. By the nature of radar sensing, real time operation is guaranteed and sharp directivity is assured. In fact, individual vehicles can be selected for communications based on the radar beam steering.

In the United Kingdom, BAE Systems is working with Jaguar to integrate communications capability with 76-GHz long-range radar. The project, called SLIMSENS, is funded by the U.K. government through its foresight vehicle program [16, 17].

In Japan, the Intelligent Transport Systems Joint Research Group at the Yokosuka Research Park (YRP) has developed two approaches to an integrated radar and communications system. The systems are intended to detect vehicles or roadside signposts and then receive messages transmitted from them regarding safety or traffic conditions. A short communication distance is assumed (less than 100m). One approach uses time-sharing: every 5-ms time period, the radar function is allocated 1 ms and the communications function 4 ms. Using this approach, 100 Kbps is achieved. Spread spectrum technology was investigated for the second approach due to its excellent resistance to interference. This system was capable of a 1-Mbps data rate.

One area investigated by the YRP researchers was signal blockage by other vehicles. In measuring the effects of this “shadowing” phenomenon, however, it was found that received power remained fairly good because signals were reflected from the road surface.

DaimlerChrysler has focused on short-range radar at 24 GHz, typically used for blind spot monitoring and parking aids, for their work in this area [18]. The Daimler system operates at a center frequency of 24 GHz using a pulse radar system with a range of 0–20m. The communications range is up to 200m and a

1-Mbps data rate is achieved. As shown in Figure 9.2, the company's implementation provides for separate bands for communications protocols, user data, and emergency notifications, which are placed at the upper end of the operating spectrum, decoupled from the sensing band.

Based on basic short-range radar entering the market in 2004, developers estimate that such an integrated system could be on the market as early as 2007.

9.1.7 Millimeter-Wave (MMW)-Based Intervehicle Communications

MMW communications offers advantages for broadband data downloads to vehicles. Work of this type is under way in Japan and the United Kingdom.

Researchers at Denso in Japan have prototyped systems to serve the expected future demand for entertainment downloads in vehicles [19]. Their Individual spot-cell communication system (ISCS) is capable of super high-speed transmission of 100 Mbps or more operating at MMW frequencies (experiments were conducted at 37 GHz). The ISCS operational concept focuses on expressway service areas (SAs), where it is highly likely that large-capacity multimedia services will become widespread. ISCS system requirements were developed based on Japanese travel patterns. In Japan, SAs are located along expressways at approximately 50-km intervals, and expressway users enter SAs once per 100 to 150 km of driving on average, staying about 20 minutes per stop. Assuming an average speed of 80 km/h, the driving time between stops will be 80–120 minutes. DVD-quality entertainment content to cover this amount of driving time is estimated to require 4 GB of information. Given other driver activities during their time at the SA, a goal was set to download 4 GB during a 5-minute period, while vehicles are parked in download zones at the SA. This requirement translates to a data transmission speed of 107 Mbps. The ISCS the base station selectively forms "spot cells" that are approximately equal to a vehicle in size, over individual vehicles that park within its service zone. This allows the use of high-gain antennas to optimize the link.

The Millimetric Transceivers for Transport Applications (MILTRANS) project is a three-year project supported by U.K. government funding, led by the BAE Systems Advanced Technology Center [20]. The aim is to design, build, and demonstrate a high-speed data link between mobile and stationary terminals operating in the band of 63–64GHz. The 60-GHz band is used because of the high atmospheric attenuation of RF signals at this frequency, which limits applications to short-range communication

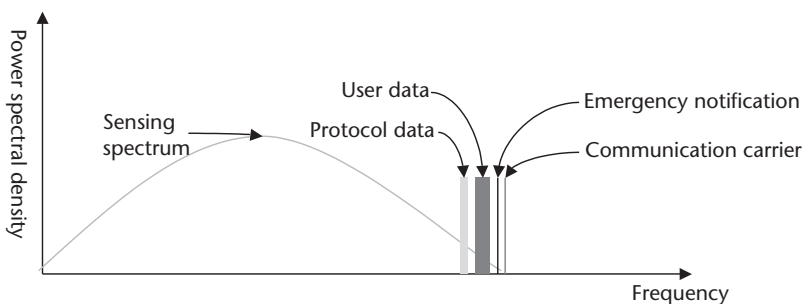


Figure 9.2 Spectral layout for integrated radar-communications system developed by DaimlerChrysler. (Source: DaimlerChrysler AG.)

only—precisely what is desired for vehicle-vehicle and vehicle-roadside communications—and therefore reduces overall interference in the larger area.

Using directional planar patch array antennas for gain and directivity, the MILTRANS prototype is designed for a range of up to 1 km.

9.2 Digital Maps and Satellite Positioning in Support of CVHS

Onboard digital maps combined with satellite positioning can be seen as a type of cooperative system, as positioning data is received from outside the vehicle. Digital maps (a shorthand for the map/satellite positioning combination) can play a crucial role in supporting active safety systems as well as navigation. In previous chapters, we saw several references, including the applications of adaptive headlights and curve speed warning. Lane-level maps, which also include a rich data set regarding roadside hardware (guardrails, signs, bridge abutments), are under development for future systems, so that, for instance, a radar system has additional data in distinguishing on-road from off-road objects.

Automotive researchers have identified a wide range of applications that could be enhanced by digital map data. These include the following:

- Curve speed warning;
- Curve speed control;
- Adaptive light control;
- Vision enhancement;
- Speed limit assistant;
- Path prediction;
- Fuel consumption optimization;
- Power train management;
- ACC;
- ACC optimized for heavy trucks;
- Stop & go Acc;
- LKA;
- LCA;
- Collision warning/avoidance;
- Autonomous driving.

The map data assists in the overall scene interpretation in several ways. Image processing systems are complemented by map data on where the road is “supposed” to be, which can generally improve lane detection and reduce false alarms. Additionally, when the presence of exit ramps and splits in the road are known from the digital map, lane detection algorithms can take these features into account. Digital map data can also assist in maintaining lane tracking during temporary dropouts of vision sensing, due to camera “blinding” by direct sunlight at dawn or dusk, for instance. For radar systems, hills may cause a

tracked target to suddenly “disappear” and three-dimensional map data can assist the system in maintaining tracking and reacquiring the target as the vehicle travels over the crest of a hill.

A particular challenge for digital mapping is in keeping the map up-to-date. Current maps are created through a labor intensive and non-real-time process, with updates generated every few months. To support active safety systems, the maps must always be accurate; therefore, real-time updating is required. This requires, in turn, methods to collect the data as well as for vehicles to download new data and integrate it with the existing onboard map.

In this section, we cover research that has explored both map-enabled safety applications and the updating process.

9.2.1 Map-Enabled Safety Applications

Integration of Navigation and Anticollision for Rural Traffic Environments (IN-ARTE) [21] IN-ARTE was a 5FW European project led by Fiat and included partners Renault, Volvo, Siemens, Navteq, and TNO. The objective was to integrate digital map techniques with more conventional sensors to implement the following active safety applications:

- Curve approach warning;
- Traffic sign information;
- Speed limit information;
- Forward obstacle warning.

Two demonstrator vehicle systems were implemented that fused forward-looking radar with a navigation system and enhanced digital road maps to accomplish longitudinal vehicle control for these applications.

Enhanced Digital Maps (EDMap) [22] EDMap focused on proof-of-concept for basic map-enabled safety applications, with a key focus on developing map database specifications and evaluating the challenging of creating high-detail maps to support these applications. The U.S. DOT partnered with DaimlerChrysler, Ford, General Motors, Toyota, and Navteq for the three-year project, which concluded in 2004. Having auto manufacturers collaborate on the project enabled them to coordinate map database content and structure, to help in developing firm requirements for mapping companies.

From a mapping standpoint, requirements of interest included map accuracy/reliability, specific map attributes needed by the applications, and a better idea of vehicle positioning system accuracy requirements.

One of the team’s first activities was to brainstorm applications enabled or enhanced by a map database (84 applications). From these, they derived functional description and requirements and compiled a final list of 33 applications that were generally defined in terms of advisory, warning, and control levels of functionality. Core applications were selected and prototype systems were constructed and tested in real-world conditions. High-detail maps for areas of Detroit, Michigan, and Palo Alto, California, were developed for the project by Navteq; these maps were more detailed than current navigation system maps but did not extend down to lane level.

Systems demonstrated were the following:

- Curve speed assistant (Ford, GM);
- Stop sign assistant (Toyota);
- Forward collision warning (GM);
- Traffic signal assistant (DCX);
- Lane following assistant (DCX).

The partners concluded that next generation digital maps are practical for safety applications in the near and midterm and noted the significant challenges in the creation and validation of lane level maps.

9.2.2 ActMAP: Real-Time Map Updating [23]

As noted above, the ability to update digital maps in real time is a key enabler for map-supported safety applications. The flagship effort in this area has been the European ActMAP project, which ran from 2002 to 2004. The project was led by ERTICO and included BMW, DaimlerChrysler, Fiat Research, and Siemens VDO from the automotive industry, along with mapping companies Navteq, Navigon, and TeleAtlas.

Map updates are required for a wide range of geographic phenomena, which require updates over a range from seconds up to months. For instance, the presence of road obstacles can change on the order of seconds, while roadworks can change on the order of weeks or months. ActMAP focused on the development of the real-time dynamic update methods needed for these digital map databases, in a manner in which new information could be instantly integrated into the onboard map database. This involved the development of requirements for updated map components (such as geometry, attributes, and dynamic content), development and validation of the update processes, and initial work toward international standardization of the methods.

Validation was performed within a test area on experimental vehicles, which implemented the following applications:

- Route guidance;
- Curve speed control;
- Speed adaptation;
- LKA;
- ACC.

Map data can assist in advising drivers on proper speeds, both in terms of road geometry and speed limits. In terms of curves and other road geometry, the digital map provides curve radius, angle, and possibly even superelevation. Based on this information, an advisory speed can then be estimated by also incorporating any information on surface quality, street width, number of lanes, shoulders, (daytime) visibility, weather (friction), and driving style of the driver. In ActMAP, BMW's prototype provided driver feedback via an active accelerator pedal, which generated a slight but clear feeling of resistance to suggest to the driver when speed should be reduced.

Fiat integrated road geometry and dynamic information with its ACC system to create a “predictive ACC” system. In this case, the set speed would automatically be reduced as appropriate for factors such as curves, intersections, or speed limit changes.

The ActMAP work is being extended in the European 6FW PReVENT integrated project in the MAPS&ADAS subproject. The intention here is to reduce the costs and complexity of map-based ADAS safety applications by providing a standardized interface to digital map and positioning data.

9.3 Cooperative Applications: Longitudinal Advisories

Cooperative vehicle-highway systems can provide warnings to drivers at high-risk areas for situations that cannot be detected by onboard vehicle sensors. These may be fixed hazards such as curves, dynamic hazards such as slippery road conditions or a disabled vehicle ahead, or even the presence of animals along the roadway detected by special sensing systems [24].

9.3.1 Japanese Operational Testing

In Japan, AHSRA has analyzed crash situations which can be addressed by CVHS, formulated requirements, prototyped systems, defined safety and reliability performance goals, established evaluation methods, and conducted field operational testing.

Curve Speed Warning [25, 26] As described in Chapter 6, AHSRA has implemented CVHS techniques for curve speed warning on particular road sections known to be hazardous.

Unseen Obstacles AHSRA has also integrated the automatic detection of disabled vehicles with driver warnings in blind curve areas. Test results showed impressive results in improving safety. For instance, in a comparison of maximum deceleration for avoiding a collision with a stopped vehicle on a blind curve, maximum deceleration without the warning was 4.8 m/s^2 , whereas it was 3.6 m/s^2 with the warning, showing that braking could be less urgent with the warning.

Systems to detect stopped vehicles, slow vehicles, and congestion were developed based on visible image processing, infrared image processing, and millimeter-wave radar. Tests conducted on the Tomei Expressway and the Oita Expressway verified the basic performance of the sensors.

Road Surface Condition Alerts In the ideal case, drivers would know about hazardous road conditions before they reach them. Systems for detecting road conditions have been widely deployed in recent years, but these typically only analyze a very small patch of pavement. What is needed are systems that can continuously survey the entire width of a large highway and even provide detail of variations across the lanes when there is a mix of ice and water, for instance.

AHSRA has performed extensive research in this area, with the intent to communicate hazardous conditions to drivers when needed. Since 1996, research has been under way on three types of sensors (vision, lidar, and optical fiber) that

distinguish and track five road surface conditions (dry, wet, water film, snow cover, freezing). In 2001, performance was verified by detection of 16,000 items of road surface condition data at Nakayama Pass on National Highway 230 in Hokkaido, where detection rates in the range of 95% were achieved.

The sensors developed by AHSRA monitor roughly three lanes simultaneously and have achieved accuracies in the range of 90% in detecting road conditions.

9.3.2 Wireless Local Danger Warnings

Within the Deufrako program described in Chapter 4, the intervehicle hazard warning (IVHW) project (which ended in 2002) was one of the earliest activities focused on vehicle-vehicle communication. Its objective was to develop a common specification of a practical hazard warning system for motorways in which disabled vehicles would broadcast a warning to all nearby vehicles, enabling the approaching drivers to proceed with greater caution. Situations such as slow traffic, traffic jams, and actual crashes were covered. Participants included government safety laboratories, motorway operator Cofiroute, and the automotive industry.

European research is taking a further step in this area, and also extending the CarTALK work, within the 6FW PReVENT integrated project. The subproject Wireless Local Danger Warning is developing a system for onboard hazard detection and decentralized warning distribution via direct and multihop ad hoc communication between vehicles.

9.4 Intelligent Speed Adaptation (ISA)

The concept of ISA was first brought forth in Sweden. ISA calls for vehicles to be “aware” of the prevailing speed limit on roads and (at minimum) provide feedback to the driver when that speed is being exceeded or (at maximum) limit the vehicle’s speed to comply with the speed limit.

In early testing, speed limit data was communicated by roadside transponders. However, today’s digital maps (at least for Europe and the United States) include speed limit information to various degrees; therefore the currently preferred approach is to use such maps and satellite positioning. Significant challenges remain, however, in creating an “air-tight” speed limit database. To this end, a prime focus of the European SpeedAlert project is to consolidate the collection, maintenance and certification of speed limit information across Europe [23].

When ISA first entered the IV scene, it was considered an outrageous idea by those who saw the driver’s authority over speed as sacrosanct. At the same time, road safety experts were convinced that, if speeds were moderated, road fatalities would decrease. The concept which has gradually gained currency in Europe (and virtually nowhere else so far) is of an advisory system that provides insistent feedback to the driver when speed is being exceeded. A strong motivator for such a system has come from an unexpected source—enforcement of speed limits (and speeding fines) have increased significantly over much of Europe (notably France) such that drivers are more likely to welcome a system that helps them stay out of trouble with the authorities.

This section reviews major work in Sweden, the United Kingdom, and France, along with thumbnails of other activities, to give the reader a sense of the quite significant level of activity in this field in Europe.

9.4.1 ISA in Sweden [27]

As noted above, Sweden pioneered the development and testing of systems to electronically assist drivers in maintaining the speed limit. The Swedish National Road Administration has led the work in this area as part of their Vision Zero initiative to completely eliminate road fatalities.

SNRA conducted major research during 1999–2002, with field operational tests in the cities of Umea, Borlange, Lidkoping, and Lund. Approximately 5,000 vehicles were driven by approximately 10,000 drivers. Volvo assisted in vehicle integration of ISA components.

The purpose of this research was to study driver attitudes and use of the systems, assess road safety and environmental impacts, and define conditions for large-scale deployment of ISA.

Using both roadside transponders and GPS/digital map techniques, the research team implemented provision of speed limit information and over-speed warning functions. An active accelerator pedal was used to communicate speed information to the drivers.

Areas of evaluation included the following:

- Traffic effects (excess speed, red light violation, yielding behavior, headway and queues, effects on travel time, fuel consumption and exhaust emissions);
- User acceptance (need for speed adaptation, influence of ISA on the driving style, workload, stress, and concentration on the driving task);
- Product design (functionality and intelligibility, consumer willingness to pay for various ISA systems).

User acceptance was generally good and, as a result of the test deployments, speed violations were reduced. Researchers concluded that better road safety was achieved without lengthening travel times on city streets and that ISA had an overall positive effect on the rest of traffic. Analysis showed that, if every vehicle was equipped with ISA, a reduction of up to 20% in serious road injuries could be achieved in developed areas. While user acceptance was high, most users thought that ISA should be mandatory, so that the ISA cars did not “stand out” in the traffic stream by going at a slower (although speed limit–compliant) speed.

SNRA is now focusing on measures such as instituting regulations for ISA, purchasing ISA for their entire public vehicle fleet, and defining economic incentives for consumers to purchase ISA.

9.4.2 LAVIA: The French Project of Adaptive Speed Limiter [28]

As noted in Chapter 4, the French government is supporting ISA experimentation and assessment to better understand driver acceptance and effects on their driving behavior. The key objectives of the LAVIA project are listed as follows:

- To assess user acceptance and usage patterns for ISA with several different functional approaches;
- To assess changes in individual driving behavior;
- To measure the reductions of speed or gaps with regard to the speed limits;
- To measure system impacts on speed limit compliance as well as any detrimental effects (i.e., reduced vigilance);
- To assess via simulation the global collective impacts on safety using field testing data.

A vehicle equipped with LAVIA knows the speed limit at any time within the region designated for the experiments. The authorized speed is encoded in an enhanced digital map for every road within the defined area, and location referencing is used to correlate the vehicle's location with the speed limit on the road being traveled. The project makes use of manual speed limiter devices already in production by Renault and PSA Peugeot Citroën.

The speed limit information is used by the onboard controller to provide three different types of driver assistance:

- Advisory system: The system is activated at the driver's option. When enabled, a warning is displayed on the dashboard if the speed limit is exceeded.
- Voluntary active system: Again, the system is activated at the driver's option. When activated, the throttle is under LAVIA control and the speed limit cannot be exceeded.
- Mandatory active system: The system is always active, with the throttle under LAVIA control. The speed limit cannot be exceeded.

In the initial testing phase, two vehicle prototypes equipped with the LAVIA system were constructed. These were equipped with systems to collect both video and numerical data. The video includes views of the driver's face, as well as the forward and rear views from the vehicle. In this way, driver reactions to the system can be observed, as well as the dynamics of the surrounding traffic (which is likely to be at a higher speed). The numerical data consists of state data (e.g., foot pedals and wiper status), kinematic data (speed, acceleration, distance), location, and the authorized speed for every location. This technical validation phase was followed by qualitative evaluation, with 15 volunteer drivers accompanied by research psychologists.

After assessment of prototypes, a fleet of 20 vehicles equipped with LAVIA (collecting quantitative data only) were assigned to 100 drivers in the Paris area for normal usage in a radius of 200 km around their home. In this way, many different types of roads and substantial variation in speed limits are being encountered. LAVIA results are expected in 2005.

9.4.3 ISA-UK [29]

An external vehicle speed control project was funded by the British government from 1997 to 2000 to study acceptance of ISA, investigate implementation technologies, carry out simulation modeling to assess side effects, and conduct user trials both in a driving simulator and on actual roads.

The major prediction from this project was that ISA in its most compulsory and versatile form (i.e., a mandatory system that is capable of dynamic speed limits based on weather and other conditions) could achieve a 36% reduction in injury accidents across the United Kingdom and a 58% reduction in fatal accidents.

The current phase of ISA work began in 2001 and is examining driver behavior with and without speed limiters activated. The project involves 20 vehicles and 80 drivers, is funded by the U.K. Department for Transport, and is being led by the University of Leeds and the Motor Industry Research Association. Trials were begun in early 2003 in four cities that represent both urban and rural driving. The systems rely on GPS/map-based speed information, and speed control can be overridden by the driver. The trials are designed to be nonintrusive: The vehicles will behave like normal cars apart from the ISA feature, with automatic data logging.

The project team is also preparing a system architecture for a mass production configuration of ISA, developing an ISA design for motorcycles and large trucks, and investigating costs and benefits of ISA.

9.4.4 PROSPER [23, 30]

Recognizing that introduction of road speed management based on ISA requires international cooperation to overcome technical, legal, and policy barriers, PROSPER was initiated by the European Commission within the 5FW program. PROSPER, which includes partners from 10 European countries, is led by the Swedish SNRA and aims to monitor ISA activities and assimilate research results on a European level. PROSPER is complementary with the SpeedAlert project mentioned above: SpeedAlert addresses organizational, technical, and operational aspects of ISA, while PROSPER focuses on the public acceptance, legal and relevant transport policy issues.

Projects being monitored by PROSPER include those described above plus the following.

- Belgium: An ISA project was initiated in 2002 by the Flemish government, involving the operation of 34 cars and three buses in the city of Ghent. The vehicles are equipped with an “active accelerator” version of ISA. An analysis of legal, liability, and privacy aspects is also under way.
- Denmark: Denmark is conducting an ISA project in Aalborg that uses 24 test drivers.
- Finland: As part of Finland’s national Vision Zero project, a test site at Lillehammer is incorporating ISA with CALM-based communications to enable vehicles to download necessary road mapping and speed limit information [31].
- Hungary: ISA field trials were carried out in the city of Debrecen and were completed in 2003. Driving data logged in 20 test vehicles is currently being analyzed. An indication of the acceptance of the system is that three out of four of the drivers wanted to keep the equipment in their cars.
- Spain: In the city of Mataró, ISA experiments were conducted during 2004. Here, 20 private drivers tested two alternative ISA systems: 1) warning via an active accelerator pedal and 2) warning via visual/audible signals. The results from the field trials are expected to be available at the end of 2004.

9.4.5 Australian ISA Research

Initial ISA research is also under way in Australia. For instance, researchers at the Accident Research Center at Monash University are performing field tests to assess ISA effectiveness and acceptability among drivers in the TAC SafeCar project [32].

9.5 Cooperative Intersection Collision Avoidance (ICA)

Intersection collisions are disproportionately severe due to the crossing-path nature of the event—passengers have less metal between them and the point of (side) impact. The causes of these crashes relate primarily to driver behavior and inattention. In a “hurry-up” society, the temptation to move on through that intersection as the traffic signal is changing from yellow to red can overwhelm otherwise law-abiding drivers. In these situations, red light running cameras—which automatically detect violations and issue traffic citations—have been quite effective. For instance, at 9 of 125 intersections in Oxnard, California, such systems were installed, resulting in a 29% decrease in injury crashes city-wide (due to a carry-over effect even for unequipped intersections) [33].

So, actions relating to conscious choices made by drivers can be modulated based on enforcement. However, when drivers are unaware that they are about to commit a violation, or when they are unaware that another driver is disregarding a traffic signal or stop sign and putting them in harm’s way, that is when ICA systems can potentially save the day.

While it is possible to develop ICA systems residing only on the vehicle, there will inevitably be times in which sensor views are obscured by foliage or buildings. Therefore, a cooperative systems approach is key to a comprehensive ICA system.

A good deal of work has been conducted in this area, starting with AHSRA in Japan, then later in the United States, and most recently in Europe. Very active programs are in place in all three regions currently. A sampling of this work is provided in this section.

9.5.1 ICA Research in Japan [34]

In Japan, ICA continues to be a priority for NILIM, and a significant portion of phase I research by AHSRA focused in this arena. The agency’s ICA work has focused on crossing collisions, right-turn collisions (crossing path), and pedestrian collisions. Some of the first-ever ICA systems were demonstrated at Demo 2000 sponsored by the Japanese government.

Following Demo 2000, AHSRA researchers constructed additional test intersections and performed field testing to identify key issues. From the testing, they noted the following:

- Some traffic patterns with high crash potential are difficult to detect with sensors (particularly with motorcycle movements between vehicles and lanes).
- Signal quality for wireless communications tends to degrade due to multiple reflections within the vehicle, particularly when stopped.
- Developing an HMI capable of depicting diverse traffic conditions is a challenge.

Based on these results, current work is focusing on adjusting the division of tasks between road and vehicle systems, as well as making greater use of map databases.

9.5.2 ICA Work in the United States [35, 36]

The U.S. DOT has sponsored a variety of ICA-related projects based on both autonomous vehicle and cooperative approaches. Generally, the deployment approach being pursued by FHWA is to initially deploy infrastructure-only systems for intersection crash avoidance. Then, as equipped vehicles increase, and as benefits increase, transition to vehicle-infrastructure cooperative systems.

The IC (described in Chapter 4) has led the way in the United States for development of cooperative ICA systems. Core members California, Minnesota, and Virginia, along with the Federal Highway Administration, have coined the term “intersection decision support (IDS)” systems to address the following scenarios:

- Warning of a potential traffic signal violation;
- Warning of a potential conflict with a hidden vehicle (for left turns);
- Warning of potential stop sign violation;
- Assistance for safe gap acceptance when entering traffic after a stop sign.

Development of intersection collision countermeasures has included defining objective test procedures, defining requirements for data communication between the vehicle and the infrastructure, and assessments of the ability of radar sensors to provide necessary position and speed information about oncoming vehicles.

In California, researchers at PATH have focused on left-turn assistance at urban signals. In such situations, it is possible that a large vehicle waiting to make a turn (in a left-turn lane) can obscure oncoming traffic when the host vehicle is looking to make a turn. In this system, vehicle movements for all points of the intersection are sensed via redundant radar, lidar, and in-pavement detectors. This data is combined with signal timing and phase information from the traffic signal controller to feed a decision-support algorithm that assesses the safety of making a left turn. If unsafe, an active LED traffic sign illuminates a “no left turn” icon in the infrastructure-only mode. In the vehicle-infrastructure mode, communications signals are transmitted via the 802.11a wireless protocol to activate an in-vehicle display. In-vehicle information allows for tuning of the warning for older drivers and other special needs.

PATH has also constructed an instrumented intersection in California for future research, to include characterizing naturalistic driving in intersections.

The Minnesota approach focuses on rural situations, particularly in “gap acceptance support” to assist drivers in entering a major road from a minor road. Data has shown that 60% of crashes at rural intersections are due to poor judgment of gap. The Minnesota IDS system is seen as a good alternative to putting up traffic signals, which can be undesirable because rear-end crashes often increase when traffic signals are installed on high-speed rural roads. Their system relies on radar detectors deployed at several locations along the main roadway to detect vehicles approaching the intersection from the left or right. This information is communicated to a central processor via an 802.11a wireless connection to enable a processor to compute which gaps in traffic are safe or unsafe for the approaching vehicle to enter the main

roadway. The processor then activates an LED “no left turn” traffic sign during unsafe conditions. The focus of the driver advice is to tell the driver when they should not enter the intersection, rather than when they should, which reduces risk of liability.

Minnesota is also leading an eight-state pooled-fund study to take this work toward deployment. The effort focuses on collecting extensive data on unsignalized rural intersections known to be hazardous and defining sensor suites that could be effective in detecting key vehicle movements [37]. The research team is designing the sensor suite and communications infrastructure for particular intersections, with the State DOTs installing the equipment for data collection. Based on the results, operational testing of countermeasures systems is planned.

The Virginia Polytechnic Institute and State University (Virginia Tech) is focusing on the straight crossing path problem, at both signals and stop signs. The intent is to detect when drivers are not appropriately slowing when they should be stopping at an intersection, and using high-visibility roadside signs to warn them to stop. Radar sensors are used to detect vehicles approaching the intersection and measure their speed relative to the proper stopping point. As above, that information is combined with traffic signal timing information to assess the probability of a traffic signal violation. If this is the case, a pulsing, high-intensity LED “stop” icon is illuminated. Virginia Tech is also developing an “intelligent rumble strip,” in which rumble strips pop-up in the roadway ahead when a vehicle is not slowing appropriately.

For the in-vehicle version of Virginia Tech’s straight-crossing-path mitigation system, GPS information is used to correlate vehicle position and speed information with the intersection layout and signal timing information relayed wirelessly to the car. In the event of a pending violation, the system issues an urgent warning, as shown in Figure 9.3.

An “intelligent intersection” test facility was created at the Federal Highway Administration Research Center in 2003 and has served as a key test bed in this work.

For the straight-path crossing problem, FHWA funded research to define algorithms for determining inattentive signal violators. They determined that measurement of speed ahead of the intersection provides a clear indication of a driver’s intent to stop or not; however, this indication is not sufficiently upstream of the intersection to provide an effective warning to the driver. They found that the key to earlier detection is in measuring both speed and acceleration/deceleration; doing so provides sufficient time to provide warnings well ahead of the intersection.

Based on the proof-of-concept research described in the section, the U.S. DOT initiated a new phase in 2004 called CICAS, with a goal to develop and deploy systems at 15% of the most hazardous signalized intersections nationally, with in-vehicle support in 50% of the vehicle fleet, by 2015 [39–41]. The agency’s approach calls for a combination of autonomous-vehicle, autonomous-infrastructure, and cooperative communication systems that potentially address the full set of intersection crash problems. The R&D phase will focus on assessing safety performance and user acceptance via field operational testing. Roadside-vehicle communications are obviously a key component and the work will benefit from the government’s parallel efforts in this area. The U.S. DOT sees the auto industry coming together with IC researchers from state DOTs to define practical systems that are feasible for deployment.

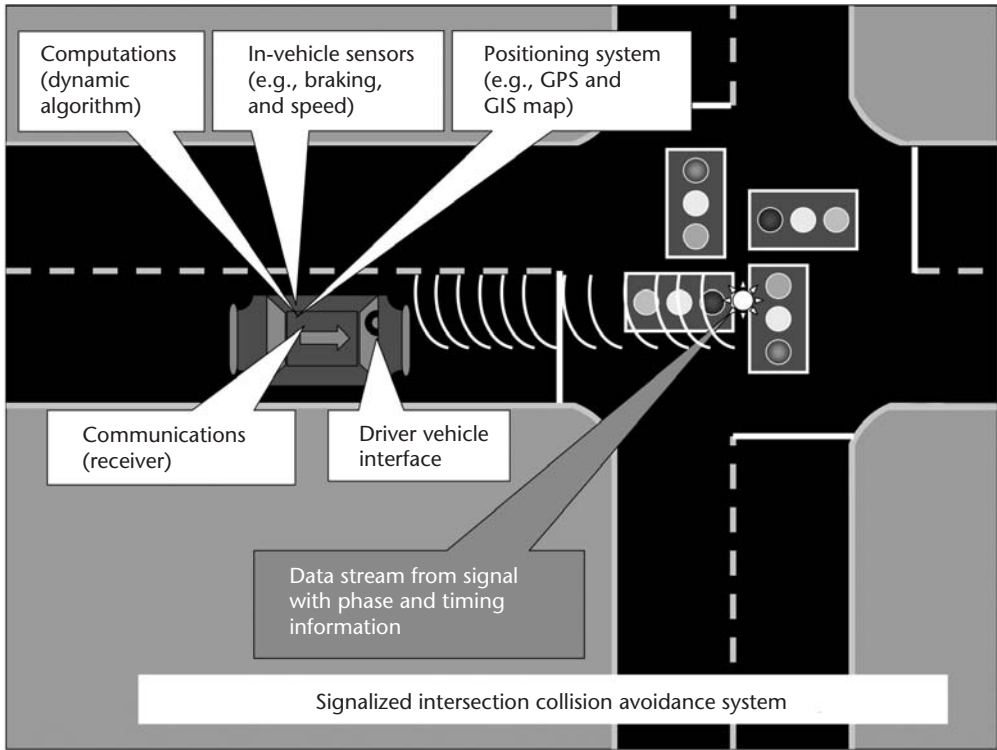


Figure 9.3 Intersection collision avoidance system developed by Virginia Tech [38].

9.5.3 Cooperative ICA R&D in Europe [42]

European ICA work is focused within the INTERSAFE project, which is part of the PREVENT 6FW Integrated Project. The project, running from 2004 to 2007, includes automotive OEM partners BMW, Renault, PSA, and Volkswagen and suppliers TRW and Ibeo. The project's objective to improve safety at intersections is being pursued through a combined approach of sensors that detect potential hazards plus sensors that localize the host vehicle within the situation. Vehicle-infrastructure communication is employed to exchange information about traffic, weather, road conditions, and other key factors.

German crash data used to focus the work shows that intersection crashes account for 15% of road fatalities, but represent about 43% of the passenger cars involved in crashes. A large number of crashes relate to right of way issues such as yield and stop signs, and crossing traffic conditions. The INTERSAFE consortium is mainly focusing on stop sign assistance, traffic light assistance, turning assistance and right-of-way assistance.

Two system development approaches, a basic intersection safety system (B-ISS) and an advanced intersection safety system (A-ISS) are being pursued; they differ in complexity and time-to-market but have similar architecture. As shown in Figure 9.4, the B-ISS approach uses two laser scanners, one video camera and vehicle-to-infrastructure communication implemented on a VW Phaeton test vehicle. Additionally, communication modules will be installed at selected intersections in



Figure 9.4 Basic ISS vehicle integration in the INTERSAFE project. (Source: PREVENT INTERSAFE.)

public traffic so that information can flow between the vehicle and the traffic signal controllers. Object detection, road marking detection, and landmark navigation are accomplished by fusing information from laser scanners and the video camera, combined with a detailed digital map of the intersection. In the resulting world model, all objects and the position of the vehicle are then known. Dynamic risk assessment is then performed based on object classification and tracking, traffic signal data, and the intention of the driver (based on turn signals, etc.). Based on the risk assessment, warnings are issued if needed. This system will be evaluated at equipped intersections beginning in 2005.

The second approach is a top-down approach using the BMW driving simulator. Dangerous intersection situations will be created in this virtual environment to allow researchers to conceptualize countermeasures independent of any physical sensor performance limitations and then define requirements for an advanced system.

Figure 9.5 depicts the overall INTERSAFE concept, including creation of the world model and performing the risk assessment. The B-ISS approach is shown as nearer term and less complex, with the more complex A-ISS following at a later time and offering higher performance.

9.6 Cooperative Approaches for Vulnerable Road Users

Avoidance of collisions with vulnerable road users (pedestrians, bicycles, and motorcycles) was discussed in Chapter 7 for vehicle-based sensor systems. Additionally, a unique cooperative approach within the European PROTECTOR project is being explored. In addition to direct-sensing approaches, PROTECTOR has investigated enhancing the performance of vehicle-based systems by means of transponders or microwave/optical reflectors carried by vulnerable road users. These techniques are being evaluated at test sites.

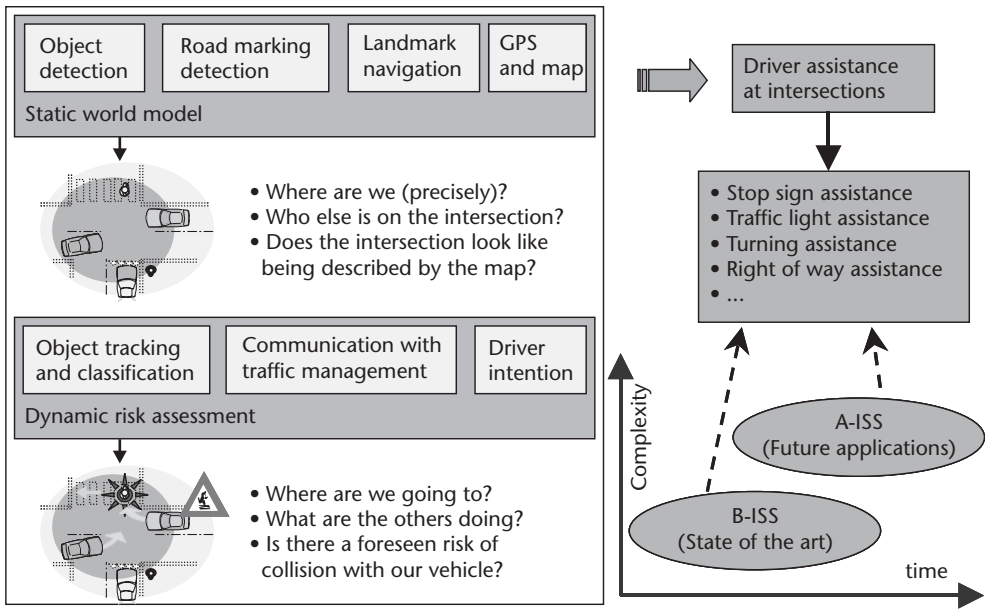


Figure 9.5 INTERSAFE concept for intersection collision avoidance. (Source: PReVENT INTERSAFE.)

9.7 CVHS as an Enabler for Traffic Flow Improvement

Unfortunately, the smartest car on the planet is absolutely powerless to alter its fate—in terms of travel time—in a traffic jam. Only through the exchange of information between vehicles and/or the infrastructure can traffic flows be improved.

Traffic congestion has a pervasive effect on society. For example, with the public driving 1,900 million vehicle hours on a daily basis, losses to the German economy due to congestion have been estimated at 250 million euros. A total of 18% of this travel is spent within stop-and-go conditions. In 1998, 2% of the routes were permanently congested and 17% were marginal. Future extrapolations show increases by as much as 351% by 2015. Figures from the United States are equally compelling—the annual financial cost of traffic congestion is \$63 billion for the 85 largest cities, with annual delay per rush hour traveler at 46 hours. Each year, an estimated 5.6 billion gallons of fuel is wasted by engines idling in traffic jams [43].

Government programs that have heretofore focused on safety are now beginning to explore cooperative vehicle-highway approaches for traffic flow improvement. This is particularly true in the Dutch Advanced Vehicle Guidance program and the Traffic Performance Assistance component of the German INVENT program. In addition to participation in INVENT, DaimlerChrysler is performing further internal work in traffic modeling/forecasting, traffic-adaptive vehicle systems, and simulations to assess their effects. Another center of research is the PATH program at the University of California-Berkeley, whose work has been sponsored by the California Department of Transportation. Over the years, many researchers have used traffic simulations simplistically modified to represent the characteristics

of ACC and more advanced systems to investigate traffic effects. Only now are advanced simulations and actual work on-road beginning to more thoroughly evaluate system concepts.

At one end of the spectrum, basic information provided to drivers about traffic conditions immediately ahead can be useful to stimulate driving behavior that optimizes flow. On the other end of the spectrum, fully automated vehicles operated at close headways can significantly increase per-lane capacities. In this section, we explore some of the ongoing work in this area. The technical aspects of fully automated vehicles will be covered in Chapter 10, whereas operational and traffic aspects are covered here.

With traffic-enhancing techniques, the dynamics of individual versus collective benefit must be kept in mind. Actions that create an individual disadvantage (such as slowing slightly to allow traffic to merge) could be beneficial to the overall flow. Are drivers willing to do this? The answer remains to be seen, but at minimum they must understand why specific actions are being taken and also trust that they are benefiting from other drivers making similar sacrifices.

It should also be noted that savings can be achieved in fuel consumption and emissions in using such techniques to reduce congestion. Therefore, IV systems are important contributor to sustainability.

9.7.1 Traffic Assistance Strategies for Improving Stable Flow

Given the huge demand on our highways, how can traffic flow under normal free-flow conditions be improved? Coordinated longitudinal control holds the answer, and adaptive cruise control offers the first foray into this realm.

Autonomous ACC As we saw in Chapter 7, current ACC systems offer the driver several headway choices. Since this affects vehicle spacing, the effect on road capacity is obvious. ACC can also affect the stability of the traffic flow based on the dynamic response characteristics of the longitudinal control algorithms. Generally speaking, controllers designed to provide a “comfortable” ride based on modest accelerations could decrease traffic stability under certain conditions, therefore giving the occupants an uncomfortable trip. This issue has not yet become a factor due to the current low market penetration of ACC, but it could become an issue over time, unless future generation systems can detect various flow conditions and adjust parameters accordingly.

California PATH researchers have performed extensive traffic simulation studies to examine IV system effects. For autonomous ACC (A-ACC), the effects of time-gap setting on traffic flow volume are shown in Figure 9.6, which was derived from a detailed Monte Carlo simulation study of A-ACC at a variety of market penetration levels. These results are for longitudinal controllers optimized for traffic flow and therefore most likely represent better performance than systems currently on the market [44, 45].

Depending on the headway chosen, note that the traffic flow effects could be positive or negative compared to a 2,300 vehicles/hour baseline (typical flows). Using the minimum headway of 1.0s offers significant advantages, whereas a large headway of 2.0s results in significant disadvantages. These effects would not begin to appear until after reaching 30% market penetration, however.

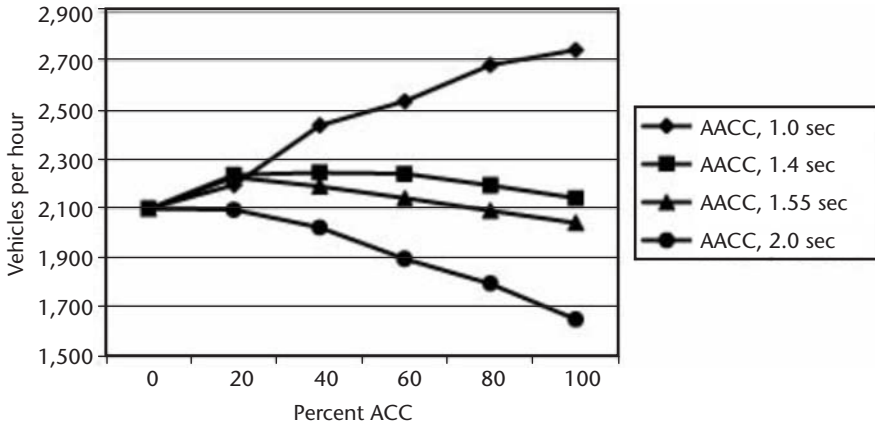


Figure 9.6 Capacity per highway lane as a function of Autonomous-ACC time gap setting and market penetration. (Courtesy of California PATH.)

One way to create a higher “per-lane market penetration” is to institute policies which encourage ACC-equipped vehicles to use the same lane in a motorway. For instance, ACC vehicles could be allowed to use carpool lanes. This creates a strong incentive to purchase ACC and provides a general public benefit as well. Nevertheless, drivers must still choose to use short headways to gain a traffic flow benefit.

INVENT researchers in Germany have conducted similar simulation studies. Their results also showed improvements in flow for headways of 1.8 seconds and less.

Responsive ACC (R-ACC) The R-ACC concept calls for ACC systems that are enabled to receive speed commands from a local traffic operations center. The speed commands could be very finely tuned to the situation both in terms of speed (increments of 1 km/hr) and location (on the order of meters). In this way, traffic managers could very precisely manage flow for lanes of equipped and unequipped vehicles by controlling the speed of only the equipped vehicles.

Would citizens ever allow their speed to be externally controlled in this way? They would if they received sufficient benefits in return, such as access to lanes designated for R-ACC vehicles or reduced road user charges, not to mention shorter trip time. Further, activating the system would always stay under control of the driver, just as with current ACC systems.

The R-ACC approach has not yet progressed beyond the concept level. Potentially, some of the distributed vehicle intelligence approaches may supersede this more centralized approach. In fact, the greatest challenge with R-ACC lies with the traffic operations center—sophisticated predictive algorithms must be implemented along with highly accurate data as to current traffic conditions in order to issue appropriate speed commands.

Cooperative ACC (C-ACC) Whereas autonomous ACC controls time gaps based on sensing the vehicle directly ahead, C-ACC benefits from the exchange of vehicle parameters between the vehicle being tracked and the host vehicle. Therefore, tighter headways become possible without sacrificing safety and greater traffic flow benefits can be gained. The communications link also gives drivers greater confidence in the system when traveling at a relatively close distance.

Parameters communicated may include position, velocity, acceleration, heading, and yaw-rate. Communications latencies would need to be quite low, on the order of 20 ms [3].

The PATH simulation study referenced above also looked at the effects of C-ACC. With A-ACC at a 1.4 second headway and C-ACC at a 0.5 second headway, the dramatic effects of C-ACC can be seen in Figure 9.7. Compared to the base case of no ACC vehicles, traffic consisting of 100% C-ACC vehicles at this headway would roughly double traffic flow.

Because driver decisions in selecting a headway are so critical to traffic flow performance, PATH started a human factors research project in 2004 to explore this issue. Drivers are using vehicles with commercially available A-ACC and equipped with a data collection system. Driving behavior using ACC is being recorded over a one-week period and the data will reflect their baseline time gap preferences. Then, C-ACC will be enabled within the same vehicle, and they will drive for a short time behind a confederate equipped vehicle. Researchers are seeking to determine the extent to which the higher performance of the C-ACC encourages these drivers to select smaller ACC time gaps, as an indication of C-ACC's potential contribution to traffic flow.

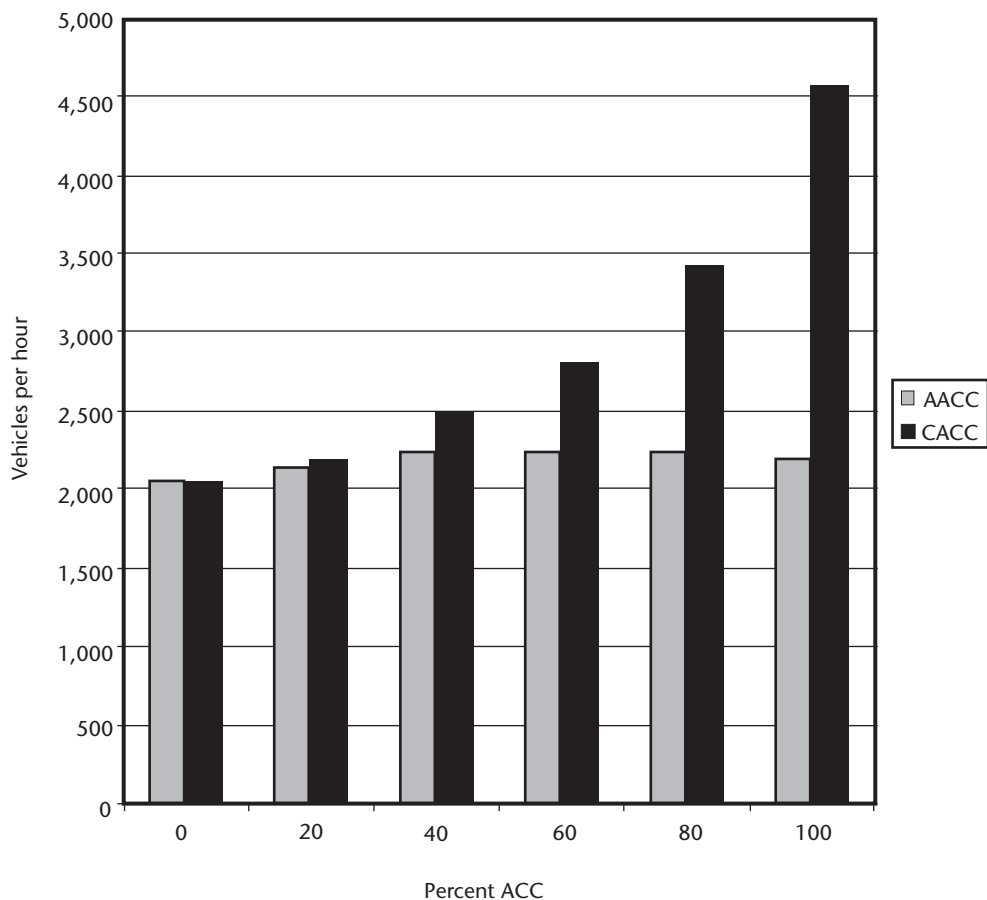


Figure 9.7 Relative effects on lane capacity of A-ACC at 1.4 second time gap and CACC at 0.5 second time gap. (Courtesy of California PATH.)

C-ACC systems have been successfully prototyped by major car companies and are now in advanced development. Their market introduction is expected before 2010. Therefore, while A-ACC systems may result in some degradation of traffic based on large headways, C-ACC could in a sense “save the day” and offer major improvements in traffic in the long run.

Close Headway Operations via Platooning [46] Clearly, vehicle headway is a major factor affecting traffic flow rates. As such, stably maintaining very short headways will offer the greatest benefits. To do this, vehicle parameters must be exchanged along a string of vehicles, not just with the one directly ahead, using a “platooning” technique. This approach would require very fast update rates and low latencies.

Platooning offers the potential for per-lane flows on the order of 6,000 vehicles/lane/hour, which is on the order of a three-fold increase over today’s traffic. This should be seen as a theoretical maximum, as entry/exit configurations and many other factors would affect overall flow rates. Further, platooning is seen as worthwhile only within dedicated lanes such that all vehicles within the flow are equipped for platooning. Of course, even achieving only half of that 6,000 vehicles/lane/hour flow rate would nevertheless constitute a major improvement to the current situation.

Platooning techniques were developed by the California PATH program and demonstrated by PATH as part of the National Automated Highway System Consortium Demo ’97. Refinements to platooning techniques, including response to failure modes such as tire blowouts, have continued since then.

9.7.2 Traffic Assistance Strategies To Prevent Flow Breakdown [47–50]

Two of the primary circumstances that can cause stable flow to breakdown are local disturbances and merging of other traffic.

Quick Responses to Local Traffic Disturbances A local perturbation of traffic causes only local disturbance initially but the effects can then spread as a shock wave. Simply put, the key strategy in these situations must be to detect these local problems very quickly, communicate both the situation and an intervention approach to affected vehicles, and then adjust speed, lane selection, and/or headway to control the perturbation within the larger flow. The sooner the response, the less the effect.

INVENT researchers have developed an algorithm for this purpose which complements local traffic data with data transmitted wirelessly from preceding vehicles. The vehicles communicating with each other can then construct a picture of traffic conditions that is local and very accurate. In essence, a lane-specific speed profile downstream of the vehicle is created. Based on this information, advisories can be provided to the driver (for lane changes) and/or automatic adjustments can be made for speed and headway. Such measures can be taken well in advance of the traffic situation. INVENT researchers expect that assistance systems with such onboard traffic state estimators will replace autonomous assistance systems within a few years.

Similar work is ongoing by AHSRA in Japan [51], which is focused specifically on the traffic disturbance caused by “sags” in the roadway, (i.e., a downhill-uphill section). Traffic congestion frequently forms on the uphill section as drivers unconsciously fail to increase throttle to maintain speed. The AHSRA approach relies on

roadway monitoring of the overall situation, and then providing lane advice to drivers to smooth traffic.

Maintaining High Flows in Merging The merging situation is somewhat less complex than random local disturbances, in that the location of merge points can be known by approaching vehicles with digital maps, and protocols can be defined for the vehicles as they wirelessly negotiate the merging process. As local and vehicle-specific data is exchanged, drivers upstream of the merge can be advised to change lanes and/or speed can be adjusted prior to the merge point to create an appropriate gap. Also, merging vehicles can perform the maneuver at an optimum speed for the overall flow.

An intriguing infrastructure-oriented approach to merging assist is being investigated by AHSRA in Japan [63]. On urban highways in Japan, the merging situation is quite difficult because the acceleration lanes for merging are short, there is relatively little spacing between merging areas due to many freeway entry/exit points, and traffic on the main highway and merging vehicles may not have visual contact with each other due to the presence of sound suppression barriers. The result is frequent rapid braking and crashes as vehicles try to maneuver in this environment, which also creates shock waves and disrupts traffic. The Guidelight merging assistance system detects the position and speed of the merging vehicle and uses a line of synchronized colored lights installed alongside the main driving lanes to indicate the presence and expected “arrival time” of the merging vehicle to the mainline traffic lane. A distance equivalent to three seconds in front of and behind the merging vehicle’s position is indicated by this moving indicator as sort of a “ghost image.” The precise position of the merging vehicle is indicated by flashing red lights, and a safety margin ahead and behind the vehicle is indicated by flashing yellow lights. When no merging vehicles are present, the guide lights are green. Drivers on the main highway can use the lights to synchronize their position and speed with the merging vehicle for a smooth merge.

Basic testing of the Guidelight approach was conducted on a test track. Although the approach is unique, the system’s purpose and operation were reasonably obvious to test participants. Deceleration was used as a measure of effectiveness, as zero deceleration implies perfect merging. Whether or not participants were informed about the service, deceleration dropped when the service was provided. At the same time, the headway necessary for merging was maintained, so that safety was maintained. In particular, elderly drivers showed a significant improvement in deceleration, which is a key result as they typically require a longer length of time for assimilating and responding to a merging situation [51].

9.7.3 Traffic Assistance Strategies Within Congestion [52]

Given that congestion will continue to occur due to lane blockages and other incidents, it is important to understand the internal dynamics of congestion as well as consider what can be done to reduce its duration.

Certainly, once a congested situation is known, traffic approaching the scene can appropriately modify speed and time gap well in advance (i.e., several kilometers) to moderate the inflow. Another option to reduce the inflow is to shift traffic partially to alternative routes. This is investigated in detail in the INVENT component project

Network Traffic Equalizer. Within the congestion itself, the techniques described above for self-organization and traffic state estimation via intervehicle communications can be effective to damp the stop-and-go waves.

INVENT simulations have shown that, within congested traffic, fuel consumption can be improved on the order of 10% by using ACC set at a 1-s headway.

Particular opportunities appear to exist for the troublesome issue of dissipating congestion once a blockage is removed. The dissipation process can be quite prolonged, as drivers at the leading edge do not immediately realize that congestion has ended and are therefore sluggish in accelerating adequately, thereby perpetuating the situation. Therefore, a system that knows where the congestion has ended and advises drivers and/or automatic controls to accelerate appropriately at that point could greatly increase outflow. In the case of low-speed ACC usage, the system could be commanded to shift to full speed mode ACC and accelerate fairly rapidly back to highway speed, to the degree allowed by preceding vehicles.

Dissipating Congestion via Driver Advisories [53] Using a driving simulator, INVENT researchers investigated this approach. The behavior of the forward segment of the simulated traffic corresponded with empirical data collected in actual traffic congestion. These vehicles are followed by cars controlled by driver models, within which the host vehicle is controlled by the test subject. When the speed of forward vehicles increases, the driver cannot tell the difference between a temporary speed-up or the end of congestion, as in the real world. However, when the end of congestion is reached, the driver is so informed and prompted to do “effective acceleration.” Researchers are evaluating aspects of driver behavior, driver understanding, compliance to advisories, and overall acceptance. Obviously, traffic flow benefits will only occur if the drivers adhere to the advice given.

In the experiments, subjects drove on a highway course of 30 km length. They were provided with data such as the distance and time until the end of the congestion. It was noted that, within the congestion, this data led to significantly smoother driving (i.e., less braking and acceleration).

However, at the end of the congestion, the advisory message to accelerate was not well understood by the subjects and its effectiveness for restoring traffic flow could not be evaluated. To implement such a tighter interaction between driver, vehicle, and traffic, other strategies will have to be devised to best integrate the three. However, it should be noted that, by the time such systems are implemented, most drivers will be experienced with driver assist technologies and are therefore more likely to comprehend such messages.

Dissipating Congestion via ACC [54] Computer simulations supporting the traffic performance assistance portion of INVENT have addressed topics such as fuel consumption and changes in travel time and capacity depending on penetration of equipped vehicles. Contrasting with the PATH work described above, which addresses free flow conditions that may move into breakdown, INVENT simulations have examined ACC-based-assist in congestion dissipation. A software model of its Congestion Assistant controller was integrated in a traffic simulation tool, which incorporated real measured congestion data for the leading (tracked) vehicle. Within the congestion, and with a typical stop-and-go ACC activated, good following behavior was observed, as expected. However, when both vehicles were leaving the congestion the distance between the two cars increased to almost 100m,

with a headway of 5 seconds. This type of behavior would be unacceptable to drivers and lead to a slow dissipation.

A new set of rules was devised for the Congestion Assistant controller, such that it would transition more nimbly to highway-speed ACC under congestion dissipation conditions. This allowed for the subject vehicle to accelerate essentially in lock-step with the leader vehicle, an ideal condition for dissipation.

Congestion Assistant Vehicle System Within the German INVENT program, a Traffic Congestion Assistant vehicle being prototyped and evaluated provides full driving control, under limited conditions, in stop-and-go traffic. Image processing and short- and long-range radar are used to detect lane markings and obstacles, respectively, as shown in Figure 9.8.

Specifically, the TCA functions are to detect forward vehicles and the lane ahead and perform ACC and lane-keeping. This includes automatic speed reduction and stopping, based on the leading vehicle's motion, as well as automatic resumption of forward motion after a short duration stop (for longer stops, the driver is signaled to activate resumption). The driver always retains the ability to override the system.

The TCA, then, comes close to providing a fully automated driver support in tedious congested driving conditions—although still several years away, this type of system is expected to be a huge hit with the driving public. If you cannot make the traffic jam disappear, it can at least be less irritating when the car is doing most of the driving.

9.7.4 STARDUST Analyses [55]

The effects of ADAS systems such as those discussed above were analyzed for a variety of traffic situations in the European 5FW Stardust project. STARDUST combined analysis at the behavioral, microscopic and macroscopic level, even providing traffic impacts for specific European cities. A key research result was to recalibrate

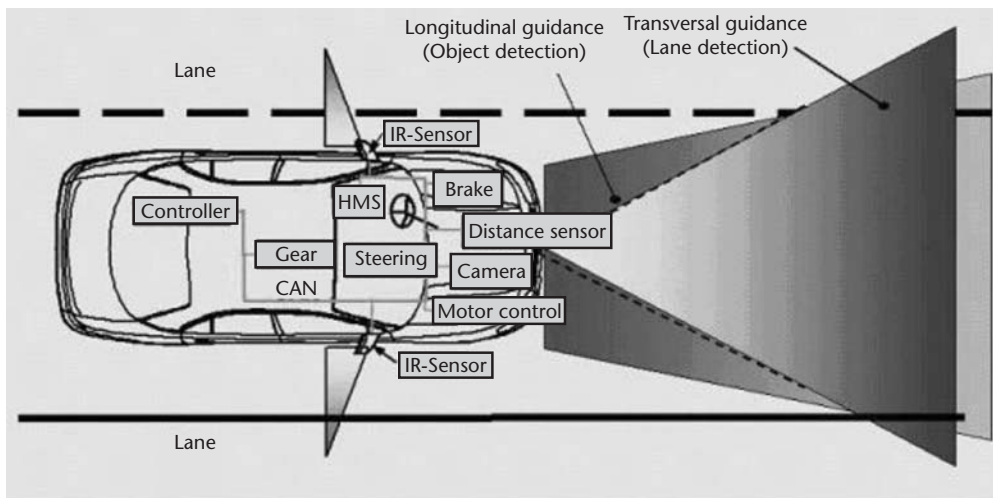


Figure 9.8 INVENT Traffic Congestion Assistant design [49]. (Courtesy: INVENT.)

large-scale traffic simulation models to accommodate the functional behavior of ADAS systems.

Using a driving simulator, researchers examined the effects of narrow lanes that might be created by restriping existing roads to create more total lanes to reduce congestion. The concern was that speeds of unassisted drivers would be reduced in narrow lanes, eliminating the flow benefits of creating them. Researchers found that more subjects maintained their average speed using lane-keeping assistance as opposed to driving in unassisted mode, showing a benefit for using lane keeping in these circumstances.

The impact of using stop-and-go ACC at signalized intersections was also investigated using driving simulators. Results showed that flows can be increased by up to 29% with all vehicles equipped with the system, due to shorter reaction time of the vehicles in startup. This simulation was performed with a conceptual stop-and-go ACC system, such that this result should only be viewed as an indicator of real world performance.

Traffic simulations were performed that incorporated the use of both high- and low-speed ACC on motorway segments. On the segments examined, trip times were reduced by up to 15%. Simulations were also performed at the level of entire traffic networks for the cities of Brussels, Oslo, and Southampton. The use of combined high- and low-speed ACC showed reduced network journey times, depending on penetration levels. At an 80% penetration level, network journey times were reduced by up to 6%, depending on the city and the assumptions used.

9.8 Business Case and Deployment Projects

To “put it all together” and provide the reader with a holistic sense for how CVHS is moving forward, this section addresses deployment activities in several parts of the world. Initiatives from the commercial sector (both automotive and telematics), the public sector, and the research domain are discussed.

9.8.1 Automotive Deployment for Cooperative Systems [7, 56]

There are numerous issues and challenges facing the automotive industry in bringing cooperative systems into usage. The situation is quite different in the three major automotive markets. Government and industry work quite closely together in Japan, and the government plays a major and reliable role in deploying roadside communications infrastructure. Their Vehicle Information and Communications System, for instance, now has 14.5 million units in use, for instance. In the United States, deployment of electronic infrastructure of any sort is up to the individual state DOTs. The U.S. DOT generally plays a facilitator role, using federal funds for leverage in some cases. The U.S. government works mainly in a collaborative fashion with the automotive industry in matters pertaining to ITS, as evidenced by the Vehicle-Infrastructure Integration initiative outlined in Section 9.8.3. The availability of dedicated spectrum for ITS DSRC in the United States greatly enhances the deployment process there. In Europe, the situation could be said to be most challenging for CVHS. While the EC plays a facilitator role to some degree, the various national governments in Europe are fundamentally independent. Rollout of electronic infrastructure cannot be depended upon, at least to

the degree required in selling automobiles to consumers who expect their IV systems to work wherever they may drive.

Generally speaking, automakers also contend that safety applications alone are not sufficient to justify the cost of integrating communications systems into vehicles—there must be additional applications as well. They are looking for attractive business models, in which either their customers desire features based on CVHS, or a cost advantage accrues to the manufacturer, or both. Further, it is absolutely necessary that CVHS features provide immediate benefits to both customers and the manufacturer; they cannot wait for either other cars or the roadside to be equipped for communications.

One deployment strategy under consideration is to provide “single vehicle applications” initially that rely on early forms of spot beacon systems (such as intervehicle hazard warning) or entertainment downloads. Entertainment downloads could be accomplished while the vehicle is parked in the owner’s garage, for instance, to download news and music overnight to which the owner could listen during the morning commute. Within as little as three years after introduction of vehicles equipped with single-vehicle applications, analyses show that sufficient numbers of equipped vehicles would exist such that multivehicle safety applications could then begin to function.

Car2Car Consortium Because an infrastructure-based communications solution is unlikely in Europe, vehicle-vehicle communications are seen as the more likely deployment route. In fact, in 2004 European auto manufacturers joined together to create the first cross-industry vehicle-vehicle communications capability, via the Car2Car Consortium. Consortium members are BMW, DaimlerChrysler, Fiat, Renault, and Volkswagen (including Audi). The consortium intends to build upon the CarTALK and FleetNet projects described in Section 9.1 by defining common technical standards and advocating frequency allocations for intervehicle communications. The systems would warn of conditions such as fog, icy roads, or stopped vehicles in the road, using the intervehicle hazard warning concept as well as the “car hopping” communications approach described in Section 9.1. to extend the communications range. The strength of the Car2Car Consortium is that, with this many car companies working together, a fair degree of fleet penetration can occur at a reasonable pace.

9.8.2 Commercial Telematics CVHS Activities [57, 58]

Telematics, in which drivers or vehicles receive information services via Internet connections, overlaps with the CVHS domain. Generally, telematics services are oriented towards convenience, trip planning, or shopping, whereas CVHS is focused more on vehicle operation and control. At a fundamental level, though, they are both about information flowing in and out of vehicles to improve the travel experience. For this reason, two telematics initiatives are discussed here.

In Japan, the Internet ITS Consortium, introduced in Chapter 4, is driven by a vision to “network all cars to create a new society.” The consortium is developing services such as traffic information, weather information, vehicle management, and parking lot services in the early years, and safety-oriented services in later years. It is also focusing on developing business models and standardization to facilitate successful deployment of these services.

In Europe, the Global Systems Telematics (GST) project is underway as part of the 6FW program. The GST vision calls for all future vehicles to be equipped with various communication technologies to interact with each other and their environment based on a common architecture and standard interfaces. Drivers and occupants would benefit from an onboard, integrated telematics system to access safety, efficiency, and convenience services wherever they drive in Europe. Further, these services will be accessible with a single system, through a single service provider. The in-vehicle telematics units will also enhance autonomous vehicle systems, by enabling updates of onboard information such as maps and road conditions.

A key focus of GST is to create an open and standardized framework architecture for end-to-end telematics. The openness relates to the ability of the architecture to support (multiple) existing and new bearers and protocols as well as common mechanisms for the removal, updating and installation of new services and applications. Standards are necessary for the key interfaces to enable the use of a wide array of supporting technologies.

Of GST's seven subprojects, two are particularly relevant to CVHS. The enhanced FCD subproject is developing new means for generating content based on vehicle reporting, and the safety channel subproject is developing a common broadcast mechanism for safety-relevant information.

9.8.3 Public-Sector CVHS Deployment Initiatives

Japan The Japanese AHSRA activities, described previously, are fundamentally CVHS approaches. Based on the results of field operational testing, the Japanese government is now moving toward system deployments with its Smartway program. DSRC will form the core of this vehicle-infrastructure communications strategy. Smartway is designated as a national strategy aimed toward the objective of zero traffic fatalities.

As illustrated in Figure 9.9, Smartway will support the user services defined by AHSRA, as well as integrating map updates, floating car data, road management, driver support at road sags, and private sector information services. A particular focus will be to provide driver support for elderly drivers. Eventually, vehicle-vehicle communications will be supported as well.

As shown in Figure 9.10, Japan intends to have high-bandwidth DSRC to support these services widely deployed in the 2007 timeframe. The Japanese government and auto industry plan to work closely together to achieve the full vision of CVHS.

Vehicle Infrastructure Integration in the United States [40, 59] Perhaps the most significant ITS initiative within the United States currently is the U.S. DOT VII activity. VII aims at achieving the safety benefits of cooperative systems and breaking through the chicken-and-egg conundrum by facilitating synchronized nationwide deployment of communications equipment on roadways and in new production vehicles. VII, which began in 2003, has brought together state transportation departments with auto manufacturers for intensive examination of the feasibility of this vision and, if promising, the development of an implementation strategy. The goal is to make a decision about full-scale deployment by approximately 2008. If a green light is given, an approximately five-year deployment phase would begin in the 2010 timeframe.

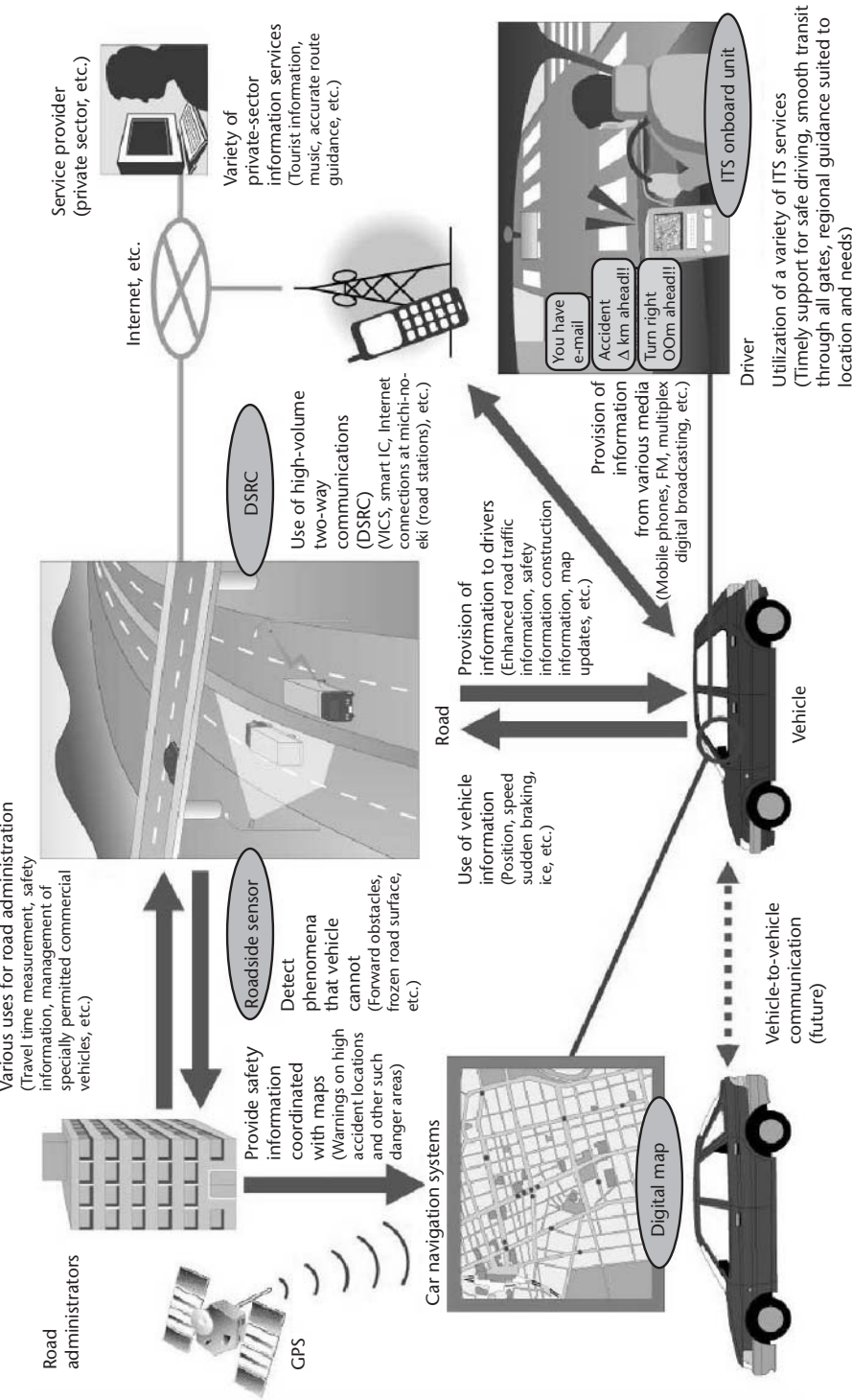


Figure 9.9 Japanese vision of Smartway deployment. (Source: NILIM, Japan.)

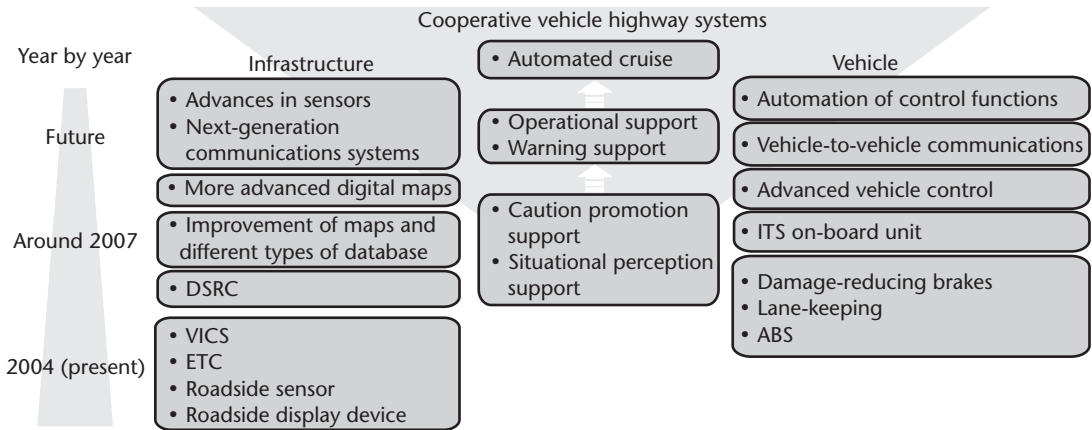


Figure 9.10 The Japanese roadmap for CVHS deployment. (Source: NILIM, Japan.)

Automakers participating in VII are BMW, DaimlerChrysler, Ford, General Motors, Honda, Nissan, Toyota, and Volkswagen. In general, VII is valuable to OEMs because it creates a communications “pipe,” (i.e., an ongoing connection with their customers after sale of a new vehicle). This gives the OEM enhanced access to the customer, enabling many potential business opportunities and customer relationship management. The fundamental motivator for most OEMs is the enhanced safety enabled by cooperative systems; however, safety may not be the primary business case enabler in the near term.

All 50 state DOTs are involved in VII via representation by the American Association of State Highway and Transportation Officials.

The benefits of VII deployment are seen as enhanced safety, improved mobility (based on more and better data), and the enabling of new private business activity. Key application areas are safety (primarily intersection crash countermeasures), collecting road information via floating car data, and providing traveler information. As with the automakers, the U.S. DOT sees safety as the top priority in the long term; the other applications are seen as “stepping stones” that may be important to deployment and the business case.

With regard to VII applications, the U.S. DOT is now looking at two categories of applications:

- **Localized:** This application set is characterized by the need for secure and highly local communications with locally relevant information. Localized applications would include intersection collision avoidance, work zone alerts, and highway-rail crossing warnings.
- **Network:** This application set is more oriented to broadcast and can be served by a variety of communications methods (e.g., cellular and satellite radio). Network applications would include floating car data techniques and traveler information.

A vast array of challenges and unanswered questions face VII and will be addressed in the coming years. These include the following:

- Who owns, installs, and operates the communication system(s)?
- Who owns and operates the real-time transportation information database?
- How will drivers respond to sharing information?
- How will data privacy concerns be addressed?
- How will liability be assessed if systems malfunction?

The U.S. DOT's work in DSRC, described in Section 9.1, is a major component of VII, as is the intersection collision avoidance R&D described in Section 9.5.

9.8.4 U.K. CVHS Study [60]

The U.K. Department for Transport has engaged in studies of CVHS since 2003. The study objectives are to do the following:

- Determine whether CVHS is a viable strategic concept;
- Develop an overarching strategy for the implementation of the CVHS vision;
- Develop business cases for CVHS at the appropriate level;
- Identify the issues that must be addressed for CVHS and proposing methodologies for addressing them;
- Verify CVHS concepts with stakeholders;
- Provide advice on the implications of CVHS for wider government policy;
- Propose a methodology for the management, coordination, and monitoring of research.

Researchers are developing scenarios, addressing policy and legal issues, and conducting financial and economic analysis.

Five settings have been identified:

- Motorway and high-speed grade separated roads;
- Rural high-speed roads;
- Suburban arterial roads;
- Suburban roads;
- Urban city centers.

To support the analysis, the following representative functional bundles have been defined:

- “Safety and network Support”—Including ISA, ramp metering, mayday, LDWS, collision warning, and autonomous vehicles;
- “Medium-tech”—Consisting of collision warning and assistance, lane keeping, stop-and-go ACC, electronic towbar, and motorway access control;

- “High-tech control and assistance”—Consisting of platooning, intelligent merging, intersection collision avoidance.

These bundles have been mapped to the settings to gain a sense of the issues involved. Particularly challenging policy issues that have been identified thus far include the following:

- Setting a framework of responsibility and liability for systems that are not completely controlled by the driver;
- Gaining the confidence of the public for the use of information essential to CVHS services;
- Finding the best balance between mandating functionality and allowing market forces to drive CVHS development, (i.e., how to best engage the auto manufacturers);
- Enforcement of vehicle standards and the use of controlled highways;
- The shift to an automated travel system and the implications of the high safety standards needed;
- Developing and delivering an operational network with sufficient speed to promote market success.

Development of business cases and an implementation roadmap are currently under way.

9.8.5 CVHS Deployment Research Initiatives

Many of the research initiatives described in this and previous chapters have examined deployment as well as technical issues. Some of their results are outlined here.

ASV Phase III [61] In Phase III of the advanced safety vehicle program in Japan, development of an intertraffic communications system is planned that would be independent of any roadside infrastructure and effective even at market penetrations less than 100%. Analyses have shown that such a system could result in avoiding 2,500 fatal collisions and 25,000 serious injuries each year.

Data such as driver intention, steering and braking operation, bus movements, and emergency vehicle presence would be communicated by the system. Initially, ASV engineers will define the required system performance and address spectrum allocation issues. Verification testing planned for 2005. The work is geared toward onboard systems expected to be available in cars by 2008.

Vehicle Safety Communications Consortium [4] Within the VSCC project in the United States, benefits accruing from deployment of applications were analyzed based on the fifth year after deployment, which allows some time for the communications devices to proliferate within the vehicle fleet. The analysis listed near-term applications offering the greatest benefits, in priority order, as follows:

- Traffic signal violation warning;
- Curve speed warning;
- Emergency electronic brake lights.

Mid-term applications offering significant benefit were listed as follows:

- Precrash warning;
- Cooperative forward collision warning;
- Left-turn assistant;
- Lane-change warning;
- Stop sign movement assistance.

Near-term application systems were considered to be deployable in the U.S market between the years 2007 to 2011 and mid-term application systems between the years 2012 to 2016.

French ARCOS Research [28] In the French ARCOS program, described previously, the full potential of CVHS has been depicted in its “target 3,” which is seen as a long-term evolution of CVHS. Target 3 is illustrated in Figure 2.9. Based on extensive vehicle-vehicle and vehicle-infrastructure communications, this future scenario includes the following:

- Knowledge of a “precaution perimeter” based on sensing;
- Knowledge of visibility conditions and road friction downstream;
- Knowledge of downstream traffic (both local and macro-level);
- Access to a dynamic network database relating to traffic, road, and weather conditions, enriched by floating car data information;
- Ability to calculate “risk functions” based on the above information;
- Ability to dynamically determine a “control law” to maintain a safe intervehicle distance.

Dutch TRANSUMO [62] As described in Chapter 4, TRANSUMO is a Dutch government R&D program whose IV component focuses on integrated and cooperative systems. TRANSUMO researchers are addressing challenges such as defining human-centered functional concepts; assessing the outcomes of these concepts on driving, safety, and traffic performance; assessing the value of the outcomes in the eyes of key stakeholders; and developing implementation strategies and policies.

The first major problem area considered is that of private cars on a typical motorway corridor with heavy congestion. The researchers are examining the safety, traffic, and environmental effects of next-generation ADAS systems such as full-speed range ACC integrated with lane-keeping, as well as cooperative modes between vehicles.

A pilot project now being defined will address the role, needs, and wants of the driver; a business case for in-vehicle intelligence; and a development path toward a future intelligent road-vehicle system. Specific activities within the pilot will include the following:

- On-road pilot testing with ADAS-equipped vehicles, including data logging instrumentation;

- Using a driving simulator to estimate and understand driver behaviors and feed development of the driver model;
- Development of a driver model capable of the control, maneuvering, and strategic levels of the driving task;
- Performing computer simulations, incorporating the driver model, that can extend pilot testing results across the entire network;
- Investigation of local, vehicle-based traffic management techniques (similar to the INVENT program);
- Identification of forms of intelligent speed control, and evaluations in terms of human factors, safety, and traffic effects;
- Generating qualitative estimates of the effect of speed-support systems on traffic safety;
- Investigation into traffic management, design and control with IVs.

Preliminary results of traffic and driver simulations, and the initiation of the on-road pilot, are expected in 2005.

9.9 Summary

Both the promise and the complexity of CVHS can be deduced from this rather lengthy chapter. Rather than lengthening it further, I offer that the main messages regarding CVHS offered here are the following:

1. CVHS can improve the performance of the entire road-vehicle system in terms of both safety and traffic performance.
2. After years of talk, the automotive industry and governments worldwide are now making substantial moves toward implementing vehicle-vehicle and vehicle-roadside communications.
3. CVHS itself is now established as the next wave of ITS.

As the Internet opened up new worlds, bringing vehicles into the connected society will open up a vast array of new services and features for vehicle owners, driven by entrepreneurial creativity and market forces. With our vehicles exchanging information and using highly accurate digital maps, our travel will be safer and more precise. The final “gap” in the wireless world will be bridged.

Chapters 10 and 11 examine specialized forms of CVHS. Chapter 10 relates to vehicle control in terms of fully automated vehicles, and Chapter 11 focuses on the information side to describe FCD techniques.

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Fully Automated Vehicles

Who among us has not been driving down an empty stretch of highway and found ourselves wondering, “Why can’t my car be programmed to do this simple job?” In fact, the concept has been around since General Motors presented a mock-up of an automated vehicle highway system at the 1939 World’s Fair.

The eventual evolution of our road transportation system leads inevitably to fully automated vehicle operations for most situations. Surely, the driver in communion with a sporty roadster on a sunny Sunday afternoon will always be an option. However, for routine driving—commuting, freight movement, passenger shuttles—automated operations just make sense. Automated vehicles are more orderly and fully coordinated, labor costs are reduced for commercial operations, and convenience (and relief from drudgery) is at its peak. Moreover, as we saw in Chapter 9, mobility increases dramatically to the extent that vehicles can automatically coordinate their movements, removing human lag times and perceptual limitations from the vehicle operation control loop.

However, this evolution relies on one major caveat—the vehicle automation systems must be exceedingly robust and reliable. The public must have the same confidence in automated vehicles that they have now in elevators, for instance. The systems must be many times more robust than our personal computers. The vehicles must behave in ways that make sense to the occupants to earn their trust. Further, they must see a clear benefit—in safety, mobility, or convenience—to invest in such systems.

When these systems were first conceived, they were called Automated Highway Systems because of the implicit assumption that the system intelligence would be shared between the vehicle and the infrastructure. Research began in the late 1950s along these lines and continued intermittently into the early 1990s. At that time, the research focus began to shift toward ever more intelligence within the vehicle, due to the rapid evolution of information processing systems and sensor technology, such that by the end of that decade it was clear that the roadway would play a largely passive role. When the technology is ready in terms of cost and performance, automated vehicles can most likely be introduced to the market with no changes required of the roadway at all. To increase robustness, magnetic markers may be added, particularly in areas of severe winters in which the painted lane markers can be obscured by snow and ice.

In the long term, roadway operators do play a key role unrelated to highway electronics by providing dedicated lanes for automation vehicle operation. In this way, the maximum traffic flow benefits are achieved. If we could start with segregated lanes in the first place, the technical challenges would be lessened, as all

vehicles would be communicating and under computer control. For passenger cars, however, the most viable deployment path calls for operation in mixed traffic initially, until market penetration reaches levels that justify lane dedication. For trucks and transit buses, however, the case can be made for segregated lanes, as described below.

In fact, given what we know now, a likely scenario for automated vehicles would be dedicated lane operations with the following technology package:

- Surround sensing (already on vehicle for precursor safety systems);
- Lane detection augmented by magnetic markers in road for severe winter areas;
- “Drive-by-wire” technology for electronic actuation of throttle, brakes, and steering;
- Intervehicle communication;
- Communication between vehicles and a traffic operations center for flow management;
- Operation on a dedicated lane.

Fully automated vehicles for specialized applications were successfully deployed in the 1990s. Mine-hauling trucks were equipped for unmanned operation by Komatsu in Australia, servicing large tracts of open pit mining, and the port of Rotterdam implemented shuttle vehicles for moving freight containers from shipside to storage areas. For people-moving, Frog Navigation Systems implemented the ParkShuttle, a “horizontal elevator” concept to carry people from satellite parking to the terminal at Amsterdam’s Schipol Airport. Additional systems have since been deployed, and new types of services are emerging as well.

The following sections review activity in vehicle automation for passenger cars, trucks, and public transport.

10.1 Passenger Car Automation

10.1.1 Highway Automation

Highway Automation R&D Worldwide During the 1990s, the fundamental capability for passenger car automation was proven in both Europe (PROMETHEUS program), Japan (AHSRA), and the United States (AHS program). The European approach relied completely on vehicle intelligence, whereas the Japanese approach was highly vehicle-highway cooperative. The U.S. approach encompassed both techniques.

In Japan, vehicle automation was first demonstrated in 1996, and a variety of active safety and automation systems were demonstrated in Demo 2000. In addition, platooning techniques were developed and demonstrated by the Mechanical Engineering Laboratory within the Japanese METI.

In France, LIVIC and its partners conducted the Route Automatisée project from 1997 to 2001, examining potential performance gains and deployment paths relating to automated vehicles [1]. The work focused on the following:

- Safety functions for rural roads;
- Automated highways for trucks;
- Suburban automated highways for passenger cars;
- Guided paths in urban areas.

Low-speed automation, requiring minimal infrastructure support, was seen as a first step. This would, over time, lead to higher speed operation on dedicated lanes. These activities would run in parallel with increasing active safety functionality and the advent of intervehicle communications and vehicle-infrastructure communications. As dedicated lanes proliferated, automated road networks would come into being and road managers could optimize traffic flows for portions of the road network. The final and ultimate stage would see all new infrastructure dedicated to automation and all new vehicles equipped to operate in automated mode.

For passenger cars, LIVIC performed extensive analyses of the safety and capacity trade-offs inherent with vehicle platooning. The overall themes of LaRA have continued, with safety functions being pursued in the ARCOS program, truck automation deployment studies (described in the next section), and CyberCar urban guided vehicles (described in Section 10.4).

U.S. AHS Program [2] The AHS work in the United States is further described here as representative of the full range of approaches to passenger vehicle automation.

The U.S. DOT AHS program was initiated in 1992 with a broad set of paper studies encompassing technology, transportation operations, and societal issues. In 1994, the NAHSC was established, led by General Motors and including Bechtel, California DOT, California PATH, Carnegie-Mellon University (CMU), Delco Electronics, Hughes Electronics, Lockheed-Martin Corporation (LMC), and Parsons-Brinkerhoff.

Based on a Congressional mandate, the purpose of the NAHSC was to design and implement an AHS prototype intended as the blueprint for future deployed systems to increase safety and road capacity. The mandate included a requirement to demonstrate this capability by 1997. During the following three years, the NAHSC consulted extensively with stakeholders to define several AHS concepts and assess their impacts and deployment paths. The NAHSC work culminated with Demo '97, which showed 21 cars, trucks, and buses operating on the segregated carpool lanes of Interstate 15 in San Diego. Vehicles were also provided by Toyota, a combined Honda/Ohio State University (OSU) team, and Houston Metro (bus transit authority). Several thousand people experienced automated vehicle operation during the event.

In Demo '97, several freeway scenarios were demonstrated, including lane changes, obstacle avoidance, and close-headway platooning, all under fully automated control. Segregated and mixed-traffic operations, as well as both autonomous and cooperative systems, were shown. Their robustness, albeit under controlled conditions, is indicated by Table 10.1. Cumulatively, these vehicles completed almost 8,000 miles of demonstration rides with no malfunctions.

Several images of the Demo are included here. Figures 10.1 and 10.2 provide a sense for the very tight intervehicle spacings in the platoon scenarios. Figure 10.3 gives an example of the several different types of driver interfaces used in the demo.

Table 10.1 Vehicle Automation Scenarios in Demo '97

<i>Demo team</i>	<i>Approach</i>	<i>Number of automated vehicles</i>	<i>Automated Vehicle-miles traveled</i>	<i>Autonomous versus cooperative operation</i>	
				<i>Lateral control</i>	<i>Longitudinal control</i>
GM/ Delco/ PATH	Platooning at ~6m headways using radar, intervehicle communications, and magnetic markers for lateral reference	8	3040	A	A
CMU/ Houston Metro	Automation of cars and transit buses using radar, machine vision, laser scanners, and intervehicle communications	5	1900	A	A/C
Cal. DOT/ LMC	Automated "maintenance vehicle" for AHS operations referencing magnetic markers	1	380	A	-
Honda/ OSU	Vehicles capable of shifting from magnetic markers to autonomous lane detection while platooning; longitudinal detection via laser range-finder and radar	2	760	A/C	A/C
Toyota	Automated cars based on laser radar and machine vision	2	760	A	A/C
Eaton- VORAD	Precursor to automation based on ACC for trucks	1	380	-	A

Figure 10.4 shows typical components installed in the trunk of a demo vehicle. Figure 10.5 shows the vision sensing system used by Honda as an example of the technologies used at that time.

Demo '97 proved the technical feasibility of vehicle automation, setting the stage for the extensive further work needed to produce highly reliable and affordable systems required for market introduction. Further, based on extensive media coverage, the demo communicated to a worldwide audience that automated vehicles, rather than being a distant fantasy, are realistic and on the way.

Shortly after the demonstration, the vicissitudes of federal funding came into play and the AHS program was terminated as being too long-range in scope. AHS R&D results subsequently became part of the foundation for the U.S. DOT IVI, which was more short-term and safety-focused. The termination of the U.S. AHS program was unfortunate, but at the same time it should be noted that its genesis, in the form of the congressional mandate, was a bit of a miracle for the early 1990s.



Figure 10.1 PATH vehicles in platoon formation at 60 mph during Demo '97. (Courtesy of California PATH.)



Figure 10.2 A perspective indicating tight intervehicle spacing within platoons at Demo '97. (Courtesy of California PATH.)

The technical advances made during the program have since disseminated into the development of the myriad active safety systems described in previous chapters.

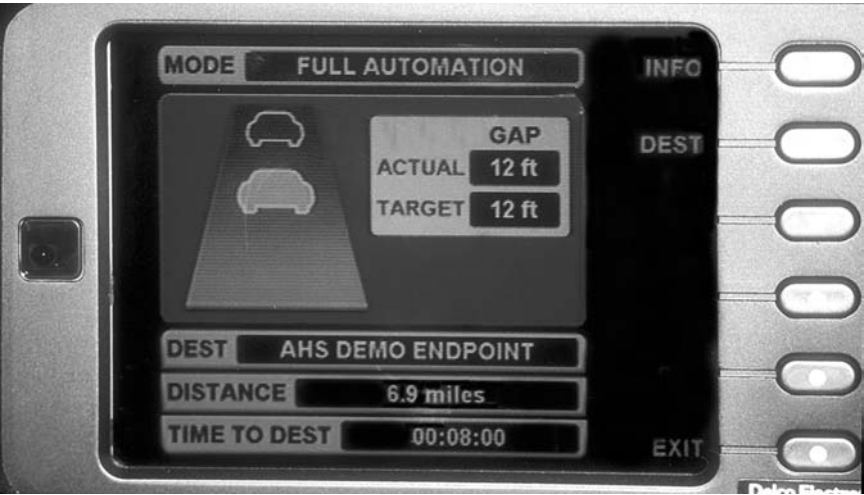


Figure 10.3 In-vehicle display for PATH automated vehicles at Demo '97. (Courtesy of California PATH.)

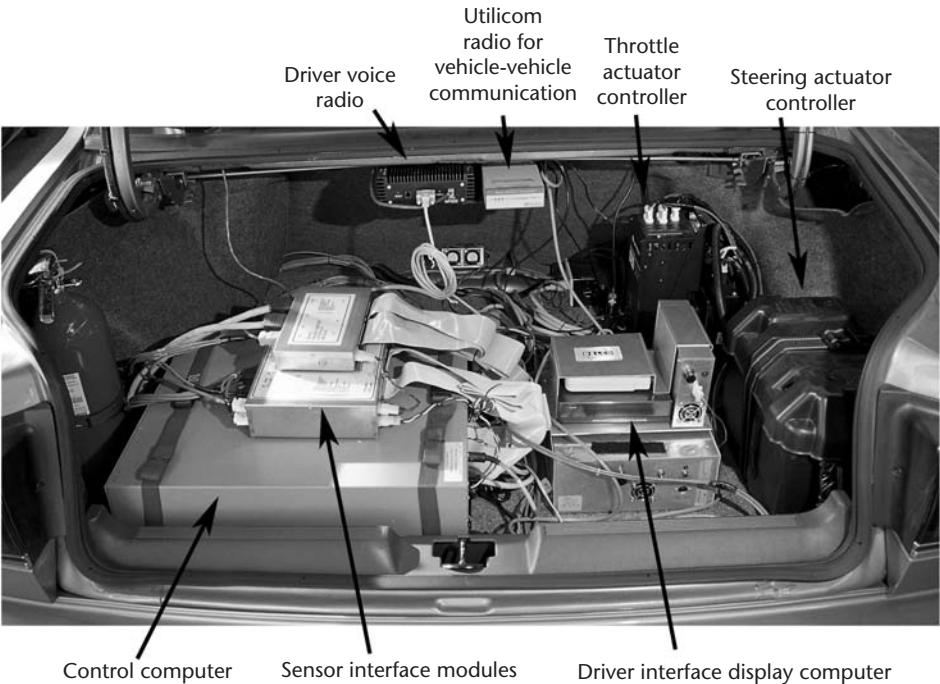


Figure 10.4 Electronic components in the trunk of a Buick LeSabre platoon vehicle. (Courtesy of California PATH).

10.1.2 Low-Speed Automation [3]

An early version of automated vehicle operation is expected to evolve from stop-and-go ACC combined with lane-keeping. In highly congested traffic, these functions would essentially comprise low-speed vehicle automation. The situation is



Figure 10.5 Camera system used in Honda vehicles at Demo '97. (Courtesy of California PATH.)

somewhat less challenging for the technology since the speeds are lower and the variables are fewer than with full-speed operation on the highway.

Automatic initiation of forward motion is seen as high risk, however, even with forward sensing. What if, however unusual it may be, a pedestrian or obstacle enters the vehicle's path after a stop, and vehicle sensors do not properly detect it? For a vehicle to move forward on its own and cause harm must be avoided at all costs. Therefore, product developers insist that some indication of driver intent is required for low-speed automation, at least initially. The traffic congestion assistant vehicle being developed within the German INVENT program, described in Chapter 9, is one of the first implementations of this concept.

10.1.3 Ongoing Work in Vehicle-Highway Automation

Chinese researchers are developing an Intelligent Highway System (IHS), which is defined as "an integrative system which is based on the road infrastructure and provides the vehicle with information services, safety alert, and automated operation" [4]. Such a system would rely strongly on an intelligent road infrastructure and incorporate cooperation between roads and vehicles. Human factors comprise one particular emphasis area.

An incremental evolutionary approach is planned, with an initial emphasis on safety assistance via driver information systems and, later, control systems. In a subsequent phase focusing on both safety and traffic efficiency, automatic driving would be employed.

A prototype IHS test system is being developed by ITS China in the proving ground for highway and traffic (PGHT) of the Chinese Ministry of Communications (see Figure 4.3). Current research focuses on automated lane-keeping based on

magnetic markers in the road and in-vehicle devices working cooperatively. Data flows for both assisted and automated operations are shown in Figure 10.6.

10.1.4 User Attitudes Toward Automated Vehicle Operations

Various surveys have been conducted regarding user acceptance of, and concerns about, automated vehicle operation. For instance, participants at Demo '97 gave a quite high rating to the systems shown there. In general, though, such surveys suffer from the limitation that the respondents have not experienced such a system. Given this caveat, some results are nevertheless interesting.

During 2000-2001, the U.K. Highways Agency funded a study to assess user acceptance of AHS, including people's reasons for or against such a system [5]. Three basic stages were presented to survey participants: enhanced driver information, driver assistance with partial vehicle control, and fully automated control. A total of 646 interviews were performed, of which 20% were with either heavy truck or motorcoach drivers.

Not surprisingly, two clear groups emerged: those who accept relinquishing control to the vehicle and those who do not. This type of opposition is a philosophical stance that will not be addressed with information, only through experience with proven systems.

Fifty-four percent of the participants could envision such a system, 22% were a "maybe," and 24% did not see it happening. If such a system did come into being, 60% said they would use it, 24% were a "maybe," and 15% responded negatively.

The respondents who accepted the concept of a fully automated highway saw the benefits as reduced road congestion, uniform speed, and greater certainty and predictability of trip times. Within the total group, four main concerns were voiced regarding AHS: system reliability, surrendering control, cost to the government (i.e., impact on their taxes), and the personal cost of purchasing a system.

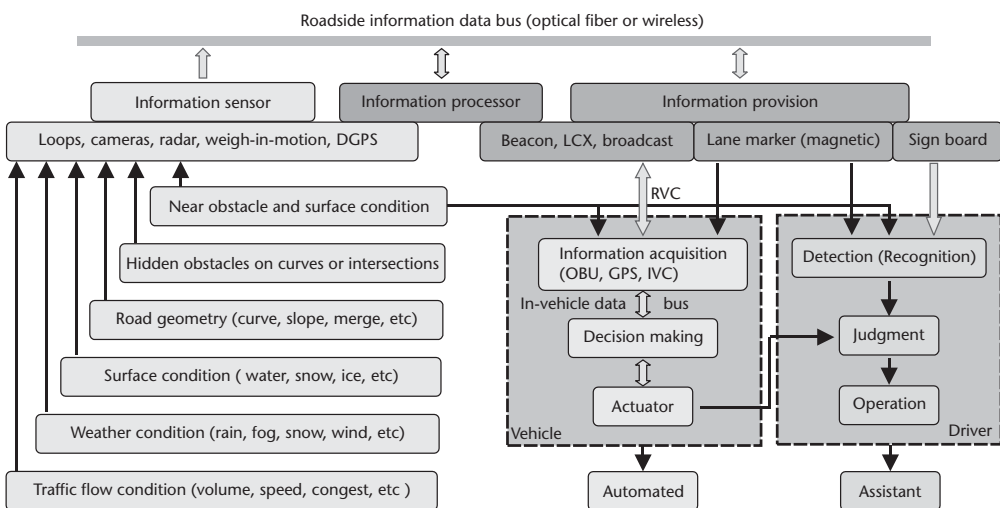


Figure 10.6 Data flows for China's IHS. (Source: National Center of ITS Engineering & Technology, China.)

10.2 Truck Automation

10.2.1 Electronic Tow-Bar Operations and Driver Assistance

CHAUFFEUR Project [6–8] The European CHAUFFEUR project focused on the development of “electronic tow-bar” technology (i.e., the ability of heavy trucks to follow one another in automated platooning mode). CHAUFFEUR, initiated in the mid nineties and completed in 2003, was led by DaimlerChrysler, with IVECO, CRF, and Renault as major partners.

Benefits for electronic tow-bar operations explored in the program included the following:

- Reduced fuel consumption (up to 20%);
- Reduced environmental impact;
- Improvement of traffic flow;
- More comfortable working conditions;
- Increased safety.

There is additionally the potential for significant savings in labor costs in the far future, with trucks actually operating in an unmanned follower mode for regular commercial service.

The electronic tow-bar system relies on intervehicle communication (5.8-Ghz) and the detection of a pattern of infrared markers on the back of truck trailers, in addition to standard radar and vision sensing. In this application, only the leading vehicle is driven by a human driver, and the “towed” vehicles are completely operated by a vehicle controller to follow the leader at a very close distance.

CHAUFFEUR2 demonstrated a three-truck platoon operating at highway speeds, with spacings of approximately 10m. Platoon coupling and decoupling, lane changes, acceleration from stop, and braking to a stop were among the maneuvers demonstrated. Significantly, DaimlerChrysler implemented this capability on a fully drive-by-wire (i.e., electronically actuated) vehicle. The design was tested in simulation for up to 10 trucks in the platoon.



Figure 10.7 CHAUFFEUR trucks in platoon mode. (Source: DaimlerChrysler AG.)

The platoon distance controller used inputs from IR image processing, onboard sensors, and sensor data from the lead vehicle and the immediately preceding vehicle. The lateral platoon controller used only the inputs of the IR image processing as the IR pattern was detected on the preceding vehicle. In this sense, the tow-bar functionality acted as a vehicle follower, as opposed to a road follower. In Figure 10.7, the circular IR pattern used for tracking can be seen on the rear of the lead truck.

Based on user needs studies, CHAUFFEUR2 also defined a Chauffeur Assistant function, in which the truck is able to follow any other vehicle at safe following distances. Chauffeur Assistant functions can be described as a combination of vision-based lane-keeping and enhanced ACC at short, but still safe, intervehicle gaps.

Brake performance monitoring was implemented in the Chauffeur Assistant to estimate available road friction. An algorithm based on wheel slip and engine torque provided real-time friction monitoring. Overall braking performance also took into account variations in stopping distances based on vehicle payload.

The CHAUFFEUR2 team examined a wide range of additional issues, including the following:

- Human machine interface;
- System evaluation;
- Safety concepts;
- Traffic simulations;
- Concepts for freight logistics;
- Cost/benefit analyses for the systems;
- User/customer acceptance;
- Legal and liability implications.

For example, Chauffeur Assistant vehicles were shown in traffic simulations to have up to a 2.5% improvement in lane capacity, and electronic tow-bar platoons were shown to be most viable in low traffic situations, given their tendency to impede lane changes for surrounding vehicles in more dense traffic.

While still some ways from entering the commercial market, the CHAUFFEUR project achieved a new level of capability in truck automation. The Chauffeur Assistant can be seen as relatively near-term, as truckers adopt mature ACC technology and marry that with new products in LKA. Implementation of truck platoons, however, is expected to take quite some time—many experts believe that this type of trucking operation would only be allowed on dedicated truckways, which have not yet been constructed (see next section).

California PATH Experimentation with Truck Platoons California PATH has been another focal point for truck automation technology. Here, researchers equipped three Freightliner tractors with full automation capability, including platooning. Evaluations were conducted to assess fuel consumption and emissions improvements with various platoon spacings.

An extensive technology suite was integrated onto the vehicles, including sensors, actuators, and communications systems as shown in Figure 10.8.

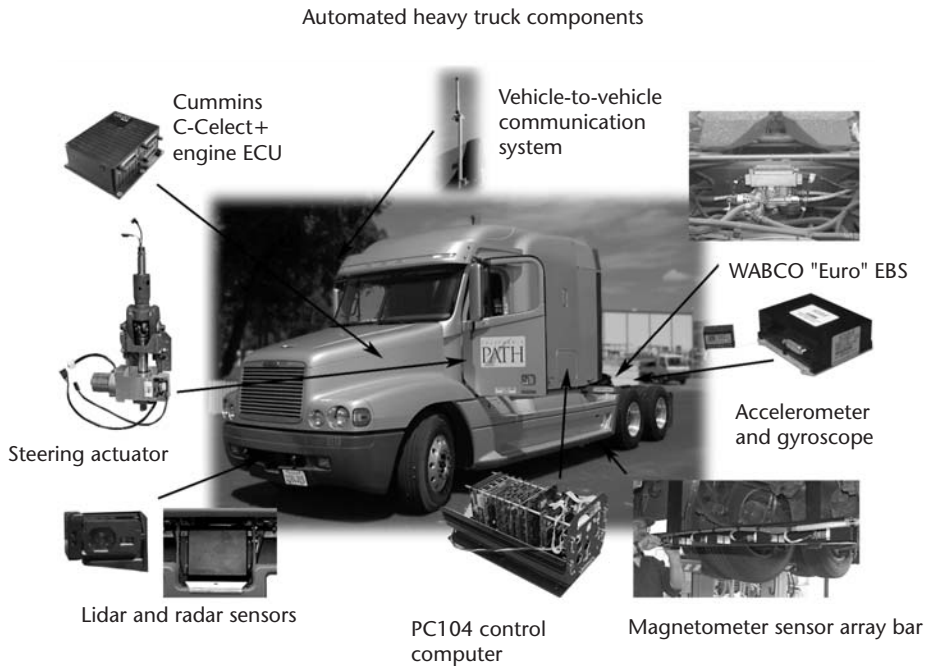


Figure 10.8 Technology suite on PATH automated truck. (Courtesy of California PATH.)

Improvements in fuel consumption on the order of 20% were measured due to platooning operations. For emissions, CO₂ reductions over 17% were noted for follower trucks at 4-m spacings. For NO_x, the lead truck gained the greater advantage, with reductions of over 4% at 4-m spacings.

10.2.2 Truck Automation for Long-Haul Application: Deployment Studies

In France, LIVIC is leading research regarding truck automation issues [9]. Interest is motivated by the freight movement situation there, in which trucks carry 80% of the goods, a figure that is increasing by 3.2% annually. Also, given France's location as a European crossroads, long-distance freight flows (150 km or more) comprise 75% of the ton kilometers. With 50% of truck travel on motorways, the potential of truck automation to address future demand (and lessen the burden on existing traffic) is high.

LIVIC has conducted a detailed assessment of truck automation deployment, including the following:

- Modeling and assessment at the vehicle level;
- Regulation;
- Nature and segmentation of freight transport;
- Business issues for freight carriers (including driver issues);
- Candidate deployment paths for progressive implementation;
- Assessment of candidate deployment paths.

Three scenarios were examined:

- Automated trucks operating in mixed traffic on existing motorways;
- Building new dedicated lanes for automated trucks along the existing motorways;
- Building new dedicated motorways for automated truck operations on new road alignments.

The first two options were rejected as impractical due to cost and space constraints, as well as a desire to avoid mixing automated trucks in or near regular traffic. The last option—building new motorways exclusively for automated trucks—was seen as worthy of further study. A 1,000-km motorway between Calais and Bayonne was defined (Figure 10.9), with one lane per direction plus an emergency lane. As an express highway, there would only be eight interchanges along this route, connecting to existing freeways.

Within this exclusive motorway concept, three scenarios were designed and considered as acceptable:

1. CHAUFFEUR-type operation with the formation of platoons outside the motorway (convoy statically constituted);



Figure 10.9 Proposed North-South automated truckway in France (shown as heavy bold line). (Source: LIVIC.)

2. CHAUFFEUR-type operation with platoons dynamically constituted on the motorway itself (convoy dynamically constituted);
3. Separate automated trucks (automated highways), with no interaction or coordination between trucks.

The researchers performed evaluations of traffic flow performance traded off against safety. The platooning simulation included the following parameters:

- Speed: 110 km/h;
- Interdistance between trucks in a platoon: 15m;
- Minimal interdistance between platoons: 45m;
- Homogeneous emergency braking inside a platoon;
- Reaction time for emergency braking: 0.4s;
- Four trucks per platoon.

Simulations were conducted for both a defined safety level 1 (no collision with hard braking by a vehicle ahead) and a more stringent safety level 2 (only minimal collisions in “brick wall ahead” case). These were compared against a base case of 1,000 trucks an hour, at 90 km/hr, for manual driving in such a facility, with the driver capable of safety level 1.

Platooning capacity for level 1 was shown to increase to 2,600 trucks per hour, with 1,800 trucks per hour for level 2. For the free agent automated truck scenario number three above, level 1 allowed 3,100 trucks per hour, with 1,800 trucks per hour for level 2. Therefore, a two- to three-fold increase in capacity is possible with truck automation, based on the simulations. Or in other words, a one-lane automated truckway could fulfill the same function as a two- or three-lane regular road. Given the safety constraints in the simulation, platoons did not show an advantage in lane capacity over the free-agent mode; however, platooning offers significant savings in fuel and reduced emissions.

What Would It Cost? Highways are notoriously costly, and the French truckway would be no exception. Total cost was estimated at over 6 billion euro, but at an average of 6 million euro per kilometer, these costs are in line with normal highway construction costs. Driver reactions were also assessed. Their prime values emerged as freedom, autonomy, and responsibility for the vehicle. They felt positive about the higher speeds possible with automation, as well as the option of sleeping while in automated mode if the systems were truly safe. Safety of the systems was a recurrent theme, as well as a desire to be able to take over control of the vehicle if they felt it necessary. The platoon concept was not well received, as it would require them to rely on the actions of other drivers if within the platoon, or pose too heavy a responsibility if they were the lead driver.

Why Not Put All This Freight on Rail? The full discussion is a complex one, but suffice it to say that some types of freight make most sense for rail, and other freight lends itself to trucks. In almost all cases, freight must get to its final destination by truck even if part of its journey is by rail. Therefore, a key factor in the truck/rail choice is the time and labor costs of load transfers between rail cars and trucks.

10.2.3 Automation in Short-Haul Drayage Operations [10]

The use of automated freight vehicles in Chicago for intermodal freight interchange was studied by California PATH and local partners under the cooperative vehicle-highway automation system (CVHAS) program. Chicago is a hub for freight movement in the United States because it is the meeting place of eastern and western U.S. railroad lines, as well as two Canadian railroads. Significant drayage truck traffic occurs between the rail-heads for the eastern and western railroad lines—the railroad gauges are incompatible, therefore freight must be off-loaded, trucked to the other line, and reloaded for freight passing through the region. Obviously, this creates a significant burden on the local road network.

In 1981, the physical feasibility of constructing truck-only lanes on available rail right-of-way to connect up to 12 of the major intermodal yards had been established. The PATH study examined the added benefit of automated truck operations on these lanes. Changes in freight flows since 1981 resulted in a modified plan; the researchers defined both a 44-mile short-term and an extended long-term alignment to serve rail yards, industrial parks, and regional points-of-entry.

Modeling was applied to represent issues such as the following:

- Vehicle travel times and container loading/unloading times;
- Distribution of container travel times to connect between terminals;
- Container capacity per lane of automated roadway;
- Interactions between automated freight operations and cross traffic;
- Capital and operating costs;
- Emissions and fuel consumption.

Based on traffic and other analyses, the following operational concept alternatives were chosen for further analysis:

- Alternative 1: Baseline concept (no CVHAS technologies, no truck-only facilities);
- Alternative 2: Truck facility without CVHAS technologies, open to all trucks, originally consisting of one standard 12-foot lane in each direction and a second lane added on key segments by 2015;
- Alternative 3: Narrow-lane truck facility exclusively for equipped trucks, with CVHAS-automated steering technology;
- Alternative 4: Narrow-lane truck facility exclusively for equipped trucks, with fully automated CVHAS technologies (automatic steering, automatic speed and spacing control with two or three truck platoons if warranted);
- Alternative 5: Time-staged automation:
 - Truck facility without CVHAS technologies before 2015;
 - In 2015, upgrading the facility to be an automated truck-way (automatic steering, speed and spacing control with two or three truck platoons);
 - One standard 12-foot lane in each direction to support manual driving in first phase.

In each of these cases, the truck lanes are accompanied by a shoulder lane to provide space to store any failed vehicles, thereby ensuring that a single failed truck does not block the entire facility.

For the cost-benefit analysis, several factors were considered:

- Travel time savings;
- Costs for equipping trucks;
- Automatic longitudinal control only versus full automation, adjusted for higher costs in the near term and lower costs in the long term, as related products proliferate in the trucking industry;
- Predicted annual growth rates in traffic demand;
- Narrower lanes for automated trucking;
- Reductions in fuel consumption (due to reduced aerodynamic drag based on platooning);
- Construction costs (between \$1.5 million and \$6.5 million per mile depending on local features);
- Right-of-way acquisition costs;
- Annual operations and maintenance costs;
- Option of charging tolls for conventional truck lane.

The cost-benefit analysis period was 20 years, from 2005 to 2025. Cost/benefits as compared to the “do nothing” baseline are shown in Table 10.2.

All new truck lane alternatives were determined to be cost-effective compared to the base case. Alternative 5 is particularly attractive since deployment of CVHAS systems occurs later, when vehicle costs are lower and traffic volumes higher.

One promising scenario of interest to the researchers, which may be examined in a future study, is the alternative of automated truck platoons with no drivers in following vehicles.

10.2.4 Insertion of Automated Truck Lanes in Urban Areas [11]

Various studies have been performed in southern California to examine how truck-only lanes could be inserted into that dense urban area to accommodate heavy freight flows, such as the numerous trucks traveling from the seaports to rail centers inland. For instance, creation of truck-only lanes on 61 km of highway SR-60 was studied and found to require extensive construction for two lanes per direction, including elevated roadways, with a cost estimate of \$4.3 billion. However, by

Table 10.2 Cost/Benefit Ratios for Truck Automation Options in CVHAS Chicago Study

<i>Alternative</i>	<i>Cost/benefit compared to the “do nothing” case</i>
Alternative 2 (truck lanes with no CVHAS)	3.78
Alternative 3 (automatic steering)	3.46
Alternative 4 (fully automated)	2.61
Alternative 5 (time staged automation)	5.32

operating three-truck automated platoons, the same capacity could be achieved with a single lane each direction and no need for elevated lanes, at a cost of \$1.37 billion, a massive cost savings.

Other discussions are under way in the San Diego area to allow driver-assisted or automated trucks to use the carpool lanes in off-peak hours, as a way of creating truck-only facilities to optimize freight flows.

For truckers to use such a system, they would obviously have to invest in automation equipment. The premise is that their operational efficiency would increase sufficiently to justify the cost.

10.3 Automated Public Transport

It is not uncommon to find forms of automated public transport in major cities, typically serving airports or subways. These rail-based approaches make sense in such cases and comprise a relatively low risk environment for the technology, as movement occurs in essentially one dimension. Automated rubber-tired public transport began public service in 1997 and various forms have been implemented since. The approach has been to minimize the complexity of the situation, either by maintaining low-speed or operating the vehicles in restricted environments.

Automated rubber-tired transport is infinitely more flexible, since roads are everywhere and rails are not. Further, unmanned versions allow for reduced labor costs.

In addition to automation of the basic vehicle movements, one special application in this arena is precision docking. Precision docking refers to the ability of a bus to stop at a precisely defined spot, both laterally and longitudinally, at the passenger-loading platform. This allows for better platform design and much faster passenger loading and unloading, which is an important operational benefit. Because vehicle-platform gaps of only a few centimeters can be achieved, persons using wheelchairs and strollers also benefit.

Here we review some of the key operational systems as well as ongoing research.

10.3.1 ParkShuttle [12]

In this arena, FROG Navigation Systems was first to market with an operational system. Its ParkShuttle was implemented in 1997 to serve passenger transport between remote parking and the terminal at Amsterdam's Schipol Airport (see Figure 10.10). Since then, another system has begun service at an office park in Rotterdam. The technology is even the basis for a fascinating "teacup" ride at Disneyland Tokyo.

FROG was originally proven in indoor factory applications. Each vehicle has an onboard computer that stores an electronic map of the operational area. Using this map, the vehicle is able to plan its route, based on a known starting position. Wheel revolutions are measured to monitor distance traveled, and passive RF transponders are embedded in the pavement as calibration points. This technique allows for positioning accuracy of less than 3 cm. Ultrasonic sensors around the vehicle's perimeter detect any obstacles, causing the vehicle to stop. The ParkShuttle is unmanned and passengers operate it in the fashion of a "horizontal elevator" to select destinations.



Figure 10.10 ParkShuttle operating at Schiphol Airport, Amsterdam. (Courtesy www.2getthere.nl.)

10.3.2 Intelligent Multimode Transit System (IMTS) [13]

The IMTS, developed by Toyota, was first implemented as a parking shuttle for the Awaji Island Theme Park in Japan. Based on its success there, the system will truly have its “coming out party” as a key link in transporting visitors within Expo 2005 in Nagoya. The vehicle design for Expo 2005 is shown in Figure 10.11.

IMTS is a driverless transit system that allows automated platoon operation on dedicated roads, as well as manual human operation on normal roads. The system is thoroughly fail-safe, based on automatic speed regulation, intervehicle communications, ground communications, and other means. In fact, due to its rail-like nature, it was necessary for IMTS to comply with stringent Japanese rail standards, which it has done successfully.

The IMTS vehicles are guided by magnetic markers in the roadway, which also provide positioning information. The steering control subsystem is shown in Figure 10.12, with the response pattern of the magnetic sensor shown as Figure 10.13. Up



Figure 10.11 An artist's rendering of IMTS in platoon operation at EXPO 2005 Aichi, Japan. (Source: Toyota.)

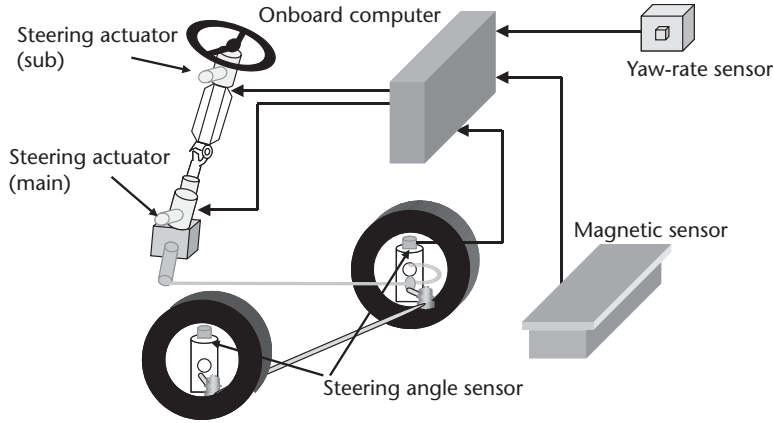


Figure 10.12 IMTS steering subsystem. (Source: Toyota.)

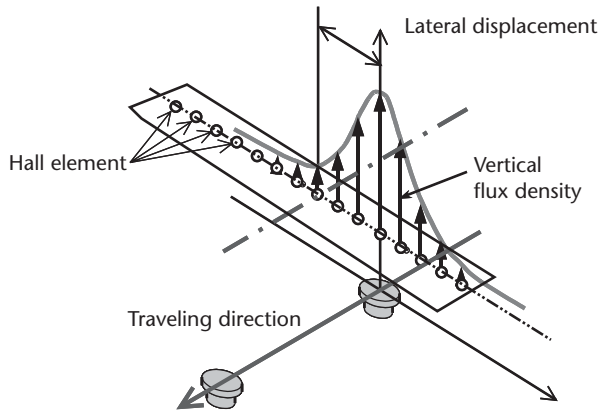


Figure 10.13 IMTS lateral guidance: response pattern of magnetic marker sensors to in-road magnets. (Source: Toyota.)

to three vehicles run in platoon formation and follow a speed profile (30 km/hr maximum) so as to ensure punctuality. Anticollision measures are based on automatic brake control and automotive sensing techniques such as radar. At the passenger platform, the stopping point is controlled precisely so as to enhance people flow.

As the three vehicles travel in platoon formation on the dedicated road, the last unit has the ability to automatically separate and travel to the regular road when needed there. It can then automatically rejoin the platoon when it is returned to the dedicated road.

Toyota has estimated that the automated portion of the IMTS operation will serve 27,000 persons each day at Expo 2005.

10.3.3 Phileas [14, 15]

Phileas is another dual-mode bus system that began operations in Eindhoven, Netherlands, in 2004. The system was designed and constructed by Advanced Public Transport Systems BV. This implementation is also on a dedicated lane, but the

overall environment is less structured, as it is operating within the city. City leaders chose this approach to get the capacity advantages similar to rail transport at the lower costs of bus transport.

The system consists of electronic lane assistance, forward sensing, and a precision docking function based on all-wheel steering. The all-wheel steering enables the vehicle to “crab-walk” its way into the loading platform (a startling maneuver when seen for the first time!). While driving in automatic mode at 70 km/h, the path in the dedicated lane is known and therefore the lane width required is small, only 6.4m for two-way dedicated lanes.

Phileas operates in three driving modes:

- Automatic mode: Braking, steering, throttle are fully automated;
- Half-automatic mode: The driver is handling throttle and braking, while steering is automatic;
- Manual mode

Guidance is based on magnetic markers placed every 4–5m in the road surface and therefore works well under most weather conditions. The magnetic markers serve three purposes:

- Reference for automatic correction;
- Safety: If in automatic steering mode the vehicle deviates more than .5m from the programmed route, an automatic stop is invoked;
- Position fixation: The vehicle constantly knows its position, useful for passenger information and vehicle management.

The extended length version of the Phileas vehicle is shown in Figure 10.14.

10.3.4 Bus Platooning R&D at PATH [11]

Researchers at California PATH have done extensive research into driver support functions for transit bus operations. In recent years they equipped three full size



Figure 10.14 Phileas automated bus system operating in Eindhoven, Netherlands (Source: Advanced Public Transport Systems bv.)

buses for automation. Figure 10.15 shows the technology components of the buses, which are capable of the following:

- Precision docking with centimeter-level accuracy;
- Automated lane keeping;
- Automated lane changing;
- Close-formation platoons (with as low as 15-m intervehicle spacing).

Doing the arithmetic, this level of platooning allows for capacities on the order of 70,000 people per hour per lane given the seating capacity of the buses. Figure 10.16 shows the buses operating in platoon mode in testing conducted in San Diego.

Another feature of the PATH work is the development of simple transition processes for the drivers when transitioning to and from automated mode.

10.4 CyberCars [16]

The CyberCars concept encompasses a fleet of fully automated vehicles that form a transportation system for passengers or goods, on a network of designated roads,

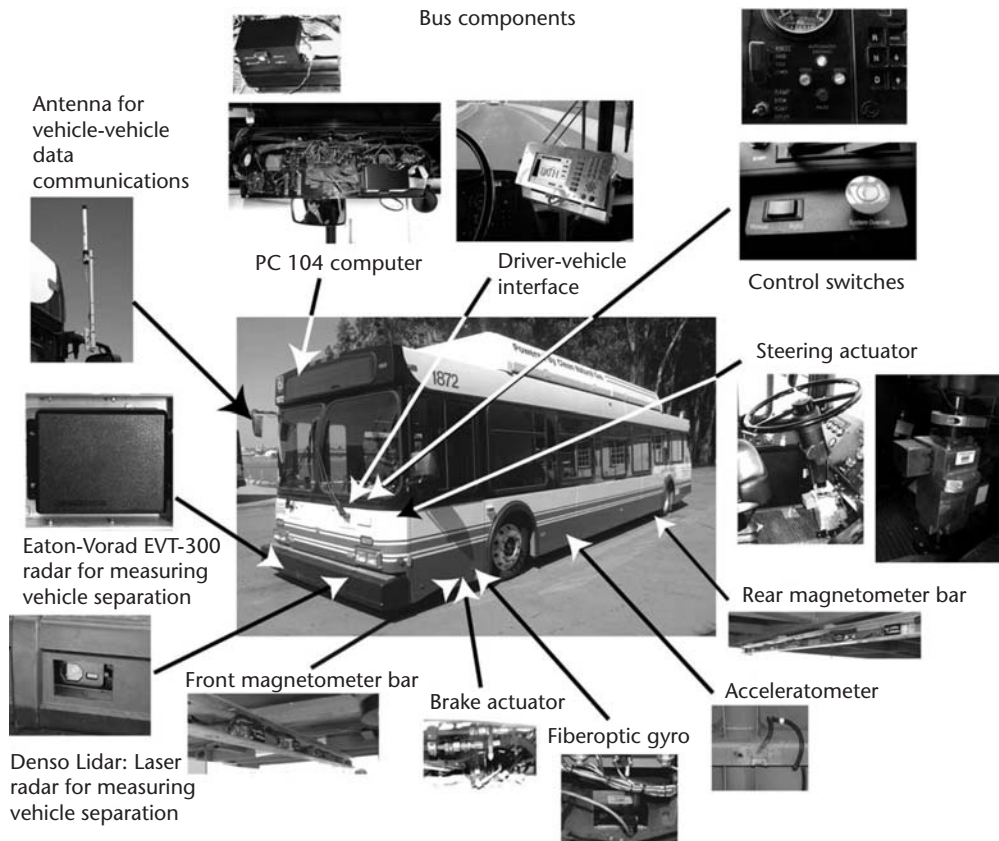


Figure 10.15 Components of automated bus systems developed by California PATH. (Courtesy of California PATH.)



Figure 10.16 Buses in automated platoon mode on I-15 in San Diego, California. (Courtesy of California PATH.)

with on-demand and door-to-door capability. Initially, CyberCars are designed for low speeds in an urban environment or in private facilities.

The CyberCars project ran from 2001 to 2004 as part of the European 5FW program. Led by the French INRIA, the project involved a wide range of partners (including Yamaha and Fiat) and 12 cities, some of which functioned as potential implementation and/or demonstration sites. The project was conducted in collaboration with the CyberMove project, which evaluated socioeconomic and local issues relating to deployment in specific cities. Activity is now focusing on initial deployment of CyberCar fleets in cities.

The objectives of the CyberCar project were to improve and evaluate the various technologies that can be applied to low-speed automation in segregated environments and assess the impacts of such systems. Further objectives were to develop the necessary certification procedures so that these systems are acceptable to public authorities, to evaluate potential sites, and to conduct large-scale experiments with CyberCar vehicles.

The CyberCar concept is motivated by the nature of historic European cities, which were not planned for intensive automobile use and are very congested. To the degree that small, public shared-vehicles can reduce automobile activity (both traffic and parking) in the central city and tourist areas, everyone benefits. Due to their low speed and small size, CyberCars are seen as especially appropriate to pedestrian-only zones in cities, providing an alternative to walking for those who need assistance. CyberCars generally have an open design and low floors so that passengers can enter and exit easily. The harbor area of Antibes, France, one of the test sites, provides a good example. A 2-km route was defined upon which three 20-seat electric vehicles operated so as to reduce car traffic in the tourist area.

The first large-scale experiment with automated guided vehicles of this type was at the Floriade flower show in Amsterdam (Figure 10.17), in which thousands of people traveled happily in vehicles supplied by Yamaha based on a golf cart platform. The technology was provided by INRIA and integrated by Yamaha.

One of the more ambitious activities participating within CyberCars is the ULTra personal automatic taxi, ambitious because it operates on its own segregated guideway [16]. The system has completed its prototype trials and has received consent from the U.K. Rail Inspectorate to carry public passengers. Under development by Advanced Transport Systems Ltd., ULTra is also investigating a dual-mode system, with vehicles that would operate fully automatically on guideway but could also be driven manually off-guideway. In addition, the U.K. Foresight Vehicle Program is funding the AutoTaxi project, led by TRW Conekt, to develop a safety critical sensor system for ULTra. This system will be based on fusing data from radar, video, and optical ranging sensors for automatic guidance and collision avoidance. ULTra is focusing on deployment in Cardiff, Wales, as the initial operational site. Figure 10.18 shows the ULTra vehicle on the guideway, and Figure 10.19 shows both ground and elevated versions of the guideway.

CyberCars Technology R&D CyberCar vehicle R&D focused in areas such as human-machine interface, controls, navigation (including path following, road following, and absolute positioning), collision avoidance (using scanning lasers, ultrasound, and stereo vision), and platooning. For example, a ParkShuttle II was developed in which throttle, steering, and brake controls were integrated; redundancy was added for safety critical functions, and three levels of braking were implemented (normal, fast, emergency).

For positioning, both infrastructure-supported (magnetic markers) and autonomous techniques (video-based localization) were investigated. For obstacle detection, laser scanning, ultrasound, and contact sensors on bumpers were investigated,



Figure 10.17 Yamaha automated guided vehicles at the Floriade Show. (Source: Yamaha Motor Europe N.V.)



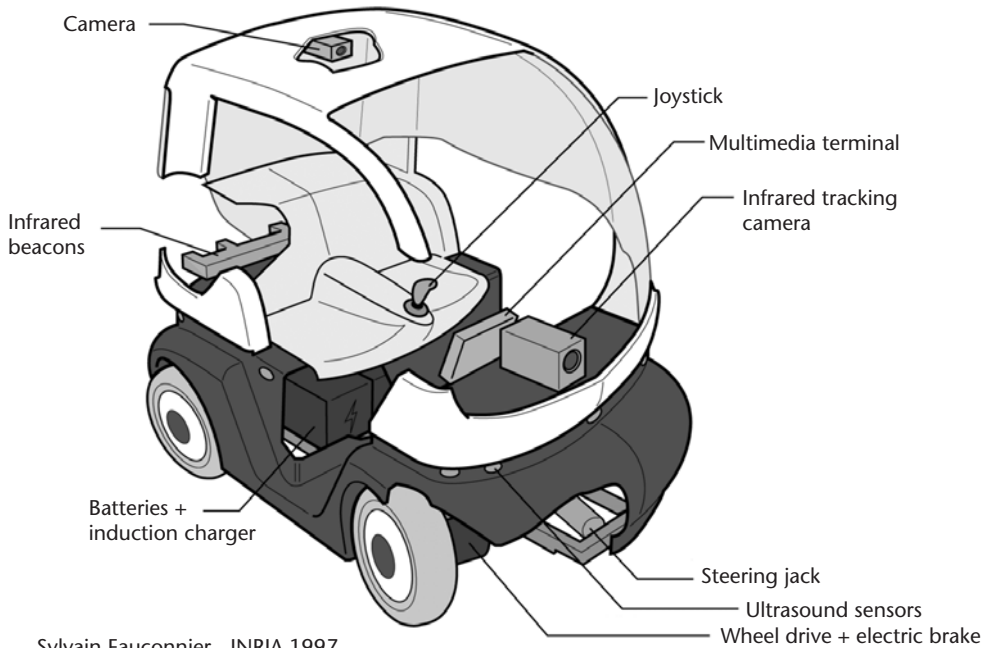
Figure 10.18 Front view of ULTra vehicle on guideway. (Courtesy of Advanced Transport Systems, Ltd.)



Figure 10.19 Elevated and ground-level ULTra guideways. (Courtesy of Advanced Transport Systems, Ltd.)

as well as advanced algorithms to control vehicle motion and negotiate the approach to a potential obstacle. Typical CyberCar components are shown in the INRIA version in Figure 10.20.

Platooning of vehicles was also investigated, as platooning may be needed as an efficient way to collect empty vehicles and return them to a central location for further use. One approach relied upon lasers and reflective beacons on the back of preceding vehicles; another technique involved image processing based on geometric features of the preceding vehicle.



Sylvain Fauconnier - INRIA 1997

Figure 10.20 The INRIA CyberCar (Source: M. Parent, INRIA.)

User Needs Assessments [18] In user needs assessments conducted by the Dutch TNO, although some concerns were expressed about driverless vehicles, a large portion of respondents from throughout Europe said they would use such a system regularly if it were available to them.

10.5 Automated Vehicle for Military Operations [19]

The U.S. Defense Advanced Research Projects Agency (DARPA) is a leading player in advanced IV research, and results are likely to be useful both to the military and in future systems for regular highway vehicles. DARPA's 2020 Mobile Autonomous Robot Software (MARS) project is seeking to develop perception-based autonomous vehicle driving/navigation, with vehicle intelligence approaching human levels of performance, in the full range of real-world environments.

For reconnaissance as well as logistics operations, the military has a goal to reduce the exposure of troops in conflict areas. Given the nature of today's military conflicts, it is not unusual for vehicle operations to occur in cities, possibly sharing the road with civilian cars and pedestrians. Therefore, smart vehicle systems are envisioned that can autonomously operate in such environments. Therefore, autonomous vehicle capabilities targeted within the MARS program are as follows:

- Basic highway: Road lane tracking, vehicle detection, obstacle detection and avoidance, and vehicle following;
- Advanced highway: Entering and exiting highways, traffic merging and highway sign recognition;

- Hybrid road/cross-country: Operate on unimproved roads and trails, locate and execute a path to safely leave a road and begin cross-country driving;
- Basic urban driving: Driving on simple suburban roads, detect and respond to humans, road intersections, traffic signals, and stop signs;
- Advanced urban driving: Full situational awareness for driving in congested urban environments where multiple vehicles and pedestrians are present and traffic is unpredictable.

A detailed MARS architecture was developed and implemented which translated destination commands from the operator into specific routes and vehicle behaviors. Basic functions of road detection and vehicle following were implemented with a combination of radar, lidar, and machine vision. Vision was employed extensively in pedestrian detection, sign detection (extracting relevant highway signs from clutter based on color and shape), and intersection and exit ramp detection. During a 1,000+ mile evaluation trip from Denver to New Orleans in 2004, the prototype system achieved over 98% automated vehicle operation within the test parameters (medium to light traffic and absence of road construction).

10.6 Deployment Options

Deployment options for some forms of automation were addressed above, but here we offer some holistic approaches to a societal transition to a road transportation system based on vehicle automation.

A key point can be easily observed from the above—vehicle automation is already here, in the form of rubber-tired people-movers and transit buses and has been for almost a decade. What's next? Several deployment paths can be identified which are concurrent and converging. The author's views here coincide with and rely also on [20, 21].

Three paths can be identified that can lead to full driving automation in large parts of the road network:

- Driving assistance techniques on passenger cars;
- Driving assistance and dedicated infrastructures for commercial vehicles;
- New forms of urban transport (CyberCars).

These concurrent approaches are proceeding in parallel and essentially use the same technologies.

For passenger cars, the preceding chapters have shown us a vigorous progression toward ever more driver support functionality. This is being driven largely by safety, which creates much of the technology base needed to support full automation.

The same suite of driver-assist technologies coming to cars are coming to heavy trucks as well. Economic efficiencies such as travel time and fuel consumption are key to these vehicle operators. Traffic efficiencies and emissions reductions are key to the government authorities. As discussed above, although major costs are

involved, major benefits also accrue to both the private and public sectors as automated truckways are constructed. It is likely, therefore, that the economic case will be made within the next several years to justify and initiate construction of such facilities, given the stresses on the regular highway system caused by increased freight volumes carried by trucks.

For urban transport, we saw above how CyberCars are beginning to see success. Shared use of public cars has already seen success in Europe; CyberCars fit into that paradigm and offer convenient conveyance in large pedestrian zones.

For passenger cars, the initial safety systems work on all roads and the onboard technology moves slowly toward full automation. For heavy trucks this is also true, but a leap to automation can be facilitated through the implementation of truckways. However, the massive investment needed for such infrastructure places this occurrence in a later phase. CyberCars, on the other hand, offer the unique situation of full automation in the near term without the need for significant infrastructure investment—the trade-off being limited geographic extent and low speeds. In between, we find the automated bus transit systems that can operate on well defined tracks at higher speeds.

How do we arrive at the point at which dedicated lanes are available to automated passenger cars, so as to begin to get the major gains in road capacity? Two paths are evident:

1. As automated busways and CyberCar zones steadily proliferate, private cars and even small commercial delivery vehicles could be granted access if they have proper automation functions. Over time these zones and routes could be linked for the purpose of creating an automated network.
2. Existing carpool lanes, which are very extensive in the United States, could be opened to private cars with advanced driver assistance systems in early years and automated capability in later years.

Both of these situations can serve to accelerate market penetration of such systems, which will eventually lead to the point at which there are so many automation-capable vehicles that it makes sense to reallocate existing normal lanes to automation. Dedicated lanes for cars would primarily serve commuting flows around major cities, and dedicated lanes for trucks would serve intercity long-haul traffic as well as specific freight bottlenecks.

Several of the preceding ideas are brought together in Figure 10.21 [21] developed by California PATH. Commercial driver-support systems, when combined with DSRC, are enabled to interact in forms such as C-ACC. At the same time, public authorities can take the steps necessary to allow access to high-occupancy vehicle (HOV) lanes for IVs. When these two come together, new advanced traffic management system (ATMS) techniques become possible, as does coordination of merging vehicles, to create a “single-lane AHS.” When control is extended over large parts of the road network, and vehicle systems become capable of automatic lane changing, a “full AHS” system exists.

In the very long run, somewhere between 2030 and 2050, extensive networks of high-capacity automated motorways can be envisioned, including freightways in which one driver is responsible for several trucks. All vehicles will

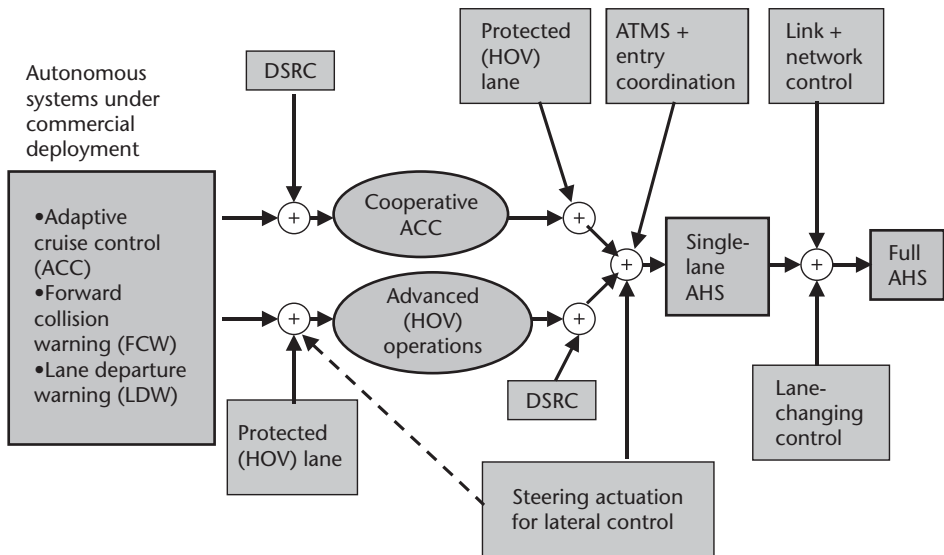


Figure 10.21 A Roadmap toward full automated vehicle operations on the road network. (Courtesy of California PATH.)

remain dual-mode and capable of being driven normally on nonautomated roadways, while still enjoying extensive driver support and safety functions.

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Extending the Information Horizon Through Floating Car Data Systems

Given the sensing and computing power on today's vehicles, each vehicle on the road is a storehouse of valuable information about current travel conditions. If only we could harvest this information and put it to good use! This is the premise of floating car data (FCD) systems, which are a subdomain within CVHS.

The rather bizarre term FCD refers to the concept of collecting information from vehicles as they go about their normal business (i.e., floating) through the road network. As this field is still maturing, another term—probe vehicles—is also used to mean essentially the same thing. Data is collected that is relevant to traffic, weather, and safety, with each message also including time and location. A central entity then assimilates and processes that data and distributes results to travelers and road authorities to support traveler information, road management, and safety. In essence, the “information horizon” for travelers is extended beyond the tens of meters provided by sensors, and beyond the hundreds of meters provided by intervehicle communications, to the entire road network. In this way, FCD systems are CVHS with the broadest coverage.

For instance, by collecting speed and location data from vehicles, the presence of traffic congestion can be easily determined. One or two vehicles that report sudden slowing could be doing so for any number of reasons. However, when dozens of them report the same speed profiles, a high certainty is gained as to the traffic picture. Thus, by “averaging” data from many vehicles, the overall situation is well characterized. Further, experiments show data reporting from only a small percentage of vehicles is adequate to get a good overall picture.

Similarly, geographically precise weather data can be generated from FCD simply based on the vehicle's location when windshield wipers are activated, combined with temperature sensors. Traction control systems, common on today's vehicles, can generate data as to slippery areas of the road, which when aggregated provides road managers an excellent resource for the deployment of snow plow and salt trucks, for instance. The same type of data, when distributed to drivers, helps them be more cautious in those slippery areas, and vehicle systems can even adjust automatically (i.e., an ACC system increasing intervehicle gap due to low pavement friction).

Of course, such data is collected now by roadside traffic counter systems and weather stations—but these are spot measurements and usually only exist on major roads. The beauty of FCD is that it provides for ubiquitous coverage of the entire road network—wherever cars are traveling.

A key idea for FCD systems is in collecting data that already exists onboard vehicles. The FCD concept does not demand that any special equipment be fitted on vehicles just to serve the FCD function. Even the communications package must be multifunctional, serving a variety of applications such as electronic payment, automatic crash notification, etc., as was discussed in Chapter 9.

Two fundamental approaches to FCD are being pursued. For information on motorways rural and suburban areas, data collection via private vehicles or heavy trucks is most appropriate. For information on dense urban environments, taxis are particularly useful, as they are numerous and already have onboard communications gear for dispatching which can be issued to send probe data.

This chapter reviews technical and policy issues, some of the activities to date in the FCD domain, and provides a perspective as to its future evolution—but first, a closer look at applications.

11.1 FCD Applications

As noted above, FCD techniques can be very useful in gaining a picture of traffic, weather, and road conditions for the entire road network. In addition, given the need for digital maps to be as accurate and up-to-date as possible, vehicles reporting exceptions to their map database can serve an important role in contributing data that supports creation of real-time map updates.

Table 11.1 provides some examples of existing vehicle sensors and their applications within an FCD approach. In many cases, of course, these parameters would be combined to create meaningful information.

The trend in FCD deployment is for traffic and weather data to be reported in first generation systems, with safety relevant data being introduced in subsequent generations.

11.2 Policy Issues Relating to FCD Techniques [1]

Some interesting policy issues arise with FCD techniques, of which only a few are reviewed here.

Foremost among these are privacy issues that arise as everyday road travelers are asked to share information regarding their movements and speeds. The case can of course be made that those who share also get the benefit of a rich information flow of data coming back to them. Further, the fundamental concept for FCD systems calls for no identifying information to be sent with the basic data. This can be easily implemented from a technical perspective; the larger issue is the public's perception of whether their privacy is protected or not. In essence, this question is not markedly different from other aspects of modern life, where we are assured that our cellphones and e-mails are not monitored by authorities or accessible by others, yet we cannot really know that this is true in an absolute sense. Rollout of FCD systems, then, must proceed carefully to gain the public's trust.

Second are issues of data ownership. FCD systems will result in massive databases of useful travel data. Do the contributors each own a share of it? Does the

Table 11.1 FCD Application Examples

<i>Onboard sensor</i>	<i>Traffic application</i>	<i>Weather application</i>	<i>Road management application</i>	<i>Safety application</i>	<i>Map Database Application</i>
Position (latitude/longitude)	Core data	Core data	Core data	Core data	map corrections
Vehicle heading	Core data		Core data	Core data	core data
Speed	Traffic flow status			Advance notice of stopped traffic	
Ambient temperature		Icing conditions	Dispatch of salt trucks	Indicator of road friction	
Windshield wiper status	Traffic slowing due to intense precipitation	Precipitation	Spot flooding	Indicator of road friction	
Fog light status		Fog, dust, smoke		Forward alert algorithms can be tuned for earlier warnings in low visibility	
Longitudinal acceleration/deceleration	Detect sudden slowdown indicating a traffic incident		Earlier dispatch of incident response teams	Advance notice of traffic incident	
Lateral acceleration			Detect hazardous ramp and road curvatures	Input to curve speed warning system	
Antilock brake system activation			Detection of slippery road for dispatching maintenance crews	Detection of slippery road	
Traction control system activation			Detection of slippery road for dispatching maintenance crews	Detection of slippery road	
Suspension			Presence of rough road or pothole		
Obstacle detection	First indication of condition to cause a traffic jam		Removal of obstacle	Input to crash avoidance system	

aggregating entity own it outright? Or, if the data can only be transmitted by equipment installed by the vehicle manufacturer, do they lay some claim to ownership? These are thorny issues that must be worked out gradually and over time, as various implementations are experimented with.

There are also divergent opinions as to the roles of government and industry in implementing FCD systems. This will, to some extent, vary regionally based on the role government plays in society overall. For instance, in Sweden, recommendations have been made that the government should finance implementation of the FCD

concept during a transitional period until there are enough equipped production vehicles on the market to provide wide benefits to all users. Alternatively, BMW has asserted that development of FCD approaches are mainly the responsibility of the auto manufacturers [2].

11.3 Technical Issues

At the technical level, communications loading dominates, which translates to operating cost and the overall business case.

Depending on the communications media used, and the FCD approach, the cost of communicating this data can quickly skyrocket as packets of data are sent every few minutes by thousands of vehicles. However, current R&D is focused on minimizing the communications loading to reduce costs.

The communications riddle has two facets: reporting data from vehicles and transmitting processed data back to the drivers/vehicles as the ultimate user. In both cases, synergies must exist with other services to support the cost of the communications equipment in the eyes of the customer.

11.3.1 Data Reporting

Data reporting occurs in the form of short messages that are time-relevant but not time-critical. Transmission delays of several minutes or even more are acceptable for traffic and weather information, whereas safety information requires less latency. It is typically the frequency of the messages, rather than their length, that affects airtime costs.

Exception-based reporting will be key to communications efficiency. By referencing an onboard database (which is updated as needed via broadcast), vehicles would only send messages when their own situation is different than information in the database. For instance, the database could contain time-of-day speed profiles for individual links in the road network.

Further, in a mature system in which the majority of vehicles are equipped to provide FCD reports, only a portion of them need to provide information for the overall situation to become clear in the data. Therefore, a communications management loop may be required to instruct onboard systems to temporarily cease reporting.

Data reporting can be accomplished through a wide variety of communication media, including cellular, cellular data, GPRS, DSRC, WAVE, and even 802.11a wireless hotspot technology. Where DSRC beacons are already common, such as in Japan for their ITS information system, DSRC is a good option and commercial airtime costs are not an issue since the system is operated by the government. In the commercial wireless arena, new cellular data services are under development that are expected to offer lower rate structures for FCD and similar data—telecommunications companies know they have a major business opportunity with vehicle-sourced data and want a piece of the action. Use of hotspots will require agreements with service operators; hotspots are beginning to proliferate along the road network to serve truckers at truckstops, for instance. The nature of the messages are not radically different from that used for electronic payment (e.g., for parking and fast food) and so the evolution of FCD reporting is tied closely to that industry.

11.3.2 Data Dissemination [3]

The task of disseminating FCD data back to users in vehicles forms a component of the larger telematics industry. Location-based telematics are expected to include services such as traffic information, personalized routing, e-mail, and geospecific advertising.

For dissemination, message size is somewhat larger than for reporting but still modest in relative terms. Data dissemination can occur through the media described above, as well as the broadcast methods of RDS-TMC, digital audio broadcast (DAB), or satellite radio. RDS-TMC is a technique of adding a data stream to the signal from FM radio stations; many FM radios in today's production vehicles are designed to extract this data stream and display information on the LCD panel of the radio. Market penetration is strongest in Europe, particularly in Germany, where in-vehicle navigation screens can be coded to show areas of congestion based upon data transmitted via RDS-TMC.

11.3.3 Data Cleansing

The concept of data cleansing is crucial to minimizing extraneous FCD reports. Data from vehicles that stop for reasons not related to traffic congestion, for instance, is not useful from an FCD perspective. This is particularly relevant for taxi-based FCD systems, since taxis can stop at any time to pick up or discharge passengers.

Onboard data used for data cleansing includes door and window status, fuel level, tire pressure, airbag status, crash sensors, and road roughness sensors.

11.4 FCD Activity in Japan

Japan has been a leader in FCD experimentation on both taxis and private cars. The Internet ITS Consortium is the major actor taking FCD forward in the commercial arena. The following activities are representative.

11.4.1 Road Performance Assessments

The Japanese MLIT has been planning and researching floating-car techniques for road administration since 1999, as part of its Smartway deployment. The intent here is to use FCD systems to assess road performance, in terms of before/after effects of road improvements, overall travel speeds, and vehicle emissions.

In 16 cities, fleets of cars and buses have been recruited to provide this type of information. In 2001, congestion information was reported via 4700 survey vehicles over 11,000 km of arterials. In 2004, this figure had risen to 10,000 probe survey vehicles. It is clear, then, that the focus here is on long-term road management and evaluation, not real-time probe processing, and therefore this activity serves as a precursor to implementation of the total FCD vision.

11.4.2 Taxi-Based Probe Experiments [4]

Under the sponsorship of the Japanese Ministry of Economy, Trade and Industry, the Japan Automotive Research Institute (JARI) has experimented extensively with

real-time probe processing using taxi fleets. A basic prototype system was verified in 1999, a large-scale field trial with 300 probe vehicles was conducted in 2001, and a public field trial was scheduled for 2004. Denso and Keio University have also been central to this work.

Their integrated in-vehicle system collects sensor data stored onboard the vehicles, receives instructions from a data center, and transmits relevant probe car data. Applications developed include travel time and weather information, based on the following data items:

- Position;
- Windshield wiper operation;
- Traveling speed;
- Fuel consumption;
- Engine rpm;
- Turn signals.

Security functions are also implemented for privacy and to protect against external attempts to tamper with the data flow (hacking). For privacy protection, authentication and encryption techniques have been implemented. It is worth noting, however, that the data overhead incurred for security and privacy increased the overall data flow by 3–5 times compared to earlier systems without these features. This, in turn, affects airtime costs and therefore must be considered in developing the overall business case for deployment.

11.4.3 Traffic Condition Detection Using Efficient Data Reporting Techniques [5]

The “brute force” method of detecting traffic conditions relies on many vehicles reporting frequently, but as noted above this is prohibitively expensive due to airtime costs. Researchers at the i-Transport Lab, NEC, and the University of Tokyo have devised highly efficient strategies to minimize the transmission cost by identifying free-flow or congested traffic conditions based on the time-space trajectory of probe vehicles. The objective is that only information on congested conditions would be reported. Based on vehicle data captured in Yokohama and Nagoya during an experimental period, a method was developed to cleanse the data and search for “trip ends.”

This data is combined with the shape of vehicle trajectories (in terms of speed, stops, and distance between stops) to classify and distinguish different traffic condition patterns.

11.5 European FCD Activity

Europe is a hotbed of FCD activity for both passenger car and taxi-based systems. FCD-based systems have been a part of early telematics offerings. The work in passenger car FCD is driven strongly by the auto manufacturers, as they see FCD-based services as one aspect of enhancing the customer relationship. At the same time, governments are facilitating FCD projects because of the benefits to road management

and society overall. Current activity can be framed in terms of 1) current commercial FCD offerings and 2) R&D toward next generation FCD systems.

11.5.1 Commercial FCD Services

A sampling of commercial FCD services is provided here to provide a sense for the degree to which FCD techniques are currently in use.

ITIS Holdings [3, 6] ITIS Holdings entered the telematics and traffic business in the United Kingdom in 1997, initially to serve trucking companies and now serving travelers in general. They ventured quite early into the FCD field by designing an in-vehicle device that logs, stores, and transmits vehicle position, speed, and direction information. The information collected enables traffic flow rates to be known in real time, and flows can also be predicted based on historical and other data. Their customers serve as both the data providers and data consumers.

One approach used by ITIS to enhance data collection is to gather information from vehicles with a high probability of being on a certain route at a particular time of day. During morning and evening rush hours, commuter vehicles would be selected; during the middle of the day, trucks may be favored. Their FCD coverage extends across motorways in several British cities, and plans call for coverage over the entire trunk road network of England, Scotland and Wales.

On the European continent, ITIS is also experimenting with measuring real-time traffic flow based on anonymously sampling the positions of mobile phones in moving vehicles, working with the Flanders government. This approach will be tested in the Antwerp region and results are expected in 2005.

Trafficmaster Trafficmaster was established in 1988 in the United Kingdom as a private company collecting and processing traffic data to offer traffic information services. The major part of its data comes from stationary sensors that are supplemented with FCD data. Their FCD approach requires subscribers to mount units in their cars to transmit and receive the traffic information.

Trafficmaster is now active across Europe, particularly in Germany and Italy.

Mediamobile Mediamobile provides data primarily from the French road administration in the Paris area, which is supplemented with FCD from 4,000 taxis. Over 40,000 customers use the Mediamobile service.

DDG The German firm DDG initially provided traffic information services based upon deployment of thousands of road-based traffic sensors. Via separate agreements with BMW and VW, it is now collecting floating car data as well. Approximately 40,000 FCD vehicles (close to 1% of total passenger cars in Germany) are reporting data [7]. DDG is currently processing 30M records daily from reporting vehicles. As a first generation system, the DDG approach is hampered by high communications costs, as vehicles are reporting at regular intervals whether data is needed or not. As will be discussed in Section 11.4.2. BMW and Daimler Chrysler are addressing this issue in their current R&D.

Taxi-FCD System [8] The Institute of Transport within the German Aerospace Center has implemented the Taxi-FCD System in 2,300 taxis operating in several

European cities (see Table 11.2). Because they are capitalizing on fleet-management information, there are no onboard expenses for data collection nor are there additional communication expenses.

The data structure is simple, with vehicle ID, timestamp, position, and taxi status being transmitted at intervals between 15 and 120 seconds. This approach yields excellent information on traffic. In fact, a city map can almost be traced out based on the travels of the reporting vehicles—Figure 11.1 shows traces of five vehicles reporting over a three-month period in the region of Regensburg, Germany.

Table 11.2 Taxi-FCD System Coverage

<i>City</i>	<i>Number of taxis</i>	<i>Share of total taxi fleet locally</i>
Berlin	300	5%
Nuremburg	500	95%
Vienna	600	12%
Munich	220	6%
Stuttgart	700	95%

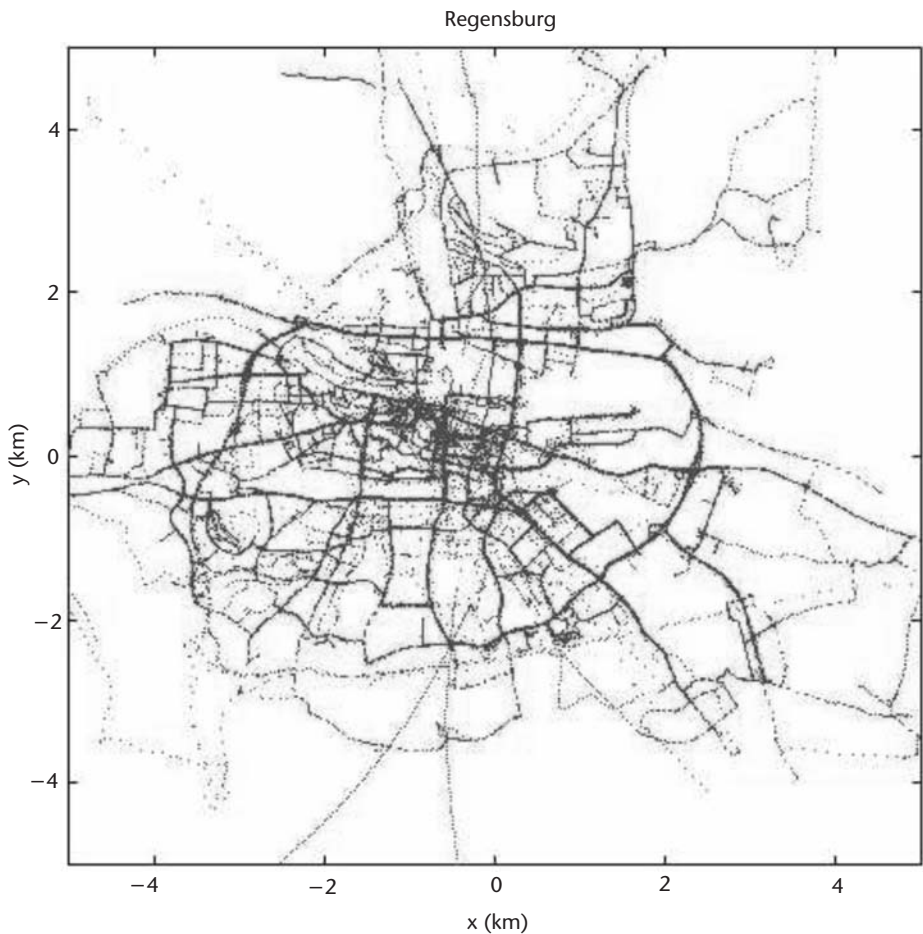


Figure 11.1 FCD from taxis in Regensburg, Germany. (Courtesy of Ralf-Peter Schäfer, German Aerospace Center, Institute of Transport Research.)

11.5.2 Research and Development Toward Next Generation FCD Services

The following projects provide a sampling of research activity funded by the public sector and the automotive industry. They are presented in a rough chronological order.

Road Traffic Advisor The Road Traffic Advisor project in the United Kingdom was an early foray into vehicle-roadside communications for evaluation purposes. Sponsored by the U.K. Highways Agency, 350 km of the motorway M4 from the London airports to Swansea was instrumented with eighty 5.8-GHz beacons. The goal was to develop the necessary in-vehicle electronics and an open architecture to support a variety of applications. Among the applications investigated, FCD was shown to be technically viable.

Sweden OPTIS Floating Car Data Pilot [1, 9] OPTIS was a project with the purpose of developing cost-effective methods of collecting traffic data in order to provide high-quality traveler information. OPTIS is part of the so-called Green Car venture being jointly conducted by the Swedish government and car manufacturers, concerning the development of vehicles with improved environmental qualities (including reductions in emissions resulting from improved traffic information and reduced travel times). Major partners in OPTIS were SAAB Automobiles, Scania Commercial Vehicles, Volvo Cars, Volvo Truck Corporation, and the Swedish National Road Administration.

At a high level, the OPTIS goal was to show the feasibility of obtaining a quality picture of the traffic status in a metropolis with wide geographical coverage, given a reasonable number of FCD vehicles. The project also sought to establish that FCD is a cost-effective alternative to stationary sensors, that FCD provides a cost-efficient means of collecting data in more situations and locations than with other methods, and that FCD can be implemented in such a way that it is commercially attractive to telematics service providers.

The specific objectives of OPTIS were to build a server solution for FCD, verify it through simulations, perform a realistic field trial to verify the simulations, and establish an action program for deployment.

Field trials with 250 vehicles took place in Gothenburg during a six-month period in 2002. The data concept was based on travel time. The cars in the study were equipped with Volvo Oncall units modified with OPTIS algorithms. Position data was transmitted to the OPTIS center where the data was processed into travel times. Map matching was performed at the center, so that the cars did not need an onboard digital map. Travel times were calculated at the road link level for each probe by determining a position in the road network and identifying when a vehicle passes the beginning and end of a link. The difference in the two times constituted the measured travel time for the link.

OPTIS evaluations indicated that high-quality travel information could indeed be produced with this system approach. The data allowed drivers to choose alternative routes at major incidents, saving as much as 25 minutes on their trip. This was in turn related to emissions reductions if such a system were deployed widely. Overall, the FCD data was shown to offer a better overall picture of the traffic situation as compared to road-based sensors. Further, the installation cost of the FCD solution was estimated to be half that of a fixed detector system.

Communications costs were assessed at a high level. Simplicity at the vehicle level resulted in higher communication loads between the probe and server, compared to an implementation in which the probe vehicle calculates link travel time onboard. Short message service (SMS) over the GSM cellular network was used in the pilot, but this is not seen as feasible for deployment due to cost. At 1/10 the price of SMS, GPRS is seen as an attractive alternative.

The OPTIS final report called for OPTIS to be followed by a large-scale demonstration project in Gothenburg and Stockholm. The recommendation called for a total of 3% of all vehicles in Gothenburg and Stockholm to be equipped with FCD equipment. The cost was estimated at approximately \$5 million. Deployment activity along these lines is under way.

Smart FCD: FCD Collection via Satellite [10] The European Space Agency has completed a feasibility test with a small number of vehicles in the Rotterdam area using satellite communication to collect FCD data from vehicles. The advantage of the satellite approach, of course, is that the entire road network is covered by the satellite footprint.

Researchers concluded that this approach to the collection of traffic information is technically feasible. Even though shadowing by large buildings was a concern, the data gathered shows that the coverage of the satellite system is adequate, even in densely urbanized areas. Further, analysis showed that traffic jams were detected effectively with the algorithms used. The project team noted that, compared to conventional detection methods, this concept offers better coverage and better data at competitive costs.

ProbeIT [11] In the United Kingdom, the ProbeIT project focused on vehicles communicating position-related information to create a dynamic roadmap database and thereby enable applications such as traffic management information and speed advice. The project, completed in 2004, included Jaguar Cars and Navteq as participants.

BMW Extended FCD R&D [2, 7] Some 78,000 FCD-capable BMW vehicles are currently operating on German roads, reporting data through the DDG service described above. Their approach to second generation FCD systems, called extended FCD (XFCD), is based on reporting by exception, data management, advanced event-detection algorithms, and data cleansing.

The key to exception reporting is the presence of an onboard data base, which is frequently refreshed by new data. Although this data refreshment requires communications airtime, it can be transmitted in a broadcast mode that is much less costly. XFCD applications implemented by BMW include traffic, weather (precipitation, visibility), and road conditions. Data elements collected include speed, acceleration, windshield wiper status, ABS signals, headlight status, and navigation data. Figure 11.2 shows the XFCD in-vehicle architecture, with the corresponding software architecture shown in Figure 11.3.

BMW researchers have performed extensive analyses to understand the trade-offs between the quality of traffic information and the necessary penetration rates of equipped XFCD vehicles [7]. They assumed a period of 10 minutes for detection of a traffic incident, which is seen as satisfactory precision for reporting on

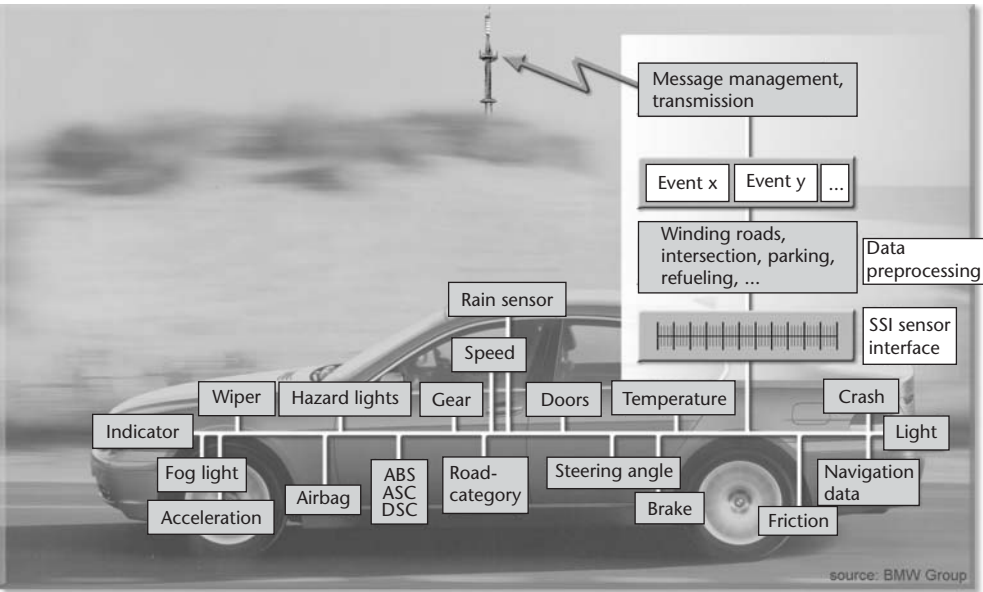


Figure 11.2 XFCD in-vehicle system architecture. (Source: BMW Group.)

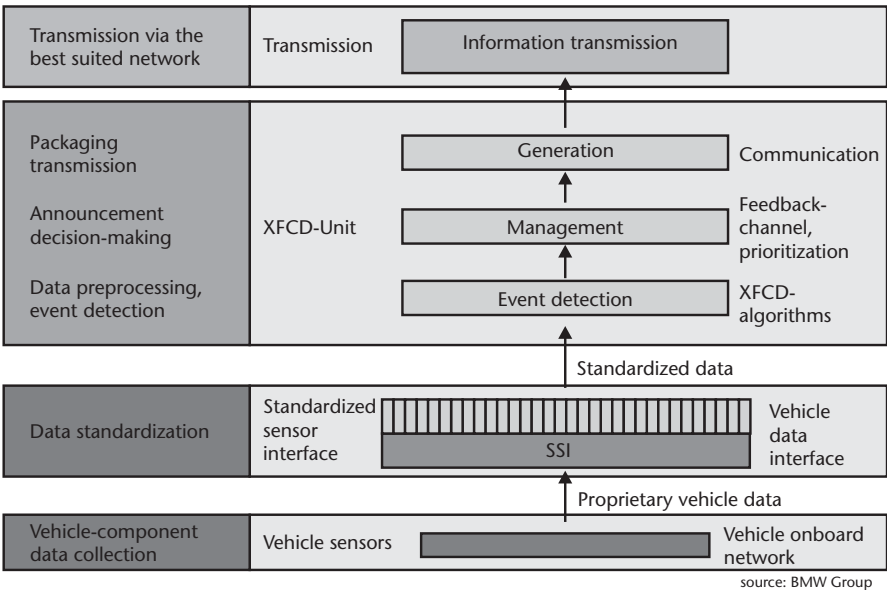


Figure 11.3 XFCD software architecture. (Source: BMW Group.)

traffic conditions. One factor affecting needed penetration rates is traffic volume. For example, mean passenger car volumes of 1,000 cars/hour require penetration rates of 3.8% to reliably detect an incident (reports from at least three XFCD vehicles) within 10 minutes. The necessary penetration rates are halved if a 20-minute detection period is allowed.

The researchers applied their methodology to the Munich road network as an example.

Results showed that, at a penetration rate of 9%, traffic conditions on 50% of the secondary network are detected. If only the primary network is analyzed, a penetration rate of only 5% is sufficient to cover two-thirds of that network. Overall, the analysis showed that an XFCD-capable fleet of 7.3% of the total number of passenger cars is sufficient to detect traffic conditions for over 80% of the main road network. For the overall German federal motorway network, analyses showed that penetration rates of at least 2% are required for good incident detection at peak traffic times, and that satisfactory traffic information can be generated on 80% of the motorway network at penetration rates of around 4%.

DaimlerChrysler CityFCD [12, 13] Daimler is similarly focused on reducing message frequency through onboard measurement of link travel time and exception reporting based on an onboard link time database.

Researchers have concluded that only 2–4 FCD messages are necessary to detect the congestion fronts, and their analysis of necessary equipped-vehicle penetration rates yielded results similar to those of BMW: a 1.5% FCD penetration rate gives sufficient service quality in urban traffic. This relies also on the traffic center employing a predictive interpolation algorithm to process the data in the most efficient way and broadcast the predicted link information to the all other FCD vehicles to update their databases.

Each CityFCD vehicle measures its travel time on a network section and makes a decision as to whether to transmit this data to the FCD service center or not, based on the previous information received via broadcast. As shown in Figure 11.4, the data broadcast from the FCD center contains both the threshold value and the travel time for the upcoming road section (T_p). The travel time for the upcoming road section can be used as an input to onboard.

Dynamic Route Guidance (DRG) Systems In terms of communications factors, this optimized message generation process was shown to reduce the amount of messages

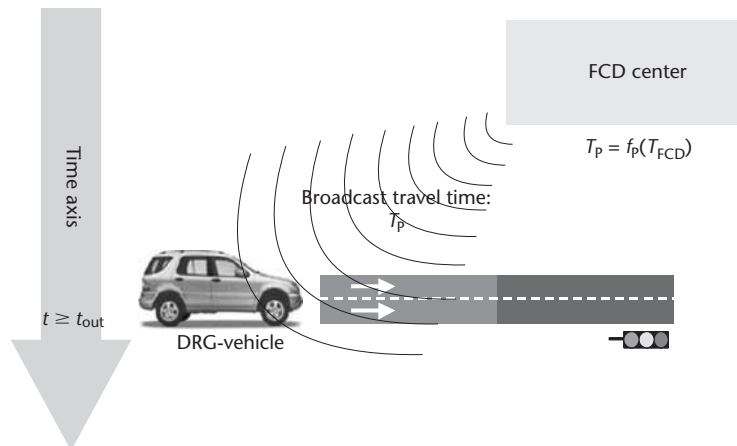


Figure 11.4 Broadcast of travel time data in the DaimlerChrysler CityFCD approach. (Source: DaimlerChrysler AG.)

by a factor of 40. Candidate communication channels for data outbound from the vehicle are GSM point-to-point, SMS, DAB, and GPRS. Data inbound to the vehicle would be transmitted via broadcast.

11.6 FCD Projects in the United States

As in Europe, both public- and private-sector FCD initiatives are under way, some of which are outlined here.

11.6.1 U.S. DOT VII

At the national level, the U.S. DOT is working with car manufacturers and state DOTs to explore VII, as described in Chapter 9. VII applications focus on localized services, such as intersection collision avoidance, and network-oriented services that focus on overall regional conditions. FCD is seen as key to the latter.

While safety applications are seen as the eventual goal, it is also a longer term goal and the VII program recognizes that various stepping stones must be in place to get there. FCD techniques are seen as part of the early VII rollout, as it is less complex technically than advanced safety applications. Further, FCD lends itself to retrofitted equipment more than many other cooperative vehicle-highway applications, and this in turn facilitates accelerated market penetration. This offers the potential to demonstrate clear system benefits in the near term, which is essential to build public and congressional support for further deployment.

State DOTs participating in VII discussions see the potential for FCD to save them money in the long term: to the degree FCD is successful, they can reduce their investments in fixed roadside and in-road traffic and weather sensors.

At the current early stages of VII, no FCD work is under way, but operational test projects are being planned.

11.6.2 I-Florida

The U.S. Federal Highway Administration and Florida DOT are cofunding an “Infostructure Model Deployment” that addresses a comprehensive range of transportation information collection and management. Experimentation with FCD techniques is one of several project components.

FCD has the potential to be particularly effective in emergency evacuation situations, which Florida has to deal with all too frequently in hurricane season. The same is true at a national level during and after a major terrorist attack, as a component of homeland security.

11.6.3 Ford FCD Experiments [14, 15]

In recent years, Ford has become a very active player in experimenting with FCD techniques. A partnership with the Minnesota DOT is currently under way, as well as fleet testing in the Detroit area.

Minnesota The Minnesota project calls for 50 state police cars, ambulances and state-owned cars and trucks to be outfitted with sensing devices to collect

traffic and weather-related data. Data elements include vehicle speed, location, heading, windshield wiper operation, headlight status, outside temperature, and traction control system status. The information will be transmitted to the condition acquisition reporting system for state roads. Based on data analysis, key information will be derived and distributed to highway message signs, 511 telephone services, and related Web sites. Vehicles are expected to begin reporting by late 2004 throughout the Minneapolis/St. Paul metropolitan area.

Minnesota DOT sees significant public sector benefits from the data collected, such as the following:

- Decreased time needed for emergency response;
- Improved traffic management;
- Improved road maintenance;
- Improved identification and location of incidents;
- Decreased cost to collect data, relative to existing techniques using roadside infrastructure;
- Expanded data collection coverage to all roads traveled by vehicles equipped with the system;
- Enhanced data quantity and quality due to fusion of data from multiple sources (such as inductive loops, road/weather information systems, vehicles, and cameras);
- Improved ability to specifically target the warnings and advisory messages to drivers (in vehicles equipped with the system) as they approach the conditions identified.

For incident detection and traffic management, MnDOT engineers see the following FCD data elements as useful:

- Travel times between major junctions (for reporting travel times);
- Abnormally slow travel on freeways (indicating stop and go conditions);
- Alternating acceleration and deceleration on freeways (indicating stop and go conditions);
- Numerous indications of significant acceleration and deceleration on freeways in a general vicinity (indicating congestion shock wave condition);
- Abnormally slow travel on nonfreeways (indicating congested conditions);
- Abnormally long stopped condition in one vicinity on nonfreeways (indicating congestion at a traffic signal, signal malfunction, or incident).

Road maintenance managers within MnDOT expect to benefit from data relevant to icing (ABS or traction control activation, windshield wiper status, ambient air temperature, humidity), which can be fused with other data to direct winter maintenance crews more effectively to needed areas. Also, pavement conditions can be indicated by frequency, amplitude and rate data from vehicle suspension components.

Detroit Ford is also equipping a fleet of vehicles in the Detroit area near its headquarters with data reporting capability. This includes more than 20 employee shuttle buses that operate in the area, as well as 15 area police cars.

11.6.4 Indiana Real-Time Transportation Infrastructure Information System [16–18]

ZOOM Information Systems, under a grant from the state of Indiana, is developing a real-time transportation infrastructure information system (RTTIIS) based on FCD techniques. Other partners in the effort include Ford, Boeing and Purdue University, with Indiana DOT and the Federal Highway Administration (FHWA) providing requirements inputs for the project.

RTTIIS objectives are to collect road condition, traffic, hazard, and vehicle data in real-time, nonintrusively, and in a cost-effective manner, from road users as they go about their daily business. Processed information will then be provided to public agencies, fleet managers, and back to the drivers themselves.

Plans call for RTTIIS to be based on an open architecture. Demonstration applications will cover a diverse range including: driver information; traffic management; roadway condition and repair; operations, public safety and crash prevention; fleet management; law enforcement; homeland security; and defense.

Initial configurations will contain satellites, both broadcast and two-way, as key elements, although many communication channels will be supported for specific applications.

The work will focus on four research subprojects addressing the following questions:

- How can current and new vehicle sensors and systems be used to identify road, traffic, vehicle data and other characteristics onboard?
- How can this information be transmitted reliably and bidirectionally to millions of vehicles?
- What is the best architecture and mechanism for storing, aggregating and accessing the data in an open way that is in line with VII principles?
- How can this multivehicle information be analyzed to determine road, traffic, and vehicle information and report or display it in a way that is actionable?

The RTTIIS project began in May 2004 with architecture definition. The 21-month project will culminate with an end-to-end, limited functionality system demonstration, which is intended to lead to more extensive deployment.

11.7 Overall FCD Processing Picture [19]

Figure 11.5 captures most facets of the discussion above by showing the overall data flows that may occur in a floating car data processing operation. The left-most box labeled “vehicle” shows vehicle sensors feeding an onboard data collection system, which is generating probe messages based on comparing current data with the onboard database. Probe messages are sent to an onboard communications device

to be sent outward to the probe processing center. The land-side processing function receives data from many vehicles, processes the data, and fuses it with other data sources to deliver processed probe data to application providers and eventually to end users. Data flowing back to vehicles from the land-side processing center updates their onboard databases and manages message flow. Processed probe data also flows back to the vehicles, which is then used by onboard applications to deliver information to the driver and/or support vehicle systems.

11.8 Looking Forward

How might information derived from FCD techniques become a standard part of our transportation experience? With momentum in both the private and public sectors, it is likely that FCD systems will evolve gradually. It is certainly fortuitous that fleet penetrations on the order of 2% or less are sufficient for good traffic and weather data. The degree to which governments such as Sweden and the United States fund early deployment activities, as they have indicated, will be key to creating a critical mass of reporting vehicles.

Private-sector momentum also comes from the larger telematics industry, which seeks to provide a wide array of services to drivers; in fact, most experts agree that no single telematics application will present a sufficient business case and therefore packages of services are the way forward. Further, the car industry seeks to have continuing connectivity to vehicles for purposes of diagnostics and software updates. Therefore, there seems to be significant motivation to create a “data pipe” to and from vehicles in coming years.

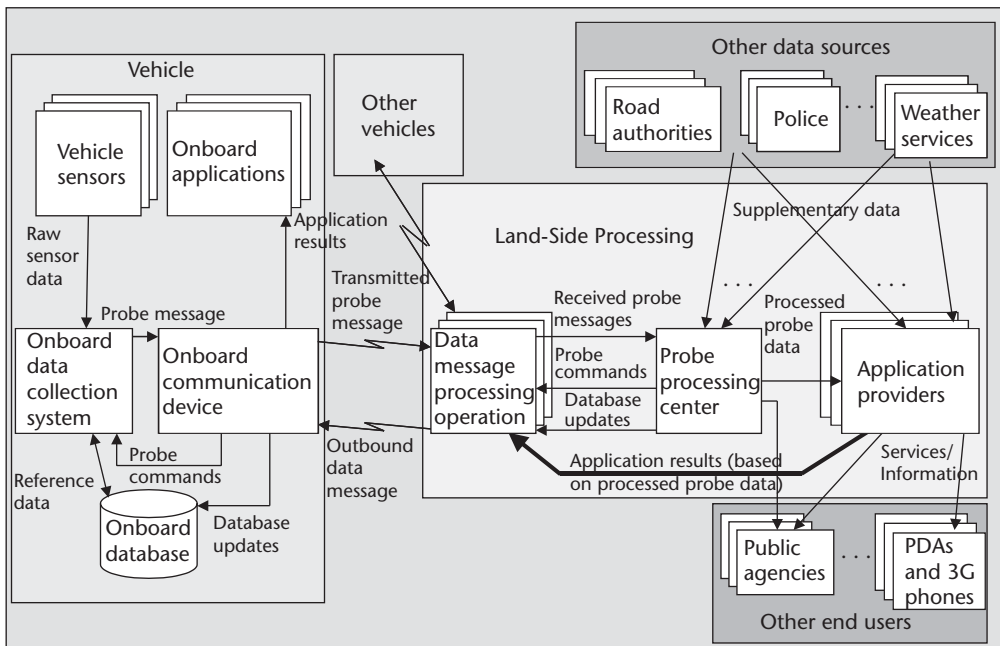


Figure 11.5 Typical FCD data flows. (Source: R. Weiland, Weiland Consulting.)

The role of consumer electronics and telecommunications players is also key. For instance, Motorola is working within the Ford FCD project to demonstrate the cell phone technology that could bring FCD-derived information inside the vehicle, and Nextel is working on developing the wireless backbone for the system.

In fact, although not discussed above, another precursor to fully vehicle-based FCD is GPS-enabled cellphones. Such units can provide speed, location, and direction; if they were to report data when speeds represented roadway travel, a basic picture of travel patterns could emerge.

From the public sector perspective, state DOTs see FCD as highly valuable in monitoring traffic and road conditions in real time, so as to better manage road and traffic conditions and provide information to the public. They see the possibility for significant cost savings, as FCD information begins to obviate the need for expensive roadside sensors.

As seen from the projects in Europe, first generation FCD systems are now in operation. Second generation systems that are more commercially viable are expected to be introduced within 2–3 years.

The BMW analyses referred to in Section 11.4.2 offered three scenarios as illustrations of how next generation FCD systems might come into widespread use over the long term [11]. The most conservative scenario calls for allowing natural market forces to lead. Here, it was proposed that possibly 15% of new mid-size through luxury vehicles sold would be XFCD-equipped by 2015, which would represent 4.3% of the total passenger car fleet at that time. The penetration level would be sufficient to provide modest performance in FCD-based data collection. Another scenario envisioned a coalition of German auto manufacturers, which together would advocate and stimulate the creation of XFCD capable vehicle fleets. Under this scenario, it was estimated that one-third of new mid-size to luxury models sold are equipped with XFCD by 2015, which would then comprise 10% of the total passenger car fleet. Based on their analyses reviewed above, 10% market penetration would be sufficient for very good performance in traffic data collection. The third and most optimistic scenario called for governments to join with vehicle manufacturers to promote XFCD. Here, penetration rates of 20% of all passenger cars could be expected by 2015, enhancing performance even further.

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IVs as Human-Centered Systems

This chapter brings together several topics that have in common “the driver” but are otherwise somewhat divergent. First, there is the driver as customer—what are their perceptions of ADAS, and their acceptance or interest in the systems based on those perceptions? Then there is the driver as system operator—what is the nature of driving and how might human and machine work together most effectively? Finally, there is the driver as a key, and fallible, player in the road-vehicle-driver triad—how can drowsy or distracted drivers be detected by vehicle systems, and what countermeasures can be applied to maintain safety?

The human factors issues that are invoked by these topics involve in-depth expertise, complex questions, and detailed research beyond the scope of this book; instead, the intent here is simply to introduce the reader to the issues.

Although there has been some outcry that the role of the driver is not adequately addressed when it comes to IV systems, in reality these systems are inherently human-centered. They must be, because of the commercial nature of most vehicle sales. Cars are a consumer product; customers must be satisfied for a product to be successful. Poor design and product debacles must be avoided at all costs because the company’s brand is at stake. In fact, this imperative creates such a high standard that significant time is added to the product development process before introduction specifically to address user issues. As noted in [1], “Future active safety systems will need to be transparent to the driver until they are absolutely needed. The key is to allow the driver to drive the car as the driver wants and only give assist when needed.”

The same is true to a lesser degree for truck and bus drivers—they must have at least a somewhat favorable opinion of a driver support system for it to be most effective. For instance, trucking companies considering new systems such as lane departure warning typically rely heavily on driver’s opinions, based on a few evaluation units, before making major investments to equip the entire fleet.

In essence, then, the driver is the water we IV fish swim in. While overt discussion of driver issues may not always be obvious, in fact driver needs and issues underlie every decision made in system design and development.

It is also my conclusion that, in general, IV-related human factors issues cannot be productively addressed at a generic functional level. Instead, very specific functional aspects must be defined in an iterative process between engineers and human factors experts for all of these systems.

This chapter surveys issues and ongoing research in these topic areas and is organized as follows:

- Driver perception and acceptance (user preferences, understanding of systems, perceived system benefits and drawbacks);
- Driverology (how do normal drivers drive in everyday situations?);
- Driver-vehicle interface (warning modes, learnability, comprehension);
- Driver-vehicle symbiosis (shared control);
- Driver monitoring and support (driver alertness, driver distraction, workload support, older driver support systems).

12.1 Driver Perception and Acceptance [2]

Assessing driver perception of IV systems and attempting to predict driver acceptance is a challenging arena with high stakes for the car companies. Customer reactions to such systems are subjective, information presented may not be absorbed or understood correctly, and a very sophisticated system can be perceived as “dumb” based on only a few anomalous experiences.

Further, drivers must not only understand and use a system properly, but they must perceive that the assistance provided is worth what they paid for it.

For more advanced functions such as LKA, a balance must be achieved between “over-trust” and “under-trust”—too much trust in the system creates dependence (and could reduce vigilance) and if there is not enough trust in the system, the product is not used and the customer may feel cheated.

It is also a fact of life that every driver-assistance system will have some limitations. For instance, LDWS may not work when lane markings are completely absent, lidar-based ACC systems may disable in heavy rain, and in cluttered environments obstacle detection systems may not correctly interpret the situation, leading to either false alarms or missed detections. Generally speaking, more robust systems could always be built, but at increased cost. Therefore, as research results move into advanced development and products are defined, key questions that must be addressed include the following:

- To what degree will drivers understand system limitations?
- To what degree will they accept (forgive) these limitations?
- Will the system be seen as valuable even with these limitations?

With regard to user perception, there are two key categories: those who are aware of the systems but have not experienced them, and direct users. Because early systems such as ACC have begun to play a role in advertising for new vehicles and the news media covers advanced system demonstration events, members of the public have generally formed opinions of these systems. Their perceptions are important to the eventual market success of specific products.

Automaker’s experience with ACC provides a promising indication. While hard data is closely held, all indications are that, with well over 100 million vehicle miles traveled by ACC-equipped vehicle owners, no incidents of serious concern have occurred. ACC satisfaction levels over 70% have been reported in driver surveys.

Various assessments of public knowledge and perceptions of IV systems have been conducted and some are reviewed here.

12.1.1 Perceived Positives and Negatives of ADAS Systems [3]

A study conducted by the Technical University of Delft in 1999 provides a good view into attitudes amongst average drivers at that time. Almost 500 Dutch drivers participated in the survey, which focused on obstacle detection systems, collision avoidance systems, adaptive cruise control, and the automated highway system. Participants in the survey received a basic description of each system, but had not experienced the systems directly. The results as shown in Table 12.1 are telling. On the negative side, distrust in the system operating correctly is obvious, such as concern that the systems will fail or brake unnecessarily. There is also strong opposition

Table 12.1 Opinions on Driver-Support Systems

<i>Obstacle Detection System</i>			
<i>Positive aspects</i>		<i>Negative aspects</i>	
Increased traffic safety	60%	Decreased traffic safety	5%
Encourages positive behavior changes	46%	Decreases attention	44%
Less attention required for driving	5%	System is irritating	41%
Reduced collision risk	42%	System can fail	39%
		System startles driver	25%
<i>Collision Avoidance System</i>			
<i>Positive aspects</i>		<i>Negative aspects</i>	
Increased traffic safety	42%	Decreased traffic safety	12%
Less attention required for driving	7%	Decreases attention	32%
Reduced collision risk	58%	System takes over control	65%
		Braking at dangerous moments	51%
		Braking at unnecessary moments	43%
<i>Adaptive Cruise Control</i>			
<i>Positive aspects</i>		<i>Negative aspects</i>	
Increased traffic safety	45%	Decreased traffic safety	9%
Improved traffic flow	47%	System takes over control	56%
		Impossible to drive fast	15%
		Unwanted headway	27%
		Braking at dangerous moments	70%
<i>Automated Highway System</i>			
<i>Positive aspects</i>		<i>Negative aspects</i>	
Always constant speed	40%	Decreased traffic safety	5%
Less attention required for driving	21%	System takes over control	56%
Improves traffic flow	65%	System takes away the fun of driving	39%
Saves energy	43%	Difficulty merging in and out of traffic	43%

Source: Hoedemaeker, 1999.

to a computer-based system taking over control of the vehicle. Concern over being startled by collision alerts was also high, highlighting one of the key challenges for system designers in defining warnings that are attention-getting without creating panic.

On the positive side, participants clearly saw the potential for improved safety and understood the traffic flow benefits offered by ACC and AHS.

Unfortunately, it is also the nature of the beast that incorrect or exaggerated opinions can exist in the public mind. A prime example from this study is the belief that ACC would prevent fast driving—showing an insufficient knowledge of such systems (particularly their on/off switches!).

12.1.2 User Perceptions Assessed in STARDUST [4, 5]

In the STARDUST project, user responses to ACC, stop-and-go ACC, intelligent speed adaptation, lane keeping, and CyberCars were assessed via questionnaires, field trials, and driving simulators. From a human factors perspective, one particular focus was to understand how drivers adapt to these systems within urban traffic flows in terms of the learning phase and long-term effects. Some results of simulator experiments with ACC and ISA systems are described here as examples of this work (the impact of lane-keeping systems to improve traffic flow in narrow lanes was reported in Chapter 9). User perceptions of the benefits and drawbacks of these systems are also reviewed.

ACC System The simulator trial with ACC indicated that drivers chose significantly lower top speeds when using ACC. The ACC System implemented on the simulator emulated the characteristics of early ACC systems introduced to the market. Drivers also used the brake and accelerator pedal more often and with more force compared to driving without the system. Researchers theorized that this was related to a possible lack of faith in the technology, and/or drivers experimenting with the system to better understand its function. Indeed, post test interviews indicated that abrupt braking events to disengage the ACC were related to distrust of the system. Drivers were expecting earlier braking than the system provided, and when they finally chose to intervene, more forceful braking was used.

The simulator studies also showed that drivers chose longer headways when driving with ACC than without. In terms of driver workload, driving with the ACC system at highway speeds was perceived as more mentally challenging (higher workload) than driving with ACC in low speeds. A longer exposure time to the technology could potentially affect this factor.

ISA System Simulator trials of ISA were conducted with a haptic-feedback ISA system in which the accelerator pedal became resistant when the speed limit was exceeded; further, the driver received a noticeable “kick” under the foot when the speed limit was passed. Results showed a significant reduction in top speed for the urban settings studied, and less lane changing compared to a baseline condition when on a motorway. Post test questionnaires showed some irritation with the “kick,” but overall drivers found the ISA system to be useful.

The STARDUST experience also confirmed the general trend that participants were more favorable towards a system after having experienced it (via a driving simulator in this case) than before.

User Acceptance In a survey of almost 1,000 people conducted by the STARDUST team, overall perceptions of the driver-assist systems examined were positive. The strongest support was for ISA, ACC, and CyberCars, followed by stop-and-go ACC systems and lane-keeping systems.

Respondents were queried about system benefits in several dimensions. They saw ISA and CyberCars as the strongest contributors to safety. CyberCars were seen as having the greatest positive effect on congestion relief. Both ACC and CyberCars were seen as being beneficial to the environment, with ACC viewed a winner in terms of fuel consumption. In terms of public funding, lane keeping, stop-and-go ACC, ISA, and CyberCars were seen as imposing high costs. This last item is curious, in that lane keeping and stop-and-go ACC essentially require no modifications to the infrastructure.

12.1.3 User Perceptions of ACC Users [6]

In a more focused project, the Dutch Rijkswaterstaat conducted a survey of 76 owners of vehicles equipped with ACC, augmented by interviews with 13 ACC users.

The results showed that a period of adjustment is necessary when first encountering ACC. Once accustomed to the system, drivers whose driving style was typically relaxed tended to brake more often and accelerate less often, whereas aggressive drivers accelerated more. In addition to motorway use, some drivers also used the system on nonhighway roads where speeds of over 80 kph were allowed, and in some cases on 50 kph roads.

Almost all drivers were positive about ACC because it increased driving comfort. The majority thought ACC improved road safety, and many said using ACC resulted in a more even speed, less speeding, calmer driving, greater following distance, increased alertness in traffic, and less frequent passing. At the same time, a considerable number said ACC sometimes led to reduced concentration.

12.2 Driverology

Understanding the driver-system interaction for IV systems relies on a fundamental baseline—how do drivers drive in normal situations? How do they make their moment-to-moment decisions in vehicle operations and their longer term trip-oriented decisions? Driverology is one term applied to these questions.

We know a great deal about the results of driver errors that result in crashes, but there has been a dearth of knowledge about ways in which drivers successfully operate their vehicles. For instance, we know relatively little about successful avoidance maneuvers, near-crashes, and driver errors that do not result in crashes. Here we review several approaches that are being used to expand the knowledge base in these areas.

12.2.1 Driving Simulators

One of the key tools used in recent years to understand driving is driving simulators. These facilities have become very sophisticated in creating a realistic virtual environment. The driver sits within an authentic vehicle cockpit and has a full view of animated traffic, to include side and rear mirrors. In the most sophisticated systems,

the traffic responds to the driver's actions as would happen on the road. An endless variety of road configurations can be displayed.

Using simulators, critical maneuvers or crash situations can be presented to the driver and their simulator vehicles can be equipped with crash avoidance functionality to enable the evaluation of functional concepts as well as driver-vehicle interface approaches.

In advanced simulators, the vehicle itself is on a moving base so that kinematics can be directly experienced by the driver to increase realism. One such simulator is the National Advanced Driving Simulator at the University of Iowa, which came on-line in the late nineties to serve U.S DOT and industry needs and was considered state-of-the-art at the time. However, several car companies have since implemented even more advanced simulators, the most recent of which being Ford's VIRTTEX, whose main purpose is to study driver workload and distraction issues that can arise with in-vehicle electronic devices [7].

12.2.2 Test Track Evaluations

Evaluating driver-system interactions on test tracks is another research method, but of course challenges exist in creating realistic crash scenarios that are not in fact dangerous to the test subjects. For evaluation of forward collision warning systems, for instance, researchers within the U.S. CAMP project constructed a long boom, at the end of which was attached the sliced-off rear portion of a vehicle, including the back wheels. The boom was designed to be energy-absorbing in the event of crash contact and was towed by a regular vehicle ahead of the test vehicle. This enabled researchers to initiate hard braking on the leading "vehicle" and assess various warning modes for drivers in the following vehicle without putting them at risk.

Further, at a U.S. DOT testing facility, a test track has been configured with a foam wall alongside the test track roadway to emulate the concrete barriers commonly found on highways. Drivers are asked to "steer at the last second" to determine a safety margin for providing road departure warnings.

12.2.3 U.S. DOT Naturalistic Driving Study [8]

Of course, even the most "realistic" simulators and test track experiences are not "real." Possibly the richest data can be gathered by monitoring drivers as they drive on actual roads. The drawback here is that the incidence of safety-critical events is very low on a per-vehicle basis. Therefore, if such data is to be collected, many vehicles have to be equipped.

Such an ambitious endeavor was initiated in 2002 by the U.S. DOT. In the agency's naturalistic driving study, 100 vehicles were equipped for one year with unobtrusive instrumentation to observe regular drivers on actual roadways. In fact, this was the largest instrumented vehicle study of its type conducted to date worldwide. The U.S. DOT's intent was to deepen its scientific understanding of how drivers drive in normal situations to provide a baseline for other research.

The vehicles are equipped with video cameras to monitor the driver's face and body movements, as well as the forward traffic situation. Additionally, a significant amount of quantitative data is collected regarding vehicle parameters. Given the large number of equipped vehicles and their time on the road, the resulting data set is

expected to exceed three terabytes. It will serve as a rich resource for researchers for years to come.

Researchers report that, in addition to significant amounts of basic data, over 40 crashes occurred in the equipped vehicles, providing a unique opportunity to understand crash dynamics. Over 300 near crashes occurred as well. Full analysis of the data is expected to be completed in late 2004.

12.2.4 Driver Performance in Traffic [4]

As noted in Chapter 9, driver performance in traffic is a key contributor to congestion. IV systems offer an opportunity here. In queuing situations, such as at traffic signals and motorway traffic jams, vehicle-level delay occurs in starting movements because of driver reaction time, maneuver delays, mechanical delays and human error. Driverology research conducted in the STARDUST program focused on quantifying such delays. Results showed that start delays on motorways were significantly higher than those on urban streets. The mean start delay on motorways was 1.27 seconds, compared to 0.93 on urban streets. This is to be expected, because drivers are in a relatively familiar and predictable situation when at a traffic signal, compared to the more or less random movements when in stop-and-go motorway traffic. This data led researchers to conclude that driver-assist systems such as stop-and-go ACC would likely have greater utility on motorways as compared to urban street applications.

STARDUST researchers also measured headway choices using a vehicle instrumented with a lidar rangefinder. The data collection covered urban motorways, urban arterial roads, and city streets in Oslo, Paris, and Southampton. The analysis focused on low-speed traffic behavior, particularly in stop-and-go traffic. Key parameters collected were time gap, distance gap, acceleration, deceleration, braking frequency, start delays, and stopping distance gaps. Results from 65 hours of driving included the finding that time gaps decreased as following speeds increased when below 60 kph and stabilized above 70 kph and further, that time gaps had greater variability in the lower speed range.

12.3 Driver-Vehicle Interfacing

The driver-vehicle interface is a core aspect of the IV system. Here we review driver warning modes and key factors for DVI subsystems and provide some particular examples as to the learnability of such systems.

12.3.1 Driver Warning Modes

For active safety systems, a wide variety of driver warning modes have been noted in describing ADAS systems in previous chapters. They are:

- Audible;
 - General;
 - Directional;
- Visual;

- Dashboard icon;
- Heads-up display;
- Haptic;
 - Resistance in accelerator pedal;
 - Resistant torque in steering wheel;
 - Tightening of shoulder belt;
 - Deceleration sensed when light braking applied;
 - Seat vibration;
 - Steering wheel vibration.

Significant research has been conducted worldwide in understanding how to best present information to the driver. This is a major research question within the GM-U.S. DOT ACAS project, for instance. There is no single “best way”—the DVI must be defined in the context of the specific functional goals of a driver support system.

12.3.2 Key Factors in Successful DVI

The European 5FW RESPONSE project defined six factors important to the successful interaction between the driver and active driver-assistance systems [9]. These are described as follows:

- **Perceptibility:** Translating the system function into an accurate mental model;
- **Comprehensibility:** Understanding the system function, operation, and situational limits;
- **Learnability:** Ability of the driver to quickly and accurately learn to control the system and assimilate information provided by the system;
- **Trust:** The degree to which the driver believes the system will perform its function;
- **Misuse potential:** The possibility of drivers choosing higher risk behaviors due to the “safety net” provided by the system (also called “risk compensation”);
- **Error robustness:** The ability of the system to maintain a safe state in the presence of driver usage errors. Ideally, an error robust system will achieve the driver’s intended result even with some degree of incorrect usage.

In Europe, current publicly funded research in DVI focuses in the 6FW AIDE integrated project and the German INVENT program.

12.3.3 Learnability of ADAS [10]

Driver-oriented issues that must be addressed in the product design process include learnability, the efficient perception and interpretation of warnings, and any modes that could annoy drivers or provoke errors in use. INVENT researchers are seeking to define simple, self-explanatory driver-assistance systems that prevent misuse but are also robust if errors happen. Two representative systems have been implemented on a moving-base driving simulator: a lane change assistance system and the traffic congestion assistant.

To assess learnability, researchers are focusing on the following:

- System-related criteria (fault-free and efficient operation; usage of all system functionalities);
- Safety-related criteria (safety-critical operation, safety-critical driving faults);
- Driver-related subjective criteria (system acceptance; stable workload; subjective assessment of comfort and safety).

Lane Change Assistant The lane change–assist system is less challenging in terms of learnability, as its function is limited to providing information and warnings as needed. It is only operating when the driver has activated the turn signal, so that the driver intention to change lanes is clear, and he or she is already attuned to the type of information being presented by the system. In the experiments, three warning modes were used: an LED display in the side mirror, a warning sound, and tactile feedback in the form of vibration of the turn indicator lever.

Subjects in the experiment drove for 20 minutes without the lane change assist followed by 20 minutes with the system activated. The results were quite positive, in that almost no user errors were made, turn signal usage increased, and the driver’s subjective assessments were favorable.

Traffic Congestion Assistant The traffic congestion assistant (introduced in Chapter 9) was chosen as an example of a system with a high level of automatic vehicle control, which invokes a completely new and different experience for the driver. The TCA provides longitudinal and lateral control on highways in congested traffic situations. In the experiments, the low-speed control was combined with a conventional ACC system to cover the complete speed range.

Driver errors were observed and classified into the following categories:

- Operational errors in using the system;
- Critical take-over situations;
- Driving errors due to distraction effects while operating the system;
- “False alarms” (driver takes over control unnecessarily, indicating mistrust);
- Errors based on incorrect understanding of system functionality.

During the experiments, the researchers noted three sequential phases of learning as shown in Figure 12.1. In the first phase, the drivers were becoming accustomed to the TCA, making errors in its use as well as driving errors. Because they were neglecting the primary driving task, more critical safety situations occurred during this phase. Drivers rated this phase as stressful, an assessment that was supported by increases in measured heart rate. Researchers concluded that this phase was completed by the end of the third lap in the simulated congested driving route.

Drivers began to show more trust in the second phase and showed indications of becoming more accustomed to the “feel” of the system. This was indicated by a decrease in the number of false alarms for some drivers. However, others continued to be reluctant to rely on the system and continued to take over control when approaching a vehicle ahead.

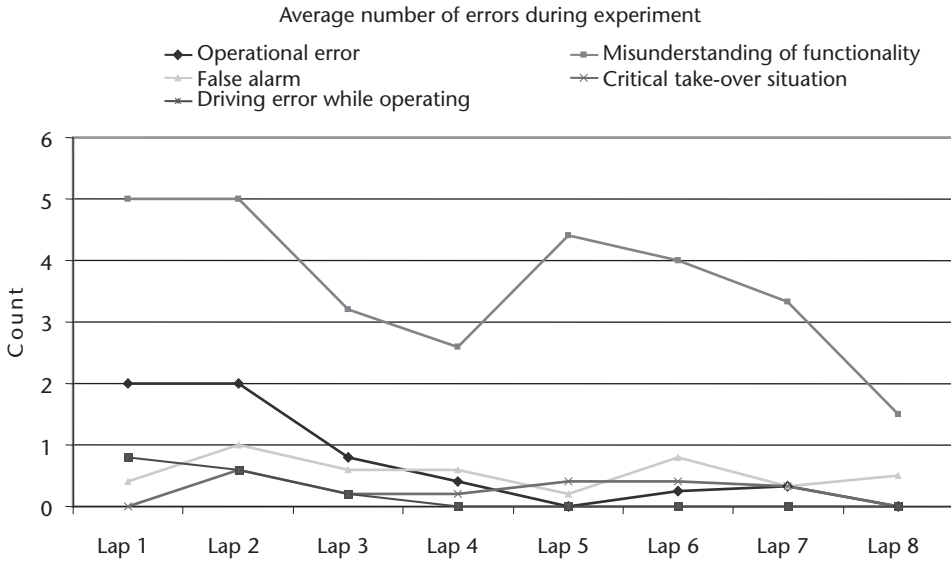


Figure 12.1 Errors observed while drivers used the INVENT traffic congestion assistant in a driving simulator. (Source: INVENT FVM.)

The driver’s active engagement with the system decreased in the final phase, showing adaptation of the driving behavior to the assistance function. At this stage, errors in operating the system are largely acceptable and do not create safety-critical distractions. Researchers noted that the driver’s subjective ratings of the system at this phase became more positive.

Based on these and other results, INVENT researchers are working to define the optimum “self-explanatory ADAS,” which requires a minimum amount of learning from the driver and in particular eliminates learning modes which result in safety-critical traffic situations. Two approaches are being pursued:

- A learning-adaptive tutor module giving the driver additional advice and explanation according to the current stage of his or her learning;
- A driver-adaptive feedback method based on driver-type categories. For instance, feedback would be different depending on the driver’s attitude towards technology.

By the end of 2005, the research team plans to complete design guidelines for start-up instructions, online help, communicating system limits, error tolerance and robustness, and strategies for prevention of misuse.

12.4 Driver-Vehicle Symbiosis

This section addresses various ways in which the driver and vehicle system can operate in symbiosis to operate most effectively. ACC and safety systems are briefly addressed, followed by a more in-depth look at driver effects when using lane-keeping assistance systems.

12.4.1 ACC Systems

When ACC is sold to a customer as an option on a new car, the buyer may watch a video to explain the system and typically does an orientation drive with the salesman. In fact, if “training” on the system requires more than this, customers will balk.

It appears that the classic customer experience with ACC proceeds through several phases, which may be applicable to future ADAS systems, as well. During the first several hours of using the system, the customer is learning the basic ACC functionality. Then, over the next several days of use, the customer tentatively uses the system, gaining confidence and deepening their understanding. For the following few weeks, the customer defers to system—when ACC is engaged, the driver takes a secondary role. Finally, a steady state situation emerges in which the customer partners with system (i.e., the driver provides control inputs along with the ACC system). For example, the driver might accelerate when changing into an unobstructed lane and then release the pedal to allow the ACC system to continue speed control.

12.4.2 Levels of Human-Machine Cooperation [21]

To frame the human-machine relationship for safety-assist functions, ARCOS researchers in France have established three levels of human-machine cooperation:

- The “meta level” focuses on a “perimeter of precaution” with a time scale of approximately 3–15 seconds. Here, the goal is to assist the driver in situational awareness and perception of the traffic and road dynamics.
- The “planning level” focuses on a “perimeter of cooperation” with a time scale of approximately 1–3 seconds. Here, functions must be allocated between the driver and automatic systems to maintain safe driving—the driver still has time to respond when warned of a situation and at the same time the safety systems may be enhancing vehicle functions such as braking ability or seat belt tension.
- The “action level” focuses on a “perimeter of safety” with a time scale of less than one second. Here, automated intervention is invoked to avoid a crash.

12.4.3 Driver Vigilance with Advanced Assistance Systems [11]

Developers of the Honda intelligent driver-support system, which provides lane-keeping assistance and ACC in highway conditions, have performed extensive testing of driver vigilance while using the system. The system has been available on the Accord in Japan since 2002.

At first glance, it would seem that simultaneous operation of LKA and ACC would result in a drop in the driver’s vigilance, because much of the lateral control and almost all of the longitudinal control is handled by those systems in steady state conditions. In case of an emergency, however, the driver’s attention is needed instantly to respond to situations beyond the functional limitations of the systems, such that vigilance must be maintained. In designing the HIDS, Honda’s aim was to define an assistance system that did not result in loss of vigilance by creating a “copilot” system in which driving tasks are shared between the driver and the system.

In normal highway driving, drivers tend to focus on the lane they are traveling in and on any vehicle just ahead of them to maintain proper lane position and headway. In effect, this leads to a narrowing of the field of vision, and also accelerates rates of physical and mental fatigue. The HIDS was designed to free up drivers' attention, so that they can monitor the road scene more comprehensively, at the same time reducing fatigue. The premise is that vigilance is increased by giving the driver assistance in monotonous driving tasks.

A key principle implemented in the HIDS is that the system actively monitors driver steering inputs and will only continue operating if the driver is actively engaged in parallel with the system inputs. Algorithms monitor steering wheel torque applied by the driver and calculate the total torque needed to maintain the lane. If the driver does not provide enough torque to reach a reference point, or if the driver has not provided a steering input over a certain period of time, the assistance temporarily stops, and the driver is alerted to perform an operation which causes him or her to reengage. This process is illustrated in Figure 12.2.

Honda engineers tested the system on motorways by asking test subjects to drive maintaining a fixed headway to the vehicle ahead and maintain the vehicle within the lane, at a fixed speed of 100 kph.

To test the premise that HIDS would allow better visual scanning of the road environment, the driver's eye movement (eye angle and angular speed) was monitored. The results shown in Figure 12.3 show that horizontal scanning doubled, and vertical scanning increased as well.

With regard to eye angular speed, eye movements during conventional driving were slower compared to those when using HIDS. Researchers concluded that there is a reduction in the amount of time the eye movement is fixed while using HIDS (i.e., the eyes are more agile). Again, this supports the thesis of improved environmental scanning.

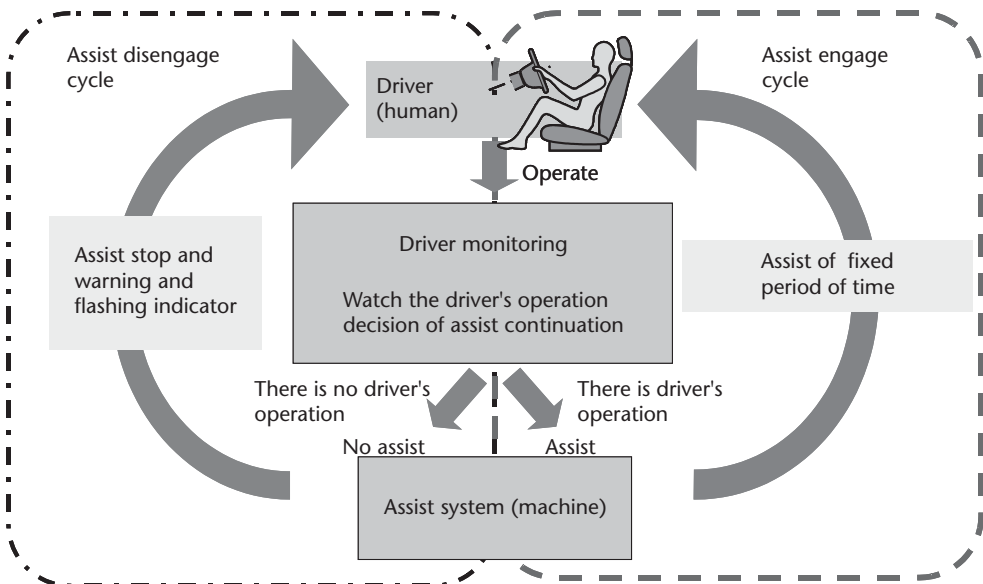


Figure 12.2 The human/machine interaction system implemented in the Honda HIDS system. (Source: Honda.)

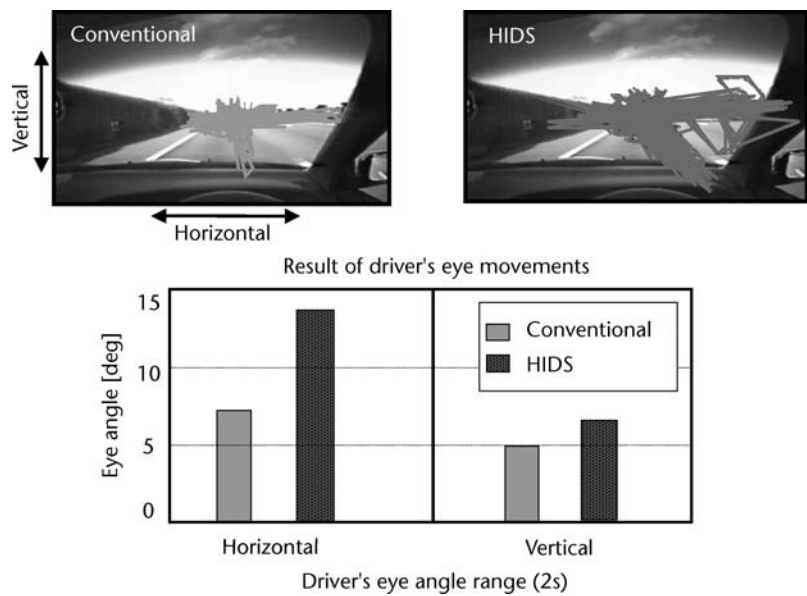


Figure 12.3 Eye angle measurements of driving with and without HIDS. (Source: Honda.)

Honda researchers also investigated drivers’ subjective perception of system benefits and how the system affected them. Four evaluation items were defined:

- Ease of becoming accustomed to the system;
- Amount of assistance;
- Driver’s alertness state;
- Level of workload reduction.

Fifty drivers drove the system for 30–60 minutes on expressways. Ninety-two percent of respondents reported that HIDS was easy to become accustomed to. Forty-eight percent judged the level of assistance to be the “right amount” and another 48% felt it was “slightly insufficient.” In terms of alertness, only 2% became drowsy. Most (58%) reported no change and 13% reported feeling more refreshed. Eighty-eight percent of respondents felt there was a reduction in workload.

Similar vigilance results were obtained in testing conducted by Nissan. Alertness was assessed on a test track with test drivers driving two-hour segments to compare the use of ACC only versus ACC and LKS. Alertness, based on the widely accepted measure of eyelid blink rate, showed no significant difference between ACC only and ACC/LKS [12].

12.5 Driver Monitoring and Support

Driver monitoring takes two primary forms: detection of driver physiological impairment and detection of driver inattention due to workload.

Systems to detect drowsiness have been the subject of intense scientific work for many years. While such systems have been developed, they have not yet been successfully implemented in mass-market vehicles as products. Driver workload managers have been successfully prototyped and are now being evaluated. Both types of systems are described here.

Additionally, the special needs of older drivers call for some form of driver support, so that they may continue to drive, and drive safely, longer in their lifetime. This is especially important as demographics worldwide show large increases in the numbers of senior citizens in the coming decades.

12.5.1 Drowsy Driver Detection and Countermeasures [13]

To detect drowsiness in a human being, physiological measures such as brain activity can be used, but these require contact with the driver to take the measurements. For automotive systems, unobtrusive noncontact techniques must be used. Further, the ideal system will detect the precursors to drowsiness at least several minutes before onset, giving the driver time to rest or take other action.

Prototype drowsy driving warning systems have been developed by the automotive industry, beginning in the 1980s by Nissan. Steady progress has been made to implement a robust system that does not irritate the driver with false alarms—to be told by one's car that you have become deficient in your driving can be quite a touchy subject—such that the system must be very accurate. Automotive product introductions are expected within the next five years.

Head-Tracking [14] One innovative method of drowsiness detection focuses on tracking head movements. The Proximity Array Sensing System developed by Advanced Safety Concepts relies on the capacitance of the driver's head relative to an electrically charged plate that is integrated into the ceiling of the occupant compartment above the driver (Figure 12.4). Very minute head movements, which can be early indicators of the onset of drowsiness, are detected in this way.

Evaluations of PERCLOS with Truckers [15, 16] The lion's share of the attention for drowsiness detection has been on monitoring eyelid movements. The U.S. DOT performed research to define and validate the PERCLOS approach, which refers to "percent closure" of the eyelids averaged over a specific time period. For example, if a driver has four eye closures of 3 seconds each (totaling 12 seconds) over a one-minute period, the PERCLOS value would be 20%.

Researchers at Carnegie-Mellon University played a key role in this research. They implemented the Copilot system, which used a camera and infrared illumination combined with image processing to identify a driver's eyes. Their technique relied on the fact that IR reflected from the eyes causes the pupils to show up very clearly in images. Once the eye was identified, the degree of occlusion by the eyelids could be measured. The system was designed with a field of view sufficient to accommodate a fair degree of head movement (over 40 cm). The driver interface consisted of both a visual display (showing increasing drowsiness) and an audible advisory that sounded when a programmed threshold was reached.

CMU performed simulator experiments with 16 commercial drivers using a high-fidelity truck simulator to evaluate this approach. Two alerting stimuli were

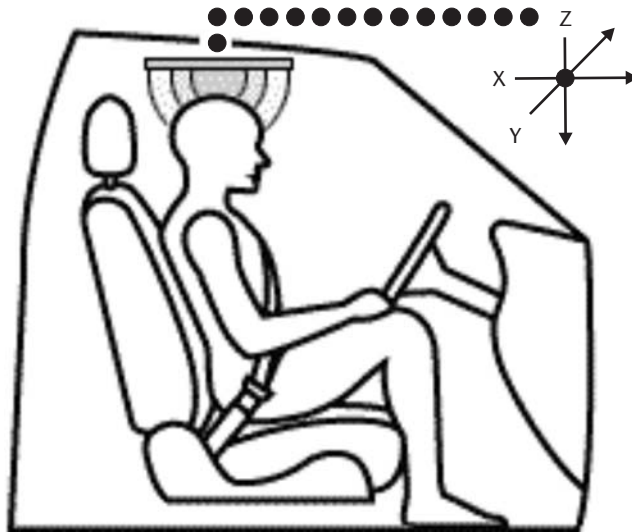


Figure 12.4 The Proximity Array Sensing System tracks head movements to detect drowsiness. (Source: Advanced Safety Concepts.)

used once drowsiness was detected: a initial voice warning alert and a peppermint scent coupled with a buzzer alert if drowsiness was sustained or reached high levels. (Scent has been shown to be an effective mode for stimulating the driver in such conditions.) During the testing, drowsiness was successfully detected. Typically the alerts did not progress to harsher levels, as drivers seemed be able to respond appropriately after initial alerts. Drivers favored the audible tone as the alert mode.

Based on success with this experimentation and small-scale trials, the U.S. DOT has conducted field operational tests with heavy truck drivers to assess PERCLOS performance. Out of this work came the Driver Fatigue Monitor (DFM), a commercial product developed by Attention Technology, a spinoff of CMU. Based on the PERCLOS technique, the DFM is designed to alert drivers of fatigue an hour before it reaches dangerous levels. It incorporates both audible alarms and visual feedback to show a driver how long their eyes were closed.

European AWAKE Project [17] The European 5FW AWAKE project has taken the most comprehensive approach thus far in integrating drowsiness monitoring within a total driver support concept. The project was led by the Technical University of Athens and included automotive partners DaimlerChrysler, Fiat, Siemens, and Autoliv, as well as a host of research organizations.

The objective of AWAKE was to increase road safety by reducing crashes caused by driver hypovigilance (i.e., drowsiness). The AWAKE system monitored both the driver and the road environment to detect hypovigilance in real-time, integrating multiple parameters. Information on the road environment, personalized driver characteristics, and advanced detection techniques were fused so as to create a more robust system.

In the AWAKE system, a hypovigilance diagnosis module detects driver hypovigilance in real time using driver eyelid behavior, steering wheel grip force, and lane-keeping performance. The researchers set a goal to achieve an accurate

diagnosis level of 90% and a false alarm rate below 1%. System performance is enhanced through personalization via a smart card inserted by the driver into an onboard reader—specific parameters regarding the driver's alert driving early in the trip are saved on the card and used as reference points for detecting fatigue.

A traffic risk estimation module assesses the complexity of the surrounding traffic by matching data from a digital map, satellite positioning, a forward-looking radar, and a driver gaze-tracking system. The output of the traffic risk estimation module is fused with the hypovigilance diagnosis module to feed the driver warning system and determine the most appropriate level of warning.

If a driver is diagnosed as awake, only imminent collision and imminent speed warnings (for curves) are activated. If the driver instead is showing signs of drowsiness but the diagnosis is not certain, advisory warnings are provided in addition to imminent warnings. Finally, if drowsiness is clearly present, drowsiness warnings are activated, with more urgent warnings provided in complex traffic situations.

Acoustic, visual, and haptic warning modes are employed. The acoustic warning includes tones as well as voice to indicate the reason for the warning. Visual alarms include icons appearing in the rearview mirror. The haptic alert is provided by a vibrator attached to the seat belt lock, which creates a stimulus that can be felt along the entire seat belt.

The AWAKE system was integrated into both driving simulators and demonstration vehicles for evaluation. The work also included an analysis of legal frameworks for such a system and the creation of recommendations to the insurance industry with regard to drowsy driver detection systems.

12.5.2 Driver Workload Support [8, 18]

Driver distraction, particular from mobile phones, has become a hot topic in recent years. As a result, research into the issues involved has ramped up. One of the key needs has been to define ways to measure distraction and driver workload in general. The U.S. DOT IVI program, working with the automotive industry through the Collision Avoidance Metrics Partnership, has focused on research into understanding and minimizing distractions that may result from in-vehicle information and telematics systems. The partnership's approach is to develop metrics and methods to quantify how attentional demands affect safety-related driving performance and then develop industry guidelines for in-vehicle systems.

What if, however, the vehicle systems could monitor and respond intelligently based on the demands placed on the driver in real-time? This is the focus of a project cofunded by the U.S. DOT and Delphi Corporation called SAV-IT. The system monitors the driver's attention placement using gaze tracking and from this continuously assesses the driver's level of distraction. Gaze-tracking is performed by an advanced video/IR system that uses stereo vision cameras integrated into the instrument panel to capture both the driver's head orientation and eye gaze angle [19].

Further, similar to AWAKE, the situational threat based on surrounding traffic is also assessed. By combining these assessments, the system prioritizes or even suppresses information presented to the driver based on traffic complexity. For instance, in a demonstration provided to the author, traffic ahead was moderately dense at highway speeds; when the driver was looking at traffic, the integrated mobile phone display was fully functional. However, when the traffic became very dense and windshield wipers

were switched on due to rain, an incoming call was suppressed and the driver was notified that a message was taken in lieu of ringing the phone.

Researchers are also optimizing collision warning alerts based on driver attention—if the vehicle ahead suddenly brakes while the driver is looking away from the road (at the rearview mirror, for instance), then an alert is issued sooner than if the driver is looking directly at the hazard. SAV-IT is planned for completion in 2005.

Other driver workload manager prototypes have been developed by Volvo (Intelligent Driver Information Manager) and other car companies, as well as Motorola. The European 5FW COMUNICAR project focused on driver workload management, as well.

12.5.3 Older Driver Support [20]

In Japan, the National Institute of Advanced Industrial Science and Technology has defined the “ITS View-Aid System,” in which driver monitoring is integrated with driver assistance to make warnings more driver-adaptive and minimize any irritation from needless or irrelevant alerts. A key aspect of this activity is to develop techniques to adapt to older drivers. In Japan, the fatality rate for drivers over 65 years of age is double the national rate (such statistics are similar in the rest of the world).

In the system, shown in Figure 12.5, visual and audible displays are optimized for the elderly and driver warnings are tuned based on the driver state (level of alertness, gaze direction, age), as well as the road condition and current intervehicle distance.

12.6 Summary

In this relatively short chapter, we have covered a lot of ground. I hope that this review has provided an indication as to the degree to which researchers are delving into the issues relating to driver-machine interactions with IV systems. However, it

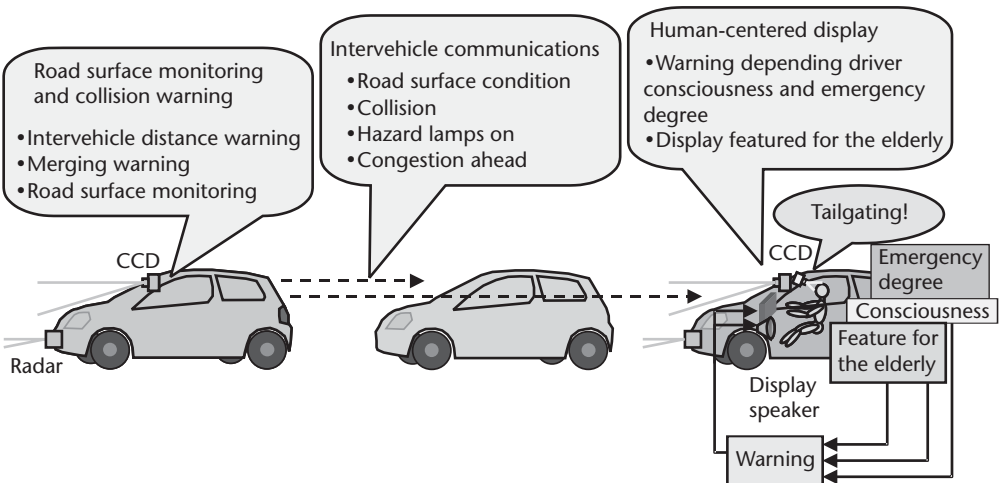


Figure 12.5 NAIST human-centered ITS View Aid system concept. (Source: National Institute of Advanced Industrial Science and Technology.)

must be stressed that the projects described here are but a small fraction of the total research in human-related aspects of these systems.

User perceptions of IV systems will continue to be a bit of a wild card—but this is of course a classic issue for consumer products and addressing it falls to marketing departments within the car companies. Since the TU Delft and STARDUST studies were conducted several years ago and ADAS systems have steadily increased their profile in the public eye since then, it would be interesting to know the results of similar surveys if taken today.

System understanding is in the hands of product design teams, including human factors experts, who both assess the strengths and weaknesses of system designs as well as optimize them. While there is more work to be done, sophisticated tools and techniques exist to perform quite thorough assessments, such that by the time a product reaches the market, it is fairly understandable to users and robust in the presence of any misuse.

As ADAS systems become increasingly integrated and offer more comprehensive driver support, automotive designers are well aware of the vigilance issues that come into play and so far appear to have found an appropriate balance between driver support and driver vigilance.

To further insure that the driver's attention is where it should be, we are nearing the point at which driver monitoring is introduced to the marketplace, both in terms of drowsy driver detection and driver workload support.

After all, though, these systems will never achieve perfection. What if something does go wrong? What about that one driver in a million who misunderstands the system, has a crash, and also has a good lawyer? Legal issues and other challenges to product introduction are covered in the next chapter.

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IV Systems Interacting with Society and the Market

This chapter addresses broader societal aspects of IV systems as well as some of the many challenges in product introduction that go beyond technical issues. Ways of addressing these challenges are reviewed as well.

Government policy plays a role in terms of regulations (or lack thereof) and can also play a role in accelerating market uptake via purchase incentives for IV systems. Governments also define policy, which may or may not be supportive, based on macrolevel cost/benefit analyses of such systems.

There is a wealth of market issues affecting the sale of ADAS, dominated by public awareness and public perception of the systems. Fundamentally, car companies exist to sell cars, not safety systems explicitly. For any individual company, ADAS must support their sales strategy.

Courts play a major role in stimulating discipline for manufacturers in product design and testing (in the ideal case) and in potentially slowing market introduction when business risks are perceived as too high. In the United States, liability concerns typically delay market introductions by two to three years. How many lives could have been saved in the United States if systems already on the market in other countries had been introduced by now?

However, the territory is a bit treacherous. If ADAS were to malfunction or be misunderstood by users so that frightening things, or even crashes, happen, public confidence in the systems can drop like a stone. Further, this can reverberate to affect introduction of similar systems. The public image of car companies can suffer immensely from such instances—and if public concern is great enough, legislators can be spurred to enact new laws affecting or even prohibiting the systems, laws that may be too “broad brush” and have a chilling effect on the entire range of active safety systems.

Of course, the converse is true as well. If the systems operate so as to dramatically avoid crashes, this will create “success stories” that will play very well in the media and create consumer demand. Such was the case with airbags initially when lives were being saved, and then airbag fortunes turned downward sharply when child fatalities occurred in isolated instances. The recovery from that misfortune has been slow and arduous. In this case, the airbag concept survived because the public saw the fundamental benefit and the consumer demand turned to a desire for smarter airbags rather than being against airbags fundamentally.

This chapter offers a brief review of some of these issues. We start with a broad focus at the societal level, addressing the roles played by both governments and

industry to bring IV systems successfully to market. Then attention turns to a variety of market issues, including a review of market introduction factors, steps towards promoting product awareness, tort liability issues, and instituting purchase incentives. This is followed by a review of government policy and regulatory issues, both in terms of vehicle regulations and radio spectrum allocation. We then address extensive work that has occurred in Europe to address nontechnical market barriers to ADAS product introduction and ongoing work to develop a Code of Practice (CoP) for design and testing of ADAS. Our final topic is a quick review of activities to establish international standards for active safety systems.

13.1 Societal Considerations [1–5]

At a societal level, one can examine the various roles and interactions of governments and industry. Generally speaking, the government must play a role in ensuring safety is not affected in any negative way by new technology in cars. On the positive side, they can also assess safety benefits offered by IV systems and publicize this information to give consumers greater confidence in the systems. Further, industry looks to government to remove any regulatory barriers to the introduction of these systems and even promote its purchase through incentives and other means when appropriate.

Another obvious government role is to provide roadside communications at key locations (such as intersections) to support cooperative vehicle-highway systems. The “chicken and egg” issues discussed in previous chapters must be worked out, so that individuals who buy vehicle systems that communicate can find communications partners and thereby get value for their money. This is a key aspect of current discussions regarding VII in the United States, in which “synchronized deployment” of communications equipment both within the cars and alongside the roads is being explored.

The industry’s priority is to control the timing of market introductions based on the readiness of technology and cost issues. The twin pressures of maintaining their public image and profitability combine to provide a high level of confidence that systems, once introduced, will perform as designed. Competition within the industry plays a key role in moving active safety systems to market, as technology is valued as a differentiator between product offerings. With regard to cooperative systems, as discussed in Chapter 9, some automakers are focusing their system development so as to avoid any interaction with the infrastructure at all, instead relying on vehicle-vehicle interaction. This is because, in Europe particularly, there is doubt that a sufficient number of countries will install an adequate density of standardized communications infrastructure, given the diversity in national priorities.

Government and industry can work together to manage public expectations for the introduction of these technologies. Cross-industry activities to harmonize system aspects and/or create standards are also highly important, and some examples are discussed later in this chapter. The eSafety forum and working groups in Europe are an excellent example of government and industry working together toward common societal goals.

Wide-ranging societal impact analyses have been conducted by many of the European projects, including CARTALK, AWAKE, and, in particular, ADASE2.

This in part reflects the public funding of the projects and also serves to provide government policy-makers with a broad perspective as to how these systems fit within the larger society. In Germany for instance, the INVENT cost-benefit analyses focus on both individual and macroscopic views, to support public policy decisions and provide a methodology for profitability calculations for manufacturers.

The European ADASE2 project recommended ways in which both government and industry could accelerate the pace of ADAS implementation and the overall success of these systems.

Recommendations for action from the public sector are listed as follows:

- To find ADAS champions at the national level who will establish a supportive policy framework and work to include all key stakeholders;
- To establish the effectiveness of ADAS via collecting better crash data, evaluation of crash data, macroscopic risk-utility analysis, and field operational testing;
- To institute proactive information campaigns to inform and train of the consumer, such as that used with seat belts;
- To introduce fiscal incentives, such as that used for pollution standards;
- To provide an effective legal and regulatory framework;
- To remove regulatory barriers;
- To provide infrastructure support (i.e., wireless communications).

With regard to crash data, current crash databases are of limited usefulness, as they have essentially been established with only passive vehicle safety in mind and the data fields reflect this. Many are now advocating the establishment of a European accident data bank focusing on vehicle safety as a whole and including precrash data so that active safety systems may be more thoroughly evaluated and proven.

Across the various governments, there is broad agreement as to the high-level safety vision, but disagreement as to how to get there. ADASE2 noted that, generally speaking, ADASs will not rise higher on government policy agendas until there is “proof” of their safety benefits.

Recommendations for action from the automotive industry were the following:

- To further develop system usability, including transparent functional presentation and ease of operation;
- To address “duty of care” and “reasonable safety” in a CoP agreed upon industry-wide.
- To establish stable processes in ADAS development and system validation;
- To harmonize particular system functions, as appropriate, to avoid customer confusion;
- To perform risk-benefit analyses on the microscopic level.

The EuroNCAP program may come into play as well for active safety systems. EuroNCAP uses a “star” system to indicate the safety level of a vehicle in terms of occupant protection. Similar ratings are done in the United States by the U.S. DOT

and the Insurance Institute for Highway Safety. These programs have been successful in translating engineering-level safety performance into a form understandable by consumers, such that star ratings are commonly found in advertising for car models. In Europe, work is currently in progress to extend the NCAP program to cover other aspects of vehicle safety, such as braking stability, lighting, and ergonomics.

E-Safety working groups in Europe are now examining the possibility of extending the NCAP approach to a “total safety” concept, incorporating both passive and active safety. Such an assessment procedure, while more challenging to create and execute than basic crash testing, could help significantly in consumer education and help drivers understand the limitations of new ADAS. However, such a rating system should be designed very carefully to avoid creating confusion for buyers or misrepresenting system capabilities.

The relative status of various societal and market factors was summarized within ADASE2 in the form of Figure 13.1. Figure 13.1 shows circles on a grid to indicate the relative state of technology, HMI, legal/social issues, political/societal issues, and infrastructure support (where applicable) for selected ADAS. A scale of 1 to 5 is used, with 5 being the strongest position.

13.2 Market Issues

What is the best way to introduce ADAS to consumers? We examine some issues and approaches here. Intense marketing of active safety systems is only valid if they help car companies to sell cars.

Fortunately, safety has a strong pull for car buyers, and safety systems, if the drivers trust and understand them, are likely to do well over time. However, as

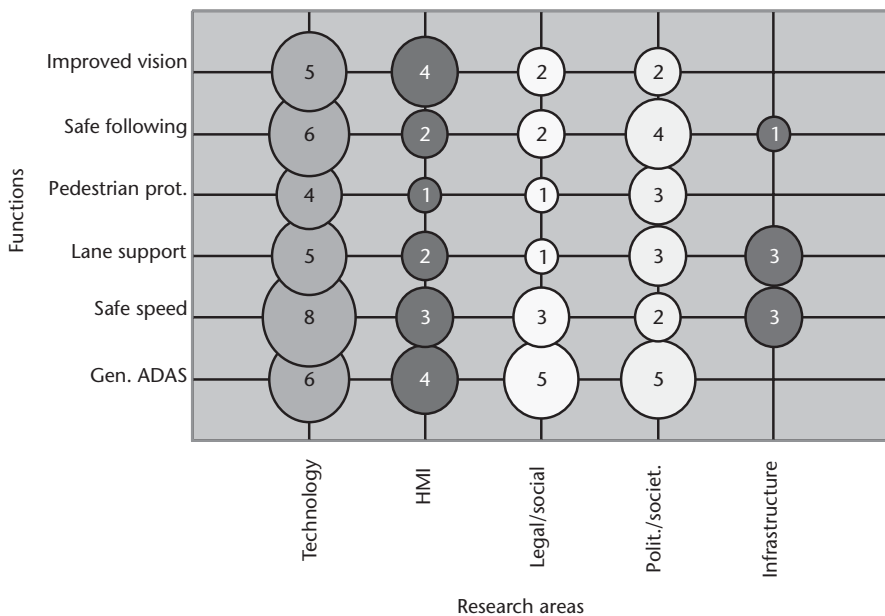


Figure 13.1 Relative status of societal and system issues for ADASs examined within the ADASE2 project. (Source: ADASE2.)

stated in the introduction, if a driver-assist system performs in a way that it gains a poor public image, or worse, is actually unreliable, then the OEM suffers negative exposure for its brand—this must be avoided at all costs. One way car companies both gain experience with their own technology and build the trust of the public is through identifying “baby steps” in system function, which are less risky in the event of failure.

An excellent example of the “baby step” approach is Toyota’s parking-assist system described in Chapter 6. Even though the functions implemented are only basic aspects of the driving experience, this system provides an opportunity for engineers to understand the performance of automated steering in the real world, in the hands of real customers. The situation is relatively low-risk for market introduction because the speeds are low and any responsibility for a collision remains with the driver, since the driver is controlling the throttle and brake.

Another example is the precrash safety system described in Chapter 7. The ACC radar is constantly active (whether ACC is or not) such that the system can detect an impending crash to prearm passenger restraints and optimize braking—nothing more. In this way, the driver remains fully in charge of any actions taken and the system optimizes reversible occupant protection systems for the worst-case outcome. Precrash systems therefore provide a proving ground for radar systems and precollision detection algorithms without going into the driver interface or control intervention domain. This in turn can pave a path toward active braking systems for collision avoidance if the precrash systems are judged to perform effectively.

ADAS are steadily coming into the market, albeit at a relatively slow pace. To some degree this is unavoidable, as there is a “technology absorption rate” for users that must be attended to. For instance, customers may be best prepared for lane-keeping assistance after first becoming familiar with their vehicle’s ability to monitor lane position with a lane departure warning system. As long as car companies compete on the basis of technology, particularly safety technology, then the pressures will remain to introduce ever-smarter onboard systems.

Like many things, drivers conscientious enough to care about buying intelligent safety systems are probably operating their vehicles by the book already: checking blind spots by glancing over their shoulders, maintaining safe following distances, pulling over for naps when they are sleepy. Since they are already diligent, why would they buy a driver support system? In many cases, they are motivated to enhance the safety of other family members who are driving—their spouses and older children.

As seen in Chapter 12, an item of key concern to drivers is controllability (i.e., the ability to override the system at any time). The driver must both have the control and perceive it this way. Ideally, as the driver gains confidence in the system, override actions decrease. System feedback is also important for gaining confidence, such as the way in which ACC systems provide a display when the system is tracking the vehicle ahead.

Some degree of coherence in the messages delivered by the auto industry to the consumer market will help promote understanding and avoid confusion regarding ADAS. With factors such as these in mind, development of a unified strategy for introducing new systems to customers is one aspect of the German INVENT program.

We survey some of the key market issues in the following sections.

13.2.1 “Safety Sells”

The premise that car companies exist to sell cars, not safety systems, is particularly true from the perspective of the dealers, who must sell cars to stay in business, whether these cars have societal benefit or not.

An interesting study was conducted in 2003 by Valeo Raytheon Systems (VRS) to introduce some car dealers to active safety systems and understand their perspectives on the systems [6]. The study engaged 100 retail salespeople from 20 car dealerships, who tested the company’s blind spot detector systems. VRS provided the dealership with a demonstration vehicle, system instructions, and surveys. The participants read the information, drove the vehicle, and then completed the survey.

Only 14% of participants had heard of blind spot detection technology prior to the study. When first introduced to the blind spot detector system, some were skeptical it would be of any use. However, several of these salespeople changed their tune after driving the demonstration vehicle and supported the system. In fact, 95% of dealers wanted such a system as an option on the vehicles they sold; 72% of them felt that the system would provide them with a competitive advantage. This was particularly true of female participants and younger respondents (under age 25).

In addition, 72% agreed that “safety sells” and considered the system a positive safety feature. At what price? They predominantly felt that \$300–\$400 was an appropriate price for such an option.

Currently, “safety” to the average car buyer means airbags, occupant protection, and other aspects of survivability after a crash has happened. The concept of crash avoidance must sink into the public’s consciousness before active safety systems can get traction in the market. In parallel, drivers must come to trust the systems sufficiently to purchase them. Gaining confidence in systems that offer frequent feedback (such as lane departure warning) is much easier than for systems that only activate in (relatively rare) developing crash situations.

13.2.2 Market Introduction Factors [4, 5]

Introducing any product into a consumer marketplace is a challenging endeavor. The problem- and solution-space for active safety systems is multidimensional and interdependent. In RESPONSE 2 (further described below), major market introduction factors were listed as shown in Table 13.1.

For car manufacturers, the key financial risks of ADAS market introduction are public image, vehicle recalls, and liability claims. Vehicle recalls can be exceedingly expensive and obviously harm public image. Lawsuits introduce a “wild card” into the equation, as legal costs and damage awards are difficult or impossible to contain.

RESPONSE 2 noted that the items in the table are influenced by the following contributing factors:

- High system complexity: ADAS are complex in themselves, and complexity is increased as they are linked via data buses with many other subsystems in the car (e.g., brakes, engine management, transmission, and power management). This complexity is further increased by redundant components and failsafe designs.

Table 13.1 Key ADAS Market Introduction Factors as Defined in RESPONSE2

<i>Market</i>	<i>User</i>	<i>Business</i>	<i>Government policy</i>
Intensity of marketing	System usability	Financial risk (recalls, brand image problems)	Ownership of infrastructure (for cooperative systems)
System cost	Aging drivers	Volatility of national and regional economy	Regulatory environment
Degree of consumer demand for safety	Customer acceptance threshold	Average economic growth rates	Legislative initiatives (or lack thereof)
Frequency and severity of crashes in the public's mind	Customer understanding of system limits	Risk of product liability	
	Compatibility of ADAS when integrated with other vehicle systems		

- **Short product lifecycles:** Tools such as computer-aided design, computer simulation, and driving simulation are enabling shorter development time; however, some risk remains that undetected product or process faults will not emerge until after the product is introduced to the market.
- **User comprehension:** System functionality and limits may not be immediately obvious to users, and they are unlikely to actually take the time to read system information. If users have an inaccurate understanding or expectation of the system, they may use it incorrectly or in an environment it is not designed for. As we saw in Chapter 12, this emphasizes the need for intuitive driver interfaces in which functionality and limits are quickly evident.
- **Lack of standard test and validation methods for ADAS:** For conventional car systems, well established test procedures exist . For active safety systems, however, there are currently no comprehensive and proven test methods that take into account the great variety of potential crash situations. While car companies have developed their own fairly rigorous procedures, no industry-wide approach exists.

In workshops sponsored by ADASE2, government policy officials, vehicle technologists, and academics assessed the various ADAS in terms of societal effects. Systems supporting safe speed, safe following, lateral support, and collision warning were, not surprisingly, rated very highly in safety. The traffic throughput advantages of these systems were acknowledged as well. However, they listed the following items as major barriers to extensive market introduction: system standardization, need for a better price/value ratio, concerns regarding driver attentiveness, product liability, and harmonization of government policies across Europe.

13.2.3 Promoting Product Awareness [7, 8]

As previously noted, public awareness of products and their benefits are key to success. To what degree is the general public aware of ADAS? Some indicators of current product awareness are available to us. In the STARDUST summary

described in Section 12.1.2, 75% or more of respondents were aware of ACC, lane-keeping, and ISA functions, a surprisingly high number. Meanwhile, 50% were aware of CyberCars, with just over 25% being aware of stop-and-go ACC.

A key precursor product to active safety systems is electronic stability control, which has reached a 30% market penetration level in Europe and 10% in North America (in terms of new car sales). Industry experts expect the installation rate to rise to 80% by the end of the decade. As products such as ESC proliferate, drivers gain confidence in the intelligence inherent in these systems, which creates a foundation for their acceptance of active safety systems based on sensing the surrounding environment.

Government activities and programs can be very helpful in creating awareness and confidence in these systems for the public. In particular, vehicle technology showcases, in which vehicles are demonstrated on test tracks or in traffic, can gain extensive media coverage that is usually positive in nature. Many such demonstrations have been held over the years, including Demo '97 (United States), Demo '98 (Netherlands), Demo '99 (United States) and Demo 2000 (Japan). More recently, demonstrations were held in conjunction with the IEEE IV conferences in 2002 and 2004 (and planned for 2005). Extensive U.S. media coverage also resulted from the national IVI demonstrations sponsored by the U.S. DOT in 2003. These were quite large events; smaller and focused events are effective as well.

Video clips from these events continue to show up on technology- and vehicle-oriented programs on television, and print articles about the technology occurs about once per month in major newspapers and magazines. In fact, the level of system awareness noted above can in large part be attributed to these types of events and articles. In future years, product advertising will probably play the dominant role.

13.2.4 Incentives to Accelerate Market Uptake

Clearly active safety systems have larger societal benefits beyond the obvious benefit for the person whose car did not crash. Society pays a price for every crash, in terms of emergency response, insurance costs, and traffic congestion. For this reason, public officials are considering ways to incentivize the public to purchase active safety systems when they buy a new car.

There are some complicating factors, however. Currently, these types of systems are only offered on high-end vehicles, and the government must be careful not to be perceived as offering “perks for the rich.” This will change over time as the systems are offered more broadly throughout the product line. At the same time, aggressive incentives will ameliorate cost impacts on any particular car and thus accelerate the broader availability of the systems across many models.

Also, in the United States and Europe, the vast majority of IV systems now on cars are forms of ACC—which manufacturers are careful to market as a convenience system, not a safety system. However, it is widely agreed that ACC forms a foundation for safety systems, and many also see ACC as having at least intangible safety benefits.

Incentives can take several forms. Monetary incentives can be provided in terms of reimbursements for the product cost, reduction in insurance premiums, or reduced road-user charges. There are also nonmonetary incentives. For instance, equipped vehicles could be allowed access to carpool lanes even for single-occupant

vehicles. Moreover, an innovative reward approach is being evaluated in the Dutch Belonitor project [9] (described in Chapter 7).

Reducing insurance premiums may seem like an obvious step to reduce crashes and reduce the insurer's liability. This is the case to some extent for insurers of truck fleets, within the context of an overall fleet safety plan including driver safety training and other features. Automotive insurers, however, have stayed on the sidelines—as a rule, they want to see several year's worth of actuarial data to prove the safety benefits before they institute any premium reductions.

When the government is offering incentives, a solid case is needed to substantiate the public benefit for using public funds in this way. Therefore, system effectiveness must generally be established through testing and analysis before incentives can go forward.

This section describes two activities relevant to incentives currently under way in the United States.

Incentives-Oriented Performance Requirements for Heavy Trucks Within the United States, a project is underway by the Federal Motor Carrier Safety Administration within the U.S. DOT to facilitate deployment of active safety systems for heavy trucks. The work focuses specifically on forward collision warning, lane departure warning, and rollover collision countermeasures, as these types of systems have been evaluated in government-sponsored field operational tests. In conjunction with industry, performance requirements for the systems are being developed, and costs and benefits are being analyzed. Although no policy regarding an incentives program has been established, these performance requirements will be available to support such a program if it comes into being.

Incentives Legislation in the United States [10, 11] In Congressional testimony provided by ITS America to the House Committee on Science, incentives were also discussed and supported as follows:

“One option for advancing deployment is to subsidize this cost to consumers through some form of a tax incentive. A tax incentive could be provided to consumers who choose to purchase vehicles equipped with proven IV safety devices. There is precedent in providing tax incentives to consumers who purchase hybrid-electric vehicles. The same principle could work in this instance.”

Tax incentives have gained some traction through the efforts on the IV Technology (IVT) coalition working with the Intelligent Transportation Caucus within the U.S. congress. The IVT coalition, led by Motorola, also includes Iteris, Valeo, Toyota, Navteq, Qualcomm, Volvo Trucks NA, Meritor WABCO, and ITS America. The 30 members of the congressional Intelligent Transportation Caucus aim to educate and inform their colleagues about the benefits of intelligent transportation systems.

Caucus leaders introduced the IV Highway Safety Act of 2004 into the Congress in mid 2004. The bill provides financial incentives to buyers of passenger cars and commercial trucks to purchase safety-oriented advanced technology devices and is specifically intended to encourage and accelerate nationwide production, retail sale, and commercial/ consumer use of IV systems.

This legislation would give tax incentives when a vehicle is purchased with an “IV system.” Individuals would be allowed a deduction up to \$1,000 on their personal

income taxes. Buyers of commercial trucks purchased with qualifying technology could exclude up to \$5,000 from the federal excise tax. After-market installations would also be eligible for these tax benefits.

Per the bill, a qualified IV system is one that “enhances the safety or security of the driver, passenger or load.” Specific devices described in the bill include: collision warning and notification systems, rollover stability control systems, LDWSs, fatigue management systems, and systems that actively monitor and adjust driver workload.

As of late 2004, the bill was still under committee consideration. Its particular fate is uncertain, but there is hope that some form of incentives legislation will be passed, given the strong industry backing that exists.

13.3 Legal Issues

Legal issues are the “gorilla” within the market introduction domain. As active safety systems have been developed on an engineering level, a perception has become entrenched with the broader ITS industry that liability issues are unsolvable and blocking market introduction. This perception is a myth—the reality is that these systems are slowly but surely coming to market. Fundamentally, liability issues are a jungle that is challenging but manageable. Lawsuits are a business reality for car companies, especially in the United States. It is highly unlikely that lawsuits can be avoided; the key is to reduce their likelihood as a part of a larger strategy of reducing business risk, at the same time trading that off against sales gains and profits as customers are attracted to cars with the latest safety technology.

Risk management, rather than risk elimination, is the paradigm. Automotive companies have been doing such risk management for decades—it is the nature of the business of selling a powerful machine to the public.

Any system that assists the driver in safe driving can also be blamed if a crash does occur; at least, this is the case in the U.S. tort liability system. To some degree, exposure to liability raises the internal standards by which active safety systems are judged as automotive companies consider bringing the systems to market. On the other hand, extreme tort liability judgments can have a chilling effect on product introductions, such that society may not reap the benefits of the systems. In fact, driver-assistance systems in almost all cases come to market in Japan or Europe two to three years prior to U.S. introduction. Outside the United States, liability climates are less punitive such that business risk is reduced.

Today, laws that explicitly address ADAS are not in force in Japan, Europe, or the United States. In some cases, though, national traffic laws, laws regarding admission of vehicles to public road traffic, and rules on behavior in traffic also apply to vehicles equipped with ADAS. For example, the intervehicle following distance requirements in Europe affect ACC design, as discussed below. Also, in Japan, functions that can be introduced on new cars are strictly controlled by the MLIT via regulations.

Prior to market introduction, the auto industry addresses these issues via extensive testing of system components as well as user evaluations. Each company does this somewhat differently, though, as no “gold standard” exists as to how “good” is “good enough” for a technological product that can never be perfect. For this reason, an initiative is under way in Europe focused on a worldwide CoP for the design

and testing of ADAS. This activity, which is reviewed below, is expected to have a significant impact on the industry.

How do car companies reduce the risk of liability for systems on the market? One example is provided by Toyota, in offering ACC on the Sienna minivan in the United States. The following legal disclaimer is found on the Sienna Web site and is likely prominent in the vehicle as well: “dynamic laser cruise control is designed to assist the driver and is not a substitute for safe and attentive driving practices. Please see your owner’s manual for important cautions and instructions” [12]. Such a disclaimer is generally not considered sufficient for a full legal defense in the event of a lawsuit but is an important component in the defense strategy.

Some of the issues reviewed here were expressed to the U.S. Congress in the testimony by ITS America noted above, which is excerpted here [10]:

“There is...a widespread perception among automotive manufacturers that IV technologies may expose automakers to product liability litigation. This concern has tempered the zeal of automakers to manufacture and sell cars equipped with these potentially life-saving devices. It is worth noting that most IV technologies on the road today were first deployed in Europe and Japan, countries that are perceived to be less litigious than the United States. I can make no recommendation on the merits of products liability reform. I would only note that industry concern with this issue is particularly deep and pervasive with respect to IV technologies; as such, this perception represents a significant nontechnical barrier to deployment.”

Dr. Walton concluded by recommending that the U.S. DOT authorize a study of non-technical barriers to the deployment of IV technologies, including liability concerns.

A general principle is that potential liability for ADAS cannot be addressed in the abstract. This was attempted in various studies in the 1990s that resulted in few answers, more questions, and, in some cases, unanswerable questions. Instead, specific functions and scenarios must be defined for a potential product, based on various types of misuse and fault modes. Only with this level of specificity can liability exposure be properly assessed.

13.3.1 Tort Liability in the United States [13]

The liability climate in the United States is by far the harshest worldwide. A complicating factor is that the U.S. tort system is not centralized; the vast majority (95%) of tort lawsuits are filed on the state level. A few facts from a Congressional Budget Office study are illuminating.

Tort liability seems to be a national plague, as the number of tort cases rose by 70% between 1975 and 1990. However, they actually fell by 19% by 2000 and the rate of filing in 2000 was 8% lower than in 1975 when adjusted for population growth. The lion’s share of the tort liability action has not been focused on automotive, but instead on medical malpractice and asbestos cases.

In 45 of the nation’s largest counties, plaintiffs won 48% of cases that reached a verdict. 49% of all cases were automobile torts (not necessarily involving auto manufacturers), and the median award to successful plaintiffs in automobile torts was \$18,000, compared to \$31,000 for all torts. However, as is widely reported in the media, astronomical damages several orders of magnitude higher have also be

awarded—these are the ones that really get the attention of the auto industry when considering introduction of ADASs.

Are tort cases effective in actually improving products offered to society? The answer is unclear, as the study concluded that “in general, data do not exist to show how liability affects the degree of care that potential injurers take” and further that “theoretical analysis alone cannot answer the key questions.”

13.3.2 Legal Issues in Europe [5]

The potential for lawsuits creates challenges in Europe as well. For instance, the manufacturer must take care that the product complies with the current technology state-of-the-art at the time of marketing. Also, customer expectations generated by the company through advertising and other means play an important role. If the actual product functionality deviates substantially from the customer expectation, the risk of product liability claims is heightened even if the product is not defective.

Existing laws in Germany were examined within RESPONSE 2 to provide an indication of the European legal climate. Germany has road traffic regulations that address factors such as speed, intervehicle distance, and overtaking maneuvers. If an ACC system allows for intervehicle gaps less than that specified in the law, the system could be deemed to contravene the law. Specific product design becomes key here—if the ACC, when enabled, defaults to a gap that is within legal bounds and smaller gaps are only enabled by the driver, then the driver, not the product, is responsible.

Another key principle in German law is that the driver always keeps control over their vehicle. This factor comes into play if nonoverridable systems are introduced and may even apply if the driver can in theory react but in reality the system reaction time is so rapid that it is beyond human abilities to intervene.

A third factor is the legal requirement that the driver is attentive to the driving situation and always ready to react appropriately. Thus, the driver-vehicle interface must be designed in a way that does not cause distraction. Similarly, in more advanced driver-support systems, the workload of the driver cannot be reduced to the degree that the driver reduces vigilance. (As seen in Chapter 12, car companies are paying strong attention to such issues.)

In terms of product liability, the European law is essentially harmonized and is based on “strict liability.” With strict liability, there is no need to prove negligence but the injured party must prove that the product was defective. Further, most EU member states provide for a product liability law on the grounds of contractual relationships and/or tort law. When tort law is applied, the focus does turn to fault with respect to manufacturer and/or supplier negligence.

Product liability comes into play if a product is deemed defective in terms of design defects, production defects, and instruction failures. For ADAS, the issues generally relate to design defects and instruction defects. Court judgments of a product as defective hinges on determination of a “reasonable degree of safety” as confirmed by product testing and “duty of care” in both design and testing. At present, a legally conforming procedure to define ADAS safety does not exist. The key concepts of “reasonable safety” and “duty of care” are not defined.

One aspect of duty of care is in monitoring ADAS after market introduction, to ascertain whether customers are using the systems correctly and safely. Any risks

detected through monitoring must be addressed, either through design modifications or further information or instructions to the customer.

A bit of good news is that, in Germany at least, product liability for “development defects” (i.e., defects that could not have been detected even by applying the utmost care) is excluded. This reduced liability is linked closely with an obligation to monitor these products extensively after market introduction. If any problems appear under customer usage, the manufacturer must react here, as well, to make necessary changes.

In many countries, safety assessments must also accommodate the “most endangered and least informed consumer,” creating additional challenges and focusing attention on older drivers, for instance.

One might think that, since ADAS can reduce the number of crashes overall, then product liability should be eased for isolated cases in which they might cause (or be accused of causing) a crash. Unfortunately, this is not the case, as product liability law does not take such big picture factors into account.

RESPONSE2 researchers concluded that, based on the above, product liability is controllable to a certain extent. They emphasized the need to translate the concepts of “reasonable safety” and “duty of care” into a CoP for the development and validation of ADAS. Such a Code could be used to establish that the product was safe according to the state of the art at the time of market introduction. They also noted that product monitoring plays a key role by enabling engineers to continually improve future generations of the systems.

13.4 Government Policy and Regulation

As noted above, governments must define policy in how they relate to industry and the marketplace regarding IV systems. This role varies with the general nature of government’s role within a particular society. In Japan, for instance, regulations apply down to a detailed functional level, such as the speed range within which ACC can operate. New IV systems cannot be introduced there unless the government gives permission. In contrast, in the United States any function can be introduced on vehicles without constraint unless a regulation applies to it. Europe falls in between these two extremes.

As concepts are developed in which vehicles exchange information with other vehicles and the infrastructure, significant policy issues loom with regard to the privacy of this data. Citizens have concerns when their identity is linked with information about their location or speed, for instance.

When applications maintain anonymity of the data, these issues are lessened. This is the case with Floating car data (FCD), where only location is relevant but driver or vehicle identity is not. For real-time vehicle health monitoring that a car company may offer to its customers, customer identity is contained within the data but location is not relevant, and concerns are therefore lessened here as well. The “hot button” is identity and location sent within the same data message.

However, the above regards technical implementation. Another key factor is the public’s perception as to whether their personal data is being protected. In essence, this is no different from their data flowing over the Internet or their telephone, but since vehicle-sourced data is a new concept, the public’s trust must be gained.

Ownership of the data is also new territory in the policy arena. If data reports from thousands of people's cars are aggregated into valuable real-time traffic data, who owns the data? Is ownership shared between all the contributors, or is it owned by the aggregator?

Enforcement represents another conflictual area. Some public safety authorities have proposed using vehicle reporting to alert them to dangerous activity on the roads, such as excessive speeding. However, if drivers know that the data they volunteer for purposes of traffic information can be used to issue them a speeding ticket, the venture is obviously doomed. This can be the case even if such a perception takes hold, regardless of reality.

To address some of these issues, the U.S. DOT has tasked the DSRC Industry Consortium (introduced in Chapter 7) to assess privacy issues with respect to communications technology for the vehicle-infrastructure integration initiative. This is planned for completion at the end of 2004. Also, the ISO Technical Committee 204 (Intelligent Transportation Systems) Working Group 16 (ITS Communications) is in the early stages of establishing a new work item to address privacy in probe data reporting.

Government agencies perform various types of analyses to support policy definition, and this is appropriate. However, in the IV domain, it is also important to be aware that some questions may be essentially unanswerable before the fact and only empirical data suffices. For instance, the allocation of liability for a crash in which both vehicle systems and drivers were actors can be analyzed "on paper" to a degree, but the ultimate answer will emerge gradually via court decisions. Another example is the specter of risk compensation (i.e., the possibility that drivers will drive more dangerously because their active safety systems give them a safety net). Again, some analysis is appropriate, and systems can potentially be designed to minimize such behavior, but ultimately the question is to what degree risk compensation may occur within the driving public. If 5% of the public (twenty-something males) drive in a riskier manner, and 95% drive normally, then the active safety systems have a strong positive benefit. If the ratios are reversed (which is unlikely), then the benefit of the systems are washed out by the increased risk. The classic "soccer mom" or "soccer dad" driver, for instance, is unlikely to drive more aggressively just because an active safety system is installed in her or his minivan. Development of public policy toward IV systems must accommodate this "fuzziness" or otherwise be bogged down.

13.4.1 Vehicle Systems Regulation

Vehicle systems are regulated in various ways worldwide. In the United States, Federal Motor Vehicle Safety Standards are issued by the U.S. DOT NHTSA, and a "type approval" system applies in Europe. As noted above, the Japanese government maintains a tight rein on vehicle offerings.

Vehicles in Europe must comply with both European Union regulations and national regulations. For instance, industry is currently calling for changes in EU headlight regulations so that adaptive front lighting can be offered. Changes are also being sought so as to enable the introduction of brake-force display (in which brake light intensity indicates braking intensity). Some car manufacturers have working braking force systems installed in vehicles they have sold, with the relevant software "switched off" and waiting for activation when regulatory changes clear the way.

In the United States, government regulations are under consideration by NHTSA. If the societal benefit is high, should NHTSA mandate active safety systems on new cars? This is an active debate within the agency and with the auto industry. NHTSA has published a rulemaking priorities plan [14] that addresses timing for possible mandates and guidelines for:

- Forward collision warning;
- Road departure avoidance;
- Driver distraction guidelines;
- Stopped vehicle signaling;
- Drowsy driver countermeasures.

Industry does not speak with a common voice regarding regulations for active safety systems. One view is that government regulations should be instituted to provide industry-wide commonality for these systems. This viewpoint supports regulations at the level of functions and system limits but stresses that the approach to driver-vehicle interfacing would always stay in the manufacturer's domain [15].

There is also the view, of course, that the government should steer clear of such regulation and allow industry to address issues as needed, either individually or through voluntary industry guidelines, such as the ADAS CoP under development in Europe (see below).

13.4.2 Frequency Spectrum Regulation

Regulation for radio spectrum has become a major issue for the vehicle industry, both in terms of RF-based sensing and communications.

Fortunately, frequently allocations were established early on for long-range radar in the 77-GHz range. This was simplified by the fact that there was no competition for spectrum in this range, as compared to the very crowded microwave bands below 30 GHz. For instance, gaining frequency allocations for short-range radar, which has been designed to operate at 24 GHz due to cost and performance factors, has been challenging. To address conflicts that this creates with other spectrum users in Europe, the SARA consortium was founded. Virtually the entire European auto industry is represented in SARA, whose purpose is to advocate allocation of spectrum for short-range radar at 24 GHz, supporting such applications as stop-and-go ACC, blind spot monitoring, side crash avoidance, intersection avoidance, low-speed parking aid, and backup assist. Permission to operate at 24 GHz is sought for a limited period so that these systems can come to market rapidly. After 2014, their plan calls for a transition to 79 GHz as a long-term solution, by which time costs for components at that frequency would come down sufficiently. The ultimate SARA mission is to achieve global harmonization of frequency allocation for short-range radar [16].

13.5 Addressing Nontechnical Market Barriers

Europe has been the center of activity in directly addressing the various nontechnical market barriers to the introduction of active safety systems. Similar but smaller scale efforts are being pursued in Japan and the United States.

13.5.1 European RESPONSE Program

The RESPONSE Program has been referred to several times in the preceding because of its breadth and depth in this domain. RESPONSE was motivated by the desire to facilitate broad introduction of active safety systems, primarily by addressing business risks and user issues.

RESPONSE began by addressing the link between system safety, human factors and legal issues. The overall orientation of RESPONSE has been toward establishing the need for a common industry methodology for the definition and validation of active safety systems, which is legally robust and valid from an engineering and human factors perspective, and further to address that need by defining a CoP.

Automotive industry participation in RESPONSE has been very high, including manufacturers BMW, DaimlerChrysler, Fiat, Ford, Opel, Peugeot, Renault, and Volkswagen/Audi.

RESPONSE has proceeded in three phases, as detailed below.

RESPONSE 1 RESPONSE 1, titled “The Integrated Approach of User, System and Legal Perspective” ran from the late nineties until approximately 2002 and was led by Ford Europe. RESPONSE 1 analyzed the legal aspects of testing and market introduction of ADAS from a European perspective. System, user, and legal perspectives were addressed in terms of information/warning systems, intervention systems with driver override, and intervention systems with no driver override.

RESPONSE 1 analysis showed that liability risks in Europe are highly complex due to the fact that the term “defective product” used in the European Product Liability Directive applies both to the equipment and human factors, covering system requirements such as dependability, controllability, comprehensibility, predictability, and the ability to withstand misuse. As noted above, responsibility shifts to the manufacturer for nonoverridable systems. Given that a risk-free technical product does not exist, and that the prevailing legal system cannot be changed (at least not by the auto industry alone), RESPONSE 1 concluded that it is best to minimize the probability of lawsuits through extensive design for reliability, good human-machine interfaces, and thorough testing. Furthermore, it determined that liability exposure can be lessened through clarifying terms and using common approaches industry-wide.

The project established that market introduction of ADAS at acceptable levels of business risk requires the development of safe systems based on a carefully specified development process. This process would be based on legally robust implementations of the concepts of reasonable safety and duty of care. Therefore, RESPONSE 1 concluded that a CoP should be defined describing a societally acceptable industry consensus in this area. Another RESPONSE 1 product was a checklist for system developers to use in identifying and addressing legal and user issues for ADAS.

RESPONSE 1 determined that the following actions were required for implementation:

- Analysis of the market introduction scenarios, identifying enablers and disablers for both the short and long term.
- Identification and development of methods for risk-benefit analysis to address both system functions and human factors issues. The need was established for both microscopic and macroscopic techniques, in such a way that the microperspective could be translated into national-level economic risk/benefit analysis.

- Agreement on a CoP for design and testing of the systems.

RESPONSE 2 RESPONSE 2, subtitled “Advanced Driver Assistance Systems: From Introduction Scenarios Toward a Code of Practice for Development and Testing,” was also led by Ford Europe and took up the charge from RESPONSE 1.

RESPONSE 2 addressed in more detail the legal aspects to be considered in market introduction (regulations, legislation, and product liability risk), clarified the terms “reasonable safety” and “duty of care,” provided an in-depth understanding of ADAS risks and benefits, and established the need for and approach to creating an ADAS CoP.

Regarding risk/benefit analysis, while useful in and of itself, RESPONSE 2 concluded that no legal defense could be based solely on RBA. It was noted, though, that RBA could be useful in litigation if the manufacturer can show that no failures could have been detected by any entity or that efficient countermeasures had been taken to avoid perceived risks. The team also established that, as noted above, a potential exclusion of liability is possible for those defects that could not have been detected based on state of the art/science at time of market introduction.

Also, functional safety standards were examined in detail. Noting that derivatives of the IEC 61508 safety meta-standard have been created for the railway, medical, nuclear, and process industries, the RESPONSE team proposed that an automotive-specific derivative be developed. Requirements on a future automotive ISO safety standard consistent with 61508 were listed as follows:

- Adaptation of the safety life cycle to automotive development;
- Hazard analysis and risk assessment adapted for automotive use cases;
- Involvement of vehicle, fleet, and user-oriented testing;
- Product liability defense bolstered by “probabilistic target values” based on the current state of the art.

European automakers are already in action here, targeting the completion of such a functional safety standard for 2009 via ISO.

A key output of RESPONSE 2 was to outline the proposed CoP. The team noted that the CoP concept is already established in EU product safety law. In particular, the CoP would help document state of art/science and “detectability” of failure modes to support legal defense.

RESPONSE 3 [17] RESPONSE 3 is subtitled: “Code of Practice for Development, Validation and Market Introduction of ADAS.” This phase of the work is actually focusing on writing the CoP, as well as gaining consensus across stakeholders. The project, led by DaimlerChrysler, began in September 2004 and has a duration of two years. RESPONSE 3 is a subproject within the PREVENT integrated project.

The CoP content is addressed in Section 13.6.

13.5.2 INVENT [18]

The German INVENT research initiative described in previous chapters is also addressing legal and user issues. Analysis of legal issues is focused on product liability, type approval, and identifying product liability or negligence risks that could be

created by specific driver assistance systems. Questions of interest include the following:

- Must the driver be able to override system interventions at any time?
- What legal problems can be expected if not all vehicles are equipped with the system in introductory phases?
- Are new regulations required to introduce these systems?

A key product will be the establishment of legal factors and criteria to support assessments of active safety systems in their early development phases. INVENT results are expected in 2005.

13.5.3 ITS America Effort [19]

As the market activity continues in the introduction of ADAS in the United States, questions abound regarding customer understanding and acceptance of the systems, liability exposure, and regulatory issues, as described above. As in Europe, this uncertainty is slowing market introduction of such systems and delaying the opportunity to realize safety benefits. Given the need to clarify these issues, the Automotive, Telematics, and Consumer Electronics Forum of ITS America has defined a project proposal entitled: “Driver Assistance Systems—Project To Address Legal, Regulatory, and User Issues for Market Introduction of Future Systems.” This effort was inspired in part by the European RESPONSE project.

The project proposal calls for a focused activity driven by the automotive industry to address relevant user, legal, and regulatory issues for ADAS. Candidate issues are: potential customer confusion based on different feature/function sets across OEMs, potential driver acceptance issues relating to false alarm rates, and examination of state-level regulations that may inadvertently preclude active safety system features. The project proposal includes a wide area scan of issues, a problem definition phase, analysis of selected user/legal issues, and definition and implementation of action plans (such as establishing a U.S. CoP, legislative agendas, and advocating purchase incentives).

Since the early nineties, countless discussions about legal and related issues have occurred in the United States with regard to active safety systems. This project is intended to go beyond the “wheel spinning” to identify and address a few issues of key importance to getting these systems in the hands of drivers, while reducing business risk for automobile manufacturers. The strength of the project lies in the direct participation of a small and focused group of automotive industry stakeholders who will define the specific topics to be addressed and the optimum means to arrive at answers which are relevant to product development and market introduction of ADAS.

Key focus areas are expected to be the development of approaches for the following:

- Achieving good customer understanding/acceptance;
- Lowering the probability of lawsuits;
- Strengthening defense in case of lawsuits;
- Improving customer education.

The project is in its early development phase and is expected to start in 2005, pending industry funding.

13.6 Code of Practice (COP) for ADAS Design and Testing [20, 21]

The CoP, as defined by RESPONSE, is outlined here. It is intended as a voluntary agreement on development guidelines between all stakeholders. The CoP can be used as a basis by individual companies to create detailed procedures for optimization of system design specifications and ADAS verification. The code, if successfully defined and accepted by the worldwide auto industry, could play an extremely important role in ADAS introduction; therefore, it is described in some detail here.

In the European context, a CoP is one aspect of “state of science and art” and in that way is helpful in legal proceedings. RESPONSE participants believe that an ADAS CoP is needed for both system safety and safety of use. The scope for the ADAS CoP is to address the development and evaluation process for ADAS (from beginning stages through the beginning of vehicle production), in a way that is valid for vehicle sales in all major markets worldwide. Design and performance standards would address “reasonable safety” and process standards would address “duty of care.” It is expected that the project will confront some of the key legal questions regarding product liability and generate recommendations. Societal aspects such as traffic effects and efficiency of ADAS usage would also be addressed.

The CoP will be written as a generic process plan that can be applied to specific ADAS applications to derive a specific process and action plan in areas such as system specification, development, organizational requirements, validation, and market introduction. Selected content from existing standards (such as design, performance, and process standards) will be used and adapted to the ADAS CoP as needed.

To translate the requirements of “reasonable safety” and “duty of care” into actionable processes and requirements, activities are split into 1) defining requirements and characteristics of a reasonably safe product (system design requirements) and 2) describing the process to ensure achievement of this safety target (development and validation process requirements). There are detailed in the next two sections, followed by a discussion of the specific human factors aspect of the CoP.

13.6.1 Defining Requirements

Development of requirements for “reasonable safety” will include guidelines that can be used by design engineers to achieve target safety levels, and procedures to define risk levels for specific functions. Relative risk is obvious between low-risk systems that provide warning only and higher risk systems (such as steering assist at highway speeds). However, the CoP seeks to provide a way to quantify and stratify these risks, through defining risk-relevant criteria (such as consequences of system failures and controllability under various circumstances).

Fundamentally, the CoP is intended to be more than a philosophical treatise; instead, developers note that it must enable manufacturers to make decisions on ADAS-related safety issues.

CoP design requirements are expected to address the following:

- Suitability of the system to the objective;
- Self-descriptiveness;
- Conformity with preexisting customer expectations;
- Error tolerance;
- Controllability;
- Predictability;
- Consistency;
- Transparency;
- Scalability;
- Learnability;
- Interruptability;
- Pace of interaction;
- Comprehensibility;
- Effectiveness;
- Familiarization;
- Driver vigilance issues.

13.6.2 Processes

On the process side, the CoP is intended to lay out a process and procedures to ensure that user requirements for both safety and usability are fulfilled. The CoP will incorporate relevant strategies for automotive product development already established and enlarge on them as needed. This includes an analysis of relevant quality and safety assurance procedures such as ISO 9001-2000.

To comply with ISO 9001-2000, the process definition will address the following:

- Organizational requirements;
- Identification of customer requirements;
- Engineering requirements;
- Design specifications;
- Hazard and safety analysis (integrating both technology and user perspectives);
- Verification procedures for fulfilling specified requirements;
- Validation procedures for determining overall system readiness;
- Methods of product/crash analysis;
- Product monitoring after market introduction.

13.6.3 Human Factors in the CoP

For the process requirements, the CoP plan is strongly focused on human factors (HF) issues. Within the CoP itself, a detailed HF process corresponding to each step of the system design process will be defined. The CoP will also provide methods for specification and validation of the human-machine interface, including the sequencing of tool usage and definition of metrics. It is stressed, however, that definition of

pass/fail criteria is not part of the CoP—this is seen as the domain of individual companies.

Also, the CoP will more thoroughly define “the least informed and most endangered user,” (including elderly, inexperienced drivers, and infrequent users), who must be accommodated.

More specifically, CoP process requirements at the HF level call for the following activities within the sequencing of ADAS development:

- HF concept specification, including definition of user needs and user requirements; market analyses; car clinics; definition of preliminary HMI; definition of basic principles for function and user interaction; and HF failure modes effects analysis;
- HF concept validation, including simulation of functional alternatives to down-select to the optimum approach, preliminary investigation of risks and benefits, applying HF-relevant metrics, and iteration back to the concept specification as needed;
- HF functional specification, including development of an optimum HMI, car clinics with a prototype system, evaluation in traffic situations, and integration with overall the vehicle HMI;
- HF functional validation, focusing on assessments by users and application of performance metrics.

The CoP is expected to be introduced by 2006.

13.7 International Standards

A full treatment of standards issues and activities is beyond the scope of this book. However, it is important to note that the standards arena is quite active for IV systems.

Within ISO TC204 Working Group 14 (Vehicle/Roadway Warning and Control Systems), standards are defined for vehicle systems that interact with the outside world, including external sensing. WG14 therefore defines ADAS standards. The process for any one standard typically lasts several years, to take into account the many opinions expressed by governments and industry participants, as well as ISO procedural aspects. Europe and Japan are most engaged in the process, as ISO standards directly affect their ability to introduce new products; this is not the case in the United States.

To date, standards have been finalized for the following:

- ACC (highway speed);
- Forward collision warning systems.

Standards are in process for the following:

- Maneuvering aid for low-speed operations;

- Extended range backup aid;
- Low-speed following;
- Full-speed range ACC;
- Lane change decision assistance system;
- Forward collision avoidance assistance system.

There remain several controversial issues to be addressed with many of these systems. Rather than defining exactly how a system should function, the standards describe only minimum performance requirements. Defining “what constitutes a reasonable minimum” can be quite contentious. Basic functional philosophy also comes into play. The definition of the forward collision avoidance system, for instance, includes active braking which may bring the vehicle to a stop or serve to mitigate the effects of an unavoidable crash. However, what should happen in the seconds immediately following this emergency intervention? After the crash (or near crash), should the brakes remain engaged to hold the vehicle, or should they release? If the brakes release, the vehicle may be on a slope and start rolling. If the driver is too disoriented to realize this and respond, further harm could occur. However, if the brakes hold, then the disoriented driver could possibly not follow the correct procedure to release them and be unable to move the car when in fact that would be best. Such thorny questions face ISO experts in defining international standards for ADAS.

13.8 Summary

Clearly, a wealth of nontechnical challenges arises in bringing IV systems to market. These range from classic marketing issues, to complex human factors questions, to potentially disastrous legal consequences. And yet, product development continues! Why? Because the benefits are so significant that, if automotive companies can indeed deliver products that are affordable and robust and really do avoid crashes, their customers will want to buy them. That, plus the fact that if they do not introduce them, their competitors will—active safety systems are part of a larger “technology race” within the industry. Legal issues, while significant, are a factor to be managed and not a fundamental roadblock.

In the government arena, eSafety and similar efforts are cultivating broad support for active safety systems, at least at the discussion level. The question remains—how active will governments be in tangible actions to promote the adoption of these systems? A particularly powerful approach is to institute purchase incentives, a proposal that is at least “on the table.”

The development of an ADAS CoP is key for the long term. Certainly, individual car companies can develop their own design requirements and processes for system and user safety. The beauty of the CoP approach is that it serves to provide an industry-wide set of standards—this will both improve system design and reduce risk for individual companies. To the degree risk is reduced, product introductions will come more rapidly. It is hoped that the substantial activity in Europe will be linked to similar activities in Japan and the United States so that we arrive at a CoP with truly worldwide applicability.

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Looking Forward: Enabling Technologies and Future Trends

What will it take for IV technology to continue to progress and reach new milestones in intelligent perception? In this chapter, I provide some perspectives on enabling technologies as well as how the many IV technologies discussed in previous chapters may roll out into the marketplace.

14.1 Enabling Technologies

The ultimate goal for a driver assistance system is intelligent perception, (i.e., the ability of the machine to understand a driving scene and assess maneuver options as effectively as a human driver). As we noted early on, in some ways the machine is innately superior, in providing 360-degree fatigue-free sensing and lightening-fast actuation. However, between sensing and actuation is the key step of judgment. Human judgment is far superior to the machine and will probably remain so for a long time. However, over time, it is achievable to for IV systems to approach the domain of making appropriate judgments for most driving situations.

For driver support, there are areas of subtlety beyond simply sensing obstacles in the vehicle's path. Ideally, future systems will be capable of assessing the intentions of other drivers—the hints we pick up as a vehicle pulls alongside us in the adjacent lane and we see the driver looking for a gap to change into our lane, for instance. When this happens, we are more prepared to respond to their next move. One day, all intentions will be communicated in data streams between vehicles, but many years will pass before this is the case 100% of the time. Our vehicle systems will perform more effectively if they can sense cues such as this.

More intelligent driver interfacing is important as well, particularly in creating confidence in the systems so that they are truly viewed as “intelligent copilots” by the user. IV systems must be smarter than PC software, which tells us things we already know and asks us inane questions before performing an action. As we saw in Chapter 12, systems are under development to provide support tuned to the driver state, placement of attention, and workload. These are superb first steps, and there is significant work ahead. When the driver interface is smart enough to issue warnings at just the right time—not too soon and not too late—users will gain respect for and trust the systems. And, as noted above regarding the intentions of other drivers, assessing the intention of the subject vehicle driver, while challenging, will also go far in creating confidence. If, as a passenger, we can watch drivers and

have some sense for what they will do next (such as checking mirrors in preparation for a lane change) then there is an opportunity to identify those features that provide that information and code them into software to make the driver-vehicle interface smarter.

In the sensor domain, key areas will continue to be sensor fusion, as well as achieving multiple aims with single sensors, such as headway monitoring with a vision system that is also providing lane departure warning. The core sensing suite will likely continue to be radar combined with monocular vision, but stereo vision could play a role in the future. Laser scanners will offer a much richer data set once costs come down further. In fact, cost reduction of all IV systems will remain a major engineering focus for years to come.

Detecting pedestrians remains a key challenge for sensor and algorithm developers. Significant progress has been made in recent years, and development of a road-ready system appears to be within reach—the possibility of which was under a cloud of doubt during the 1990s as being “just too hard.” Nevertheless, this area requires continuing and significant R&D for robust systems to be produced.

Another challenging area for intelligent perception is in road sign recognition—early systems now exist but significantly improved performance is needed. Sign recognition systems can enable onboard vehicle control systems to automatically adjust speed, or better detect an intersection layout, for instance, to improve driver support.

What about road condition? As drivers, if there is an icy patch ahead on a frigid night, we would prefer to know about it before we get there so that we can slow down and be more cautious. Further, our onboard IV systems can take information about current road/tire friction to adjust operating parameters appropriately. Today, roadside systems can sense road conditions, but these are just spot measurements. Also, a key benefit resulting from future floating car data systems will be the detection of slippery spots by vehicles that can then provide this information to others. However, in the ideal world, an onboard system would have a look-ahead capability to sense potential pavement hazards ahead when there are no roadside sensors or other cars reporting. Various techniques have been experimented with in laboratories, and it is hoped that a robust solution will emerge.

Clearly, communications technology is an enabler for many IV applications. The good news is that most IV system requirements do not create stressing requirements on the state-of-the-art in communications. In fact, in many cases off-the-shelf systems can serve communications needs. The challenge here is in integrating communications systems effectively into vehicles with minimal cost. For instance, how many antennas and transponders are needed for a vehicle to communicate with all of its neighbors in all directions, as well as roadside entities? Communications within the radar signal also holds promise for some productive synergies. In all cases, establishing standards for intervehicle and road-vehicle communications is absolutely essential.

Some unique challenges are presented by ad hoc vehicle-vehicle communications, particularly the need to communicate with specific vehicles that are nearby. For instance, in coordinated merging into the traffic stream, the communications systems must be capable of exchanging data only between traffic in the targeted merge lane and traffic on the entrance ramp, without being confused by data from

vehicles in other lanes. In these cases, the communications relevance focuses not on “who they are” as is typical in wireless communications, but on “where they are.” Initial investigations have been performed using geoaddressing techniques and highly directional antennas. More development work lies ahead to create truly robust and reliable communication links.

One of the most fundamental enablers for widespread deployment of advanced forms of IV systems is nontechnical (i.e., the ability of road authorities to work hand-in-hand with vehicle manufacturers) so that vital information within roadside systems is available to vehicle systems, and vice versa.

Precise positioning and digital maps are other key enablers for future active safety systems. The major challenge is to define cost-effective methodologies and standards for creating digital maps and updating them in real time.

Last, we are still far from deeply understanding how drivers drive and, when it comes to crashes, the many dimensions of crash precursors. Therefore, the scientific and engineering establishment would benefit greatly from continued research in driverology and data collection regarding naturalistic driving.

14.2 Looking Forward

The next wave of products will see increasing reliance on digital maps as well as wireless communications. Communications is being driven strongly by telematics, entertainment, and electronic commerce, and current standards activities are gaining momentum. Mapping applications for safety will in fact rely on wireless communications for real-time map updates.

At a functional level, ACC will proliferate into a wider range of vehicle models; in fact, it has already reached below the premium brands to be offered on Toyota minivans and Nissan mid-range cars, for instance. Forms of full-speed range or low-speed ACC are also expected to proliferate fairly quickly beyond Japan. This will greatly enhance the overall value equation for the customer—they will be assisted in normal driving, dense driving, and even traffic jams. In terms of lateral support, lane departure warning will evolve into forms of LKA and again move beyond Japan. Drivers will have the use of combined ACC and LKA. As part of a more comprehensive driver-monitoring and workload support system, these advanced functions will be implemented in ways which maintain vigilance or warn drivers if their vigilance is waning.

With respect to safety systems, we will certainly see movement from individual crash countermeasures to more integrated and complex systems, so as to cover a more comprehensive range of crash situations.

Congestion relief remains relatively untapped ground on a global basis, although it is fortunate to see the research investments being made in Germany and the Netherlands. Significant worldwide research in this area is expected to be the “next big wave” in IV R&D because the potential to stabilize and improve traffic flow is so promising and a goal worthy of significant public investment.

How might the market develop? Various predictions have been made, which generally place increases in market volume for IV systems at 10% or greater each

year [1]. Automotive suppliers, while keeping details close to the vest, have made some statements that at least indicate how products might roll out over time for the American and European markets. Delphi [2] expects side object detection to reach the market in 2006, with advanced front object detection systems coming in 2007. It envisions that its drowsy driver and driver distraction alert technologies, as well as an integrated camera-radar backup aid, will enter the market in 2008. Siemens [3] and TRW [4] have both estimated that lane-keeping could be available in the 2008–2009 timeframe. Bosch [1] has stated that full braking to stop a vehicle and avoid a crash could be available in 2009.

Certainly, driver support functions such as ACC, LDWS, blind spot monitoring, and lane change support are well established and expected to become available across many car lines over time. The success of lane-keeping assist on the worldwide market is less certain, as the degree of user demand has not been fully established, but some form of LKA is expected to enter wide use. Widespread introduction of pedestrian avoidance is also uncertain, in this case due to the technical complexity of achieving robust performance and the differing perception of need for pedestrian detection depending on the road and traffic conditions in various parts of the world. For automated operations, including CyberCars, it is too soon to say—such systems will certainly be produced and deployed, but the extent and pace at which they will come into common use will take some time to become more clear.

So how will it all roll out? Wiser authors might shy away from estimating product introduction dates, yet surely the reader is interested to have some sense of this. So what follows (Table 14.1) is a best guess, geared toward the U.S. automotive market (which is typically the last to see new IV products after Europe and Japan).

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Table 14.1 Availability of IV Systems in the United States Automotive Market (Rough Estimate)

<i>Now</i>	<i>By 2007</i>	<i>By 2009</i>	<i>By 2011</i>	<i>by 2013</i>	<i>by 2015</i>	<i>by 2020</i>
Adaptive Cruise Control	Forward crash mitigation	Driver fatigue monitoring	Intersection collision warning (roadside-based)	Low speed automation (congested traffic)	Intersection Collision Warning (vehicle- roadway cooperative)	Automated Vehicles (for highway driving)
Night vision	Low-speed ACC	Lane-keeping assist	Speed keeping assistance	Cooperative ACC		
Lane departure warning	Adaptive headlights	Lane departure avoidance	Forward Crash avoidance			
Forward collision warning	Basic vehicle-roadside Communications	Driver workload management/attention monitoring	Advanced vehicle-roadside communications			
	Side/blind spot monitoring	Lane change assist	Basic vehicle-vehicle communications	Advanced vehicle-vehicle communications		
	Early map-supported safety applications	Automatic parallel parking	Advanced map-supported safety applications			
			Pedestrian detection/warning			

Conclusion

We have seen in the preceding chapters that a wealth of activity is occurring to research, develop, and bring to market systems based on IV technology. First generation systems are on the market worldwide, and second generation systems have been introduced in some regions as well. Driven by healthy government and commercial R&D investments, we are on the verge of a “cooperative systems” revolution, in which vehicles actively communicate with the world around them to enhance overall performance (trip time, traffic flow, safety, convenience), all to support the driver.

As was discussed in the previous chapter, IV systems will continue to proliferate, with early systems becoming available across a wider range of vehicles while more advanced features steadily roll out on the premium cars. Importantly, the concept of “cars that don’t crash” has taken root within the major car companies as their vision of the future. Equally important, the “vision zero” concept is spreading to more and more governments across the world as the touchstone for their road safety programs.

Heavy trucks and transit buses will continue to adopt systems that make economic sense, and as volumes produced increase for all vehicle types, IV systems will become more economically attractive. Governments around the world have an opportunity to accelerate this process by instituting purchase incentives programs—every car with a safety system benefits every other car sharing the road with them, such that the societal case for incentives is strong.

The convergence of wireless communications with vehicles has powerful momentum, as the telecommunications industry sees potential for significant profits in offering location-based services that make us more productive as we drive. In fact, there is a comprehensive convergence occurring between communications, digital maps, infrastructure intelligence, sensing, and in-vehicle electronic infrastructure—all driven by strong commercial motives, which defines a new landscape and brings a broad array of possibilities.

We are seeing the R&D domain, already healthy on the commercial side, being pushed aggressively by military investments in autonomous vehicles. As the military continues to develop mobile robots to deal with urban combat and to adopt automated vehicle techniques to move freight in hostile territory, sophisticated architectures and algorithms are emerging that will likely be useful for commercial purposes. Military and commercial R&D, fundamentally, will take us from mere sensing to the goal of “intelligent perception.”

Combating traffic congestion, however, will remain a purely civilian endeavor. Development of IV systems to enhance traffic flow is just beginning to be established as a

research investment area on a worldwide basis. IV traffic assistance systems will take advantage of sensors, communications, and computing power already on the vehicle for other purposes to provide extra benefits. It is hoped that this research area will become as solidly established as safety, because the public clearly wants relief from traffic jams. If you ask the average commuter which they want more of—safety or traffic flow—there is a very good chance they will vote for traffic flow. Crashes are for them an exceedingly rare event, yet congestion faces them daily. Further, an individual driver can control his or her safety to some degree by how he or she drives but is powerless within a traffic jam. Going beyond safety, government policy at the highest levels truly needs to increase attention on what I call “the second half of the problems on the roads.”

So what might our future view from behind a steering wheel look like? How might society change over the long term? We as drivers will have more of a “local look ahead” capability, such that we will know about slow traffic or obstacles ahead and decelerate gradually—emergency braking based on “surprise” will be much less common. This in itself will obviously reduce crashes. And when emergency scenarios do evolve, the majority of vehicles will be capable of at least mitigating, if not avoiding, a crash. Further, the driver support provided by our IV systems will be aware and sensitive to our focus and preferences as drivers. Trip times will become much more reliable for both people and freight, and we may over time see a transition to truckways for automated freight movement. Automation for our private vehicles is an inevitable evolution that is just a matter of time, as almost everyone would like some relief from the tedium of driving. While it might be overkill for our cars to take us from driveway to driveway, we can expect to enjoy automated operations on the motorways.

I recently gave a speech to a group of owners of automotive “body shops” who fix crashed cars as their livelihood. When I was about halfway through the talk, they jokingly began calling me “the bad news guy” because the upshot is that crashes will reduce over time, and so will their business! Imagine the possibility that car crashes in the future will be as rare as airplane crashes are now.

In fact, with a little arithmetic, we can take a look at how this might play out. The crash rate will be affected by the introduction date of crash avoidance systems, which car models the systems are offered on, the sales rates, and the overall fleet replacement rate. Taking the United States as an example, approximately 13 million vehicles are sold each year, which constitutes roughly a 5% vehicle replacement rate per year. Theoretically, then, the entire fleet is replaced within a 20-year period.

When will significant numbers of vehicles be sold with crash avoidance systems? As a benchmark, I estimate that more than 50% of new vehicles will be sold with at least some type of active safety system by 2015. By that point, if not sooner, we can expect to see a noticeable effect on the crash rate, as consumers would have been purchasing IV systems for 15 years by that time. With more and more equipped vehicles on the road after 2015, benefits will start to accelerate such that significant reductions will be seen by 2025 and major reductions roughly ten years after that. There is a countervailing trend, however: Vehicle miles traveled continue to rise on a national basis in all of the developed countries. So, the number of crashes may continue to increase for some time even as crash rate goes down.

So, buckle your seatbelts, and head down to your local car dealer for a test drive. The era of the Intelligent Vehicle has begun.

Appendix: Web Site Resources

Videos, presentations, and other information regarding many of the topics covered can be downloaded at <http://www.IVsource.net>. Other Internet resources are listed below.

Commercial

2 Get There	http://www.2getthere.nl
Advanced Public Transport Systems	http://www.aps-phileas.com
Advanced Safety Concepts	http://www.headtrak.com
Attention Technologyz	http://www.attentiontechnology.com
Autocruise	http://www.autocruise.com
Bendix	http://www.bendix.com
BMW Connected Drive	http://www.connected-drive.de
Continental	http://www.conti-online.com
Delphi	http://www.delphi.com
Eaton VORAD	http://www.roadranger.com
Ford	http://www.ford.com
Irisbus	http://www.irisbus.com
ITIS	http://www.itisholdings.com/itis
Mobileye	http://www.mobileye.com
PSA Peugeot Citroen	http://www.psa-peugeot-citroen.com
Renault	http://www.renault.com
Seeing Machines	http://www.seeingmachines.com
Siemens VDO	http://www.siemensvdo.com
Toyota	http://www.toyota.com
Advanced Transport Systems (ULTra)	http://www.atstld.co.uk
Valeo	http://www.valeo.com
Visteon	http://www.Visteon.com
Volkswagen	http://www.volkswagen.de
ZOOM Information Systems	http://www.ZoomInfoSystems.com

Government Agencies and Programs

Australian Transport Safety Bureau	http://www.atsb.gov.au
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Deufrako Program (France – Germany)	http://www.deufrako.org
European Commission eSafety Website	http://www.europa.eu.int/information_society/programmes/esafety/index_en.htm
European Commission Information Society Technology Directorate	http://www.cordis.lu/ist
French INRIA Institute	http://www.inria.fr
French La Route Automatisée Program	http://www.lara.prd.fr
French LIVIC Laboratory	http://www.inrets.fr/ur/livic/livic.e.html
German INVENT Program	http://www.invent-online.de
Japan Advanced Cruise-Assist Research Association	http://www.ahsra.or.jp
Japan Advanced Safety Vehicle Program	http://www.mlit.go.jp/jidosha/anzen/
Japan Communications Research Lab	http://www2.crl.go.jp
Netherlands AVV Transport Research Center	http://www.rws-avv.nl
Netherlands TRANSUMO Program	http://www.transumo.nl
Swedish National Road Administration	http://www.vv.se
UK Foresight Vehicle Program	http://www.foresightvehicle.org
USDOT Federal Transit Administration	http://www.fta.dot.gov
USDOT ITS Website	http://www.its.dot.gov

Projects

ActMAP	http://www.ertico.com/docs.adase2.net/responsehttp://www.ertico.com/activiti/projects/actmap
ADASE2	http://www.adase2.net
AWAKE	http://www.awake-eu.org
CARSENSE	http://www.carsense.org
CarTALK	http://www.cartalk2000.net
Centro Recherche Fiat Projects Page	http://www.crfproject-eu.org
CHAUFFEUR	http://www.chauffeur2.net/final_review
PEIT	http://www.eu-peit.net
PreVENT	http://www.prevent-ip.org
PROBE-IT	http://www.probeit.org.uk
PROTECTOR	http://www.crfproject-eu.org
RADARNET	http://www.radarnet.org
SAVE-U	http://www.save-u.org
SpeedAlert	http://www.speedalert.org
STARDUST	http://www.trg.soton.ac.uk/stardust/
Vision 2030 (UK)	http://www.transportvisions.org/vision2030.htm

Academia

University of California – Berkeley PATH Program	http://www-path.eecs.berkeley.edu
University of Minnesota	http://www.its.umn.edu

University of Twente	http://www.aida.utwente.nl
Virginia Tech Transportation Institute	http://www.ctr.vt.edu

Associations

ERTICO (European ITS)	http://www.ertico.com
ITS America	http://www.itsa.org
ITS Australia	http://www.its-australia.com.au
ITS Japan	http://www.its-jp.org
ITS Korea	http://www.ITSKorea.or.kr
ITS Netherlands	http://www.connekt.nl
ITS Sweden	http://www.its-sweden.com
ITS United Kingdom	http://www.its-uk.org.uk
United Nations Global Road Safety website	http://www.globalroadsafety.org

News and Information

ITS Cooperative Deployment Network Newsletter	http://www.nawgits.com
Intelligent Vehicle Source	http://www.IVsource.net

Acronyms

5FW	5th Framework Program (European Commission)
6FW	6th Framework Program (European Commission)
A-ACC	autonomous ACC
ACAS FOT	advanced collision avoidance system field operational test
ACAS	automotive collision avoidance system
ACC	adaptive cruise control
ADAS	advanced driver assistance systems
ADASE	advanced driver assistance systems Europe
AFS	adaptive front lighting
AHS	automated highway system
AHSRA	Advanced Cruise-Assist Highway System Research Association
AIDA	applications of integrated driving assistance
A-ISS	advanced intersection safety system
ANCAP	Australian New Car Assessment Program
APIA	active-passive integration approach
ARL	Army Research Lab
ASV	advanced safety vehicle
ATMS	advanced traffic management system
AVCSS	advanced vehicle control and safety system
AVG	automated vehicle guidance
AVV	transport research center
AWS	advance warning system
B-ISS	basic intersection safety system
BRT	bus rapid transit
C-ACC	cooperative ACC
CALM	continuous air-interface for long and medium
CAMP	Collision Avoidance Metrics Partnership (U.S. DOT)
CBLC	communication-based longitudinal control
CG	center of gravity

CICAS	cooperative intersection collision avoidance systems
CMBS	collision mitigation braking system
CMU	Carnegie-Mellon University (CMU),
CoP	code of practice
CRF	Centro Ricerche Fiat (CRF)
CVHAS	cooperative vehicle-highway automation system
CVHS	cooperative vehicle-highway system
DAB	digital audio broadcast
DARPA	Defense Advanced Research Projects Agency
DFM	driver fatigue monitor
DRG	dynamic route guidance (DRG)
DRM	digital road map
DSRC	dedicated short range communications
DVI	driver-vehicle integration
DVSMS	dynamic vehicle safety management system
EC	European Commission
ECBS	electronically controlled braking system
ETC	electronic toll collection
EVSC	external vehicle speed control
FCA	forward collision avoidance
FCC	Federal Communications Commission
FCD	floating car data
FCM	forward collision mitigation
FMCSA	Federal Motor Carrier Safety Administration
FTA	Federal Transit Administration
GPRS	general packet radio service
GPS	global positioning system
GST	global system for telematics
HMI	human-machine interaction
HOV	high-occupancy vehicle
IC	Infrastructure Consortium
ICA	intersection collision avoidance
ICT	information and communication technology
ICWS	integrated collision warning system
IDA	integrated driving assistant
IDS	intersection decision support
IHS	Intelligent Highway System
IN-ARTE	Integration of Navigation and Anticollision for Rural Traffic Environments
IST	Information Society Directorate (European Commission)

INRETS	French National Institute for Transport and Safety Research
INRIA	National Institute for Research in Computer Science and Control
IP	integrated project
IPA	intelligent parking assist
ISA	intelligent speed adaptation
ISCS	individual spot-cell communication system
ISO	International Standards Organization
ISS	integrated safety system
ITS America	Intelligent Transportation Society of America
ITS	intelligent transportation system
IV	intelligent vehicle
IVBSS	integrated vehicle vehicle-based safety system
IVHW	intervehicle hazard warning
IVI	IV initiative
IWF	information and warning function
JARI	Japan Automotive Research Institute
LaRA	la route automatisée
LAVIA	limiter adjusting to the authorized speed
LCA	lateral control assistance
LCPC	Central Laboratory for Roads and Bridges
LDWA	lane departure warning assistance
LDWS	lane departure warning system
LIVIC	Laboratory for the Interactions between Vehicles, Infrastructure, and Conducteurs
LKA	lane-keeping assist
LMC	Lockheed-Martin Corporation
LSA	low-speed automation
MARS	mobile autonomous robot software
METI	Ministry of Economy, Trade, and Industry
MILTRANS	millimetric transceivers for transport applications
MIRA	Motor Industry Research Association
MLIT	Ministry of Land, Infrastructure, and Transport
MMIC	monolithic microwave integrated circuit
MMV	millimeter wave
NAHSC	National Automated Highway System Consortium
NHTSA	National Highway Traffic Safety Administration

NIAIST	National Institute of Advanced Industrial Science and Technology (Japan)
NILIM	National Institute for Land and Infrastructure Management
OPTIS	Optimized Traffic in Sweden
OSU	Ohio State University
PAG	Premier Automotive Group
PATH	Partnership for Transit and Highways (PATH)
PSS	predictive safety system
R-ACC	responsive ACC
RALF	radar automated lane following
RBA	risk/benefit analysis
RDA	road departure avoidance
RDWS	road departure warning systems
RSAP	Road Safety Action Plan (European)
RTTIS	real-time transportation infrastructure information system
SA	service area
SCC	safety concept car
SIL	safety integrity level
SMS	short message service
SNRA	Swedish National Road Administration
TNO	The Netherlands Organization for Scientific Research
TREN	Energy and Transport Directorate (European Commission)
UMTS	universal mobile telecommunications system
UPA	ultrasonic park assist
U.S. DOT	U.S. Department of Transportation
UTRA-TDD	UMTS terrestrial radio access time division duplex
VFM	vehicle flow management
VICS	vehicle information and communications system
VII	vehicle Infrastructure Integration
VRS	Valeo Raytheon Systems
VRU	vulnerable road user
VSCC	Vehicle Safety Communications Consortium
WAVE	wireless access vehicular environment
WHO	World Health Organization
XFCD	extended floating car data
YRP	Yokosuka Research Park

About the Author

Richard Bishop, founder of Bishop Consulting, supports clients internationally in research and business development within the intelligent vehicles arena—providing services in partnership development, intelligent vehicle applications, industry trend analysis, and business strategy. Clients include federal government agencies, public transit providers, vehicle manufacturers, suppliers, research laboratories, state departments of transportation, and technology firms worldwide. He also lectures as an expert in intelligent vehicle systems.

Mr. Bishop serves as a U.S. expert to the ISO TC204 Working Group 16 on ITS Communications, focusing on developing standards for Floating Car Data and millimeter-wave communications. He is also publisher of IVsource.net, the only Web site focusing exclusively on the coverage of intelligent vehicle developments.

From 1991 to 1997, Mr. Bishop managed the U. S. Department of Transportation's program in vehicle-highway automation research and development, facilitating the establishment of the National Automated Highway System Consortium and providing federal program management for the Consortium's extensive program of research, development, and stakeholder involvement. These activities culminated with Demo '97 in San Diego, which successfully showcased automated vehicle technology to the transportation community, international media, and the public. During this time, he also established the International Task Force on Vehicle-Highway Automation and is currently the chairman.

During the 1980s, Mr. Bishop held positions as a radio engineer, systems engineer, and engineering manager within the U.S. Department of Defense. He holds a B.S. in electrical engineering from Auburn University and an M.S. in technical management from Johns Hopkins University. He is currently enrolled in the Applied Healing Arts master's degree program at the Tai Sophia Institute.

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