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13. ABSTRACT
This report summarizes the current state of deployment of Intelligent Transportation Systems and related technologies by the private sector in the United States. Coverage is focused primarily on in-vehicle entertainment, information and communications services, and safety systems. The report also discusses relevant trends and recent developments in the marketplace.

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Introduction

From its beginnings, the federal Intelligent Transportation Systems (ITS) program has viewed cooperation with the private sector as essential for the timely implementation of ITS technologies and services. Indeed, one of the program's four guiding principles is "to create a new industry by involving and emphasizing the private sector in all aspects of the program." This has been achieved through ongoing partnerships in research, capacity building, standards-setting, and other areas.

As it happened, much of the early deployment of ITS consisted of systems that were produced by private companies but acquired and used by public sector agencies. Highway departments, for example, installed loop detectors, cameras, advanced traffic signals, and other technologies to manage arterial and freeway traffic, while transit agencies deployed electronic fare collection and automatic vehicle location to improve operations. These and other public agencies likewise developed advanced traveler information systems (ATIS) to keep the public informed about current travel conditions and options.

In order to measure the progress of these public sector activities, the ITS Joint Program Office has sponsored a Deployment Tracking effort, which gathers deployment data from public agencies across the country. The Deployment Tracking database serves as a resource for the broader ITS community with data on levels of installation and use of these technologies.

With the re-organization of the federal ITS program into a tiered set of initiatives comes a recognition that the success of many of these initiatives will rest not only on ITS *products* developed by the private sector, but also on *installation decisions* made in the private sector. Most notably, several initiatives are predicated on the deployment of specific safety- and mobility-related systems by the major vehicle manufacturers. To give an example, the Cooperative Intersection Collision Avoidance Systems initiative has the following as its goal statement: "Reduce crashes through ICA systems, with deployment at 15 percent of the most hazardous signalized intersections nationally, with in-vehicle support in 50 percent of the vehicle fleet by 2015." As this goal statement suggests, public sector investment alone will not be sufficient for CICAS to achieve its safety goals; it will also require the automakers to commit to a sizeable investment in the associated in-vehicle technologies and to installing them according to this timetable.

Because of these kinds of interdependencies between public- and private-sector efforts, both sides have an interest in understanding the other's activities. Market research reports written for the automotive community frequently describe federal and state ITS undertakings – proposed standards, pending legislation, funding decisions – that have potential ramifications for businesses. This research report is designed to provide what might be called the flip side of that coin: information on private-sector ITS activities that have potential implications for the federal ITS program, including current deployment status and estimates of future activity. This information will allow federal initiative managers to anticipate, rather than react to, developments in the private sector, and will permit a more complete understanding of the market conditions, business issues, and technical and non-technical issues associated with each type of ITS technology.

In short, this report is designed to serve two roles: first, to serve as a basic source of information for the ITS community on private sector deployment of ITS, much as the existing Deployment Tracking effort does for public sector deployment; and second, to help guide the research, development, and investment decisions of the federal ITS program by providing information on related activities in the private sector.

Scope of the Research

Given these roles, the specific focus of the report is therefore on ITS that are both (1) related to any of the Tier I initiatives and (2) subject to deployment decisions made in the private sector. As will be discussed in more detail later, this encompasses an array of in-vehicle technologies in the areas of *telecommunications*, *information*, *entertainment*, *driver assistance*, and *safety*. Because many of the ITS envisioned in the federal initiatives are years away from deployment, the report takes a broad definition of "related" technologies and also includes coverage of potential "predecessor" technologies. Although some of these systems (such as in-car DVD players) have only tangential links to the federal initiatives, they are included because they may become integrated with future ITS, for example as a means of information delivery. They may also share conceptual similarities or technical components with the envisioned ITS, such that information on their deployment status can serve as a rough indicator of the level of consumer interest and automaker investment in initiative-related areas of ITS.

By design, this report is focused on private passenger vehicles only. It excludes ITS that are exclusively for use in heavy commercial vehicles or public transportation systems.

Methodology

The overall plan for the research was to identify the set of relevant technologies based on the criteria described above, and then to gather progressively more information about these technologies' development and deployment status. This approach was undertaken in several phases.

First, the work plans for the Tier I initiatives were reviewed in order to understand the goals of each initiative and the extent to which these goals might be linked to any private sector ITS deployments. The initiative task plans were also compared with the ITS Taxonomy to identify the specific Intelligent Vehicle and Intelligent Infrastructure systems that were potentially associated with each initiative. Based on these reviews, a preliminary "data matrix" was developed listing the in-vehicle systems and technologies of potential interest on one axis, and the range of data points that might be gathered for each – such as number of US vehicles currently equipped – on the other axis. This matrix was used as an overall guide for further research, with the understanding that not all of these data points could be feasibly be obtained for each technology.

As a starting point in gathering deployment data, a literature search was performed using low-cost and publicly available sources, including media reports, press releases, academic papers, and ITS and trade newsletters, notably the *Hansen Report on Automotive Electronics*. The Convergence 2004 conference, an industry forum on automotive electronics sponsored by Society of Automotive Engineers, was also attended to gain access to information on automakers' plans for in-car technologies. The papers and discussions at Convergence also shed light on a related set of issues – the non-technical barriers to further deployment of automotive ITS, such as business model issues, privacy, and consumer acceptance.

The information gathered from media reports, press releases, academic papers, ITS newsletters, and the Convergence conference was summarized in an interim work product showing the deployment information gathered for each in-vehicle ITS technology. This chart noted ongoing research and development efforts and listed automakers' current and future production levels. It also included some details on production costs, retail prices, expected market growth, relationships to other technologies, and any relevant external developments, such as pending legislation.

This interim chart was shared with the ITS initiative managers during a series of interviews (in person, by phone, and by e-mail) in order to obtain their feedback on the information collected and topic areas where additional data would be useful. The suggestions received regarding the most useful areas for follow-up research were used to prioritize the purchase of commercial market research reports. Information from these reports is available in the internal USDOT version of this report but has been omitted here in order to comply with the terms of the licensing agreements with these firms. USDOT staff requiring additional detail on production costs, deployment levels, and projected sales volumes may wish to consult that version of the report. Finally, the Discussion section at the end of this report briefly highlights some of the broader trends and marketplace conditions that emerge from an analysis of the findings.

Findings

This section presents the data and information that were collected on private sector deployments of ITS-related technologies of interest. In order to make the report as useful as possible to different readers and audiences, there are several layers of detail. In the narrative section below, technologies are introduced one by one, and a basic description of each system – what it is and what it does – is provided for those who may be less familiar with it. This is followed by a qualitative discussion of its current deployment status and, wherever possible, information on its availability on the automotive market, production costs, consumer pricing, and sales volumes. Significant market trends or business and legal issues that might influence further development are also discussed where applicable. Note that the names for products and systems vary from manufacturer to manufacturer; this report uses the ITS Taxonomy names wherever possible.

In-vehicle entertainment

Most in-vehicle entertainment systems have only tangential links to the kinds of safety and mobility applications being pursued by the federal ITS program. Information on these entertainment systems is included here both as contextual information about the vehicle marketplace, but more specifically also because certain entertainment components may become the building blocks of future safety-oriented systems. For example, the display screens used for entertainment can also be used to provide in-vehicle signing or warnings, and "surround sound" has been discussed as a means of enhancing audio safety warnings.

Rear seat video systems generally combine a digital videodisc (DVD) player with one or more video display screens and speakers (and/or headphone outlets), thus allowing backseat passengers to watch movies and other programming in the car. A number of variants and configurations of this product are available, from inexpensive aftermarket products that are simply strapped to the back of the front-row headrests, to factory-installed screens mounted on the ceiling or seatbacks. In some cases, there may also be screen(s) in the front seat area, which are disabled for safety reasons while the vehicle is on.

Sales of these systems have grown rapidly in recent years. They are now available on about 70 vehicle models in the US – including nearly every minivan and SUV on the market,[1] and approximately 1.5 to 1.6 million units were sold in 2004[2]. This growth is due both to the reductions in cost and bulk of the components, as well as growing consumer demand for rear-seat entertainment, particularly among parents wishing to keep young children entertained on long car trips.

High-definition radio makes use of the terrestrial broadcast frequencies currently used for AM and FM radio, but with digital transmission that generates higher-fidelity sound quality. It also allows radio stations to broadcast multiple programs at the same point on the radio dial; for example, a classical music program could be sent simultaneously with a lower-bandwidth talk program, or traffic and weather information to be shown on the HD radio receiver's text display unit.

As of April 2004, about 300 radio stations in the US had acquired high-definition capabilities, including 100 that are currently broadcasting digitally[3]. HD radio receivers are available on the aftermarket, though as original equipment they are currently available on only six vehicle nameplates, with more likely to come. Greater availability is expected as more local radio stations make the conversion to high-definition broadcasts. However, the business model for this technology is still to be determined – HD radio may be advertiser-supported as radio is now, or it may be based on subscriptions – and this will undoubtedly have an impact on the rate of deployment of HD radio receivers in production vehicles.

Satellite radio, as its name suggests, is a means of broadcasting audio programs via a satellite network rather than via conventional radio waves. Compared to conventional AM/FM radio, satellite radio offers both improved sound quality and a wider range of programming options, featuring dozens of specialized channels for musical genres, talk shows, sports, comedy, and other entertainment. Satellite radio's other advantage is that its signals can be picked up in remote areas that are outside the range of most broadcast stations.

The two US satellite radio networks, XM and Sirius, had approximately 3.8 million and 1.4 million subscribers, respectively, as of early 2005[4]. XM's subscriber base has since grown to about 6 million, and Sirius' has grown to about 2.2 million.

An increasing number of production vehicles feature satellite radio receivers as optional or standard equipment, often bundled with a year's subscription to the radio service[5]. Nissan, for example, offers XM Radio as an option on all eighteen of its Nissan and Infiniti models in the US market,[6] and Hyundai has announced that XM Radio receivers will be standard equipment on all of its models in 2007[7]. All told, XM Radio is available on vehicles from carmakers representing about 56% of U.S. car sales – GM, Saab, Honda, Acura, Toyota, Lexus, Nissan, Infiniti, and Hyundai. Sirius Radio is offered on Ford, Chrysler, Mercedes, and BMW vehicles, which together represent about 36% of U.S. car sales.[8]

Like high-definition radio, satellite radio receivers have a visual display that can show lines of text, such as song and artist information or traffic, weather, and sports updates. Some automakers are beginning to partner with satellite radio companies to deliver real-time traffic updates and other information services to the vehicle via dedicated satellite radio channels (more on this below).

Satellite television has become widespread in the residential market – 20 million US households subscribe to a service – but has gained relatively little ground in the in-vehicle market, despite being available as an aftermarket option for about eight years. In large part, this is due to the cost – basic models start at $2,000 – and the need to install bulky equipment.[9] As it stands now, in-vehicle satellite TV installations have been "mostly limited to RVs, motor homes, and commercial vehicles"[10]. However, as the cost and size of the satellite equipment comes down, consumer interest has grown, especially since a rising number of vehicles (see above) already have the display screens necessary to view video programming. Already at least one car model, the Cadillac Escalade, offers satellite TV as a dealer-installed option ($2,695)[11]. The company that supplies Cadillac, KVH Industries, has also been selling aftermarket mobile satellite TV systems ($2,295) through its own distribution network since September 2003.[12] Satellite firm RaySat will also soon be offering an aftermarket product ($3,500) that combines satellite television with internet access[13].

Some industry analysts have suggested that the number of cars with satellite television will reach 3 million by 2011, but automotive electronics expert Paul Hansen believes that estimate to be unrealistic at today's price levels[14]. Hansen also cites the bulk of the units – around 30 inches square and 5 inches high, and weighing 45 pounds – and their poor reception around tall trees and buildings as limiting their appeal to consumers[15].

Multi-channel audio uses multiple audio channels and speakers to create a more realistic and engrossing set of audio effects – commonly known as "surround sound." This technology has been available in cinemas, and even home theatres, for some time, and is currently being adapted to the much more challenging acoustic environment of the automobile interior[16]. The demand for this product will be closely tied to that of rear seat video and other in-vehicle entertainment options, but for now is still in development. In addition to the entertainment value, it has been suggested that multi-channel audio would be a useful addition to safety warnings and navigation assistance. For example, an audible warning that a hazard is approaching from the right could be made to originate from the right-hand side of the car, or an instruction to turn left could come from the left-hand side of the car[17].

MP3 players – i.e. the popular devices that allow the playback of digital music files – have also begun to make an entrance into the vehicle market. BMW added a connection compatible with the Apple iPod® in 2004, and similar connections are available (or will be shortly) on GM, Nissan, Volvo, Mercedes, Nissan, Alfa Romeo, and Ferrari models[18]. In this way, drivers are easily able to transfer their digital music files to the vehicle without having to maintain a separate set of files just for the car. BMW reports strong demand for the iPod adapter kits, which cost $149 plus dealer installation, and plans to equip new models with in-console adapters that will connect iPods or other electronics. Meanwhile, aftermarket products are also selling well; one popular version is an adapter kit from Belkin that allows music from MP3 players to be played over the car stereo system via FM transmission[19].

The logical extension of this trend is ***in-vehicle hard drives and wireless local area networks (LANs)***, which would permit the storage and transfer not just of music files, but of every sort of computer file – databases, documents, entertainment – between home, office, and car via wireless connections. This would essentially make the car "another room in the house," and more widespread use of in-vehicle hard drives and LANs would eventually allow drivers to send and receive content to and from other "wi-fi hotspots," including other vehicles[20]. Indeed, some commentators have described scenarios in which consumers would not drive to a video store to rent a movie, but would merely download the movie file via wireless internet connection from a convenient location (perhaps a gas station); it could then be transferred to the home entertainment system via a wi-fi connection in the garage, or indeed viewed in the car on a rear-seat video system[21]. These kinds of linkages would be likely to eliminate the need for hardware-specific connections such as the MP3 player.

At present, in-vehicle hard drives are not unheard of, but aside from those used in navigation devices, they are available only as specialized aftermarket products. However, at least one electronics firm is actively developing a more consumer-oriented version, in this case a device that would combine a radio receiver, compact disc player, and hard drive. Also in development are storage devices using flash memory systems and wireless LAN connections based on one (or more) of the 802.11 standards[22].

In addition to the technical issues associated with transmission standards, data security, and encryption, the use of in-vehicle hard drives and LANs to transfer entertainment content and other copyrighted products raises intellectual property issues that will have to be resolved before their use becomes more widespread.

Deployment summary
Entertainment

Rear seat video	W	In 2004, offered as option in 70 vehicle models; 1.5 million units sold; average cost $1443. Also widely available as an aftermarket option -- $304 million in aftermarket sales in 2004. Sales estimate for 2010: 4.26 million units.
High-definition radio	W	6 vehicle nameplates have HD radio; others in progress. Consumer willingness-to-pay estimated at $300-500. Business model still unclear.
Satellite radio	W	Factory-installed AM/FM/Satellite radios an option for many vehicle models, especially at high end, in some cases bundled with one-year subscription to satellite radio service. Nissan offers XM radio as option on all 18 Nissan and Infiniti models. All Hyundai models will have XM satellite radio receivers as standard equipment by 2007. Total subscribers as of end-2005: Sirius 2.2 million, XM 6 million.
Satellite TV	L	In-vehicle installation is not widespread. Aftermarket systems have been available for about 8 years (prices: $2000-5000). Soon available as dealer option on Cadillac Escalade. Aftermarket satellite product combines in-car TV with internet access.
Multi-channel audio	R	In development; could be used for audible safety warnings and navigation assistance.
MP3 players/ connections	L	BMW added connectors for Apple iPods in 2004. Also available or forthcoming at GM, Nissan, Volvo, Mercedes, Nissan, Alfa Romeo, and Ferrari, and via numerous aftermarket devices.
In-car hard disks and wireless LANs	R	In development. Combined radio/CD/HDD device for entertainment, also flash memory systems. Wireless LAN based on 802.11 technology also being developed.

W = widely available in US
L = limited commercial availability
R = still in research and development phase

Information and communication services

The technologies described in this section are those designed to provide telecommunications and information services to vehicle occupants. This includes a wide range of overlapping functions but excludes services that are primarily entertainment-oriented, which are addressed separately above.

Concierge services is the name sometimes given to a set of telecommunications- and location-based services designed to assist motorists. In its most typical form, a hands-free mobile telephone link and GPS unit are used to connect the vehicle with a remote telephone operator who can pinpoint the vehicle's location. The operator can then, depending on the specific features of the service, provide a number of different types of assistance, from summoning emergency personnel to the scene of a crash, providing travel directions and navigation assistance, or calling for roadside assistance in the event of a breakdown. More full-featured (and costly) service plans offer even more personalized services, such as travel planning and restaurant recommendations and reservations. Other common features of these systems are remote door unlocking and tracking of stolen vehicles.

These services have become widely available through systems provided by ATX and OnStar. The most common business model is for the hardware and the first year's service to be included in the retail price of the car, with subsequent years sold on an annual subscription basis. ATX supplies the systems used on Mercedes and BMW vehicles. In 2004, it had approximately 535,000 subscribers, of which about two-thirds were paying customers, with the rest still in their first year of service[23].

OnStar is a division of General Motors, and OnStar units are standard equipment on about one-third of GM models, with about 2.5 million subscribers in 2004[24]. This number will be rising substantially soon, as GM has announced plans to install OnStar on all of their North American vehicles in 2007[25]. The percentage of drivers who will choose to continue their OnStar subscription beyond the initial year is the subject of some debate; subscription packages range from $199 to $800 depending on the range of services requested.

Two offshoots of concierge services perhaps warrant a separate discussion because of the way they link the GPS and telephone technology to onboard sensors that monitor the condition of the vehicle. The first is ***crash notification***, which is linked to sensors that can detect when airbags have been deployed. The service therefore allows emergency personnel to be summoned to the crash site without any instructions from the driver. (GM has developed a more sophisticated crash notification system linked to OnStar that detects not just airbag deployment, but other more minor crashes; it is available on the Chevrolet Malibu and may be expanded to other models[26].) The second is ***remote diagnostics***, which is linked to sensors monitoring the condition of the engine and electronic systems. Using remote diagnostics, motorists who experience car trouble or see a "service engine soon" light can receive a quick diagnosis of the problem via the telecommunication system.

In each of these cases, the required interface with onboard sensors adds several layers of technological complexity to the telecommunications service. Interestingly, however, this does not result in crash notification and remote diagnostics being marketed as "premium" services for which a more expensive subscription package must be purchased. OnStar, for example, includes both in its most inexpensive package. The reason is that these services serve certain business and marketing objectives. In the case of crash notification, it reinforces the safety image of the vehicle and the broader idea of "peace of mind" behind the wheel. Remote diagnostics also helps with customer relationship management to the extent that it encourages car owners to seek more frequent maintenance and to use their dealership for repairs and service rather than an independent garage. GM has recently begun to offer OnStar Vehicle Diagnostics at no extra charge – a service that runs monthly diagnostic checks on the customer's vehicle and sends an e-mail if any problems are detected[27]. It has also begun using OnStar for another aspect of relationship management – providing motorists with in-car notification of vehicle recalls as a supplement to paper mailings[28].

At the same time, there are indications that consumer response to telematics – and OnStar in particular – has been less enthusiastic than envisioned. Audi and Subaru previously had agreements with GM that allowed them to install OnStar on their vehicles, but these agreements have been terminated due to low consumer interest. Volkswagen was expected to do the same this year, citing consumer take-up rates of less than 1 percent[29].

Onboard navigation systems use GPS (or, in principle, other locational services) in concert with specialized mapping software and display units to provide motorists with maps, turn-by-turn directions, and other navigational services. By one estimate, sales of these units in new vehicles have grown from about 25,000 in 1998 to 850,000 in 2004, an average of roughly 80 percent each year[30].

Another way of looking at the growth of onboard navigation is through the rates of availability and purchase. J.D. Power and Associates reported that 116 vehicle models on the US market offered navigation systems as an option, up from 85 the year before and seven in 1998[31]. The *Hansen Report* estimates that navigation units were available as optional or standard equipment on 20 percent of new vehicle models in the US, and were actually installed on 3 percent of new vehicle sold. For 2004, it estimates these figures to be 35 percent and 5 percent, respectively, climbing to 50 percent and 10 percent by 2008[32].

Due to their popularity, navigation units have also become integrated into other top-selling onboard electronics. Pioneer, for example, markets a navigation unit that combines a front-seat map display screen with audio and rear-seat video for backseat passengers.

Traffic and weather updates have been provided by local radio stations for many years, and thus have been available in any vehicle equipped with a radio. However, new delivery methods have created a new generation of reports that are much more detailed, timely, and comprehensive that the conventional radio reports. The two main satellite radio providers, XM and Sirius, now offer traffic and road weather updates via 20 or 21 dedicated channels – one for each of the top metropolitan areas. These channels are available nationwide, so that a traveler in the New York area could, if the need arose, tune into the Boston traffic report at any time. There has been some discussion in Congress as to whether this is compatible with satellite radio's regulatory approvals, and at least one bill (HR 998) would place restrictions on the satellite operators' ability to provide local information. However, this bill has been described as not impeding the current practice of offering local information on a national basis.

The other weather-related information service of note is "Storm Hawk," offered by WeatherData, Inc. Storm Hawk is a subscription information service that uses GPS and a wireless communications link to supply personalized, location-specific weather information and warnings to subscribers' personal digital assistants (PDAs). This service costs $1,500 to $1,900 for the hardware plus about $120 per year for a subscription[33].

Given the growth of both navigation systems and traffic information, it is not surprising that some services now offer ***navigation integrated with traffic updates***. The current generation of these systems works by tying the navigation software together with geographically coded information, transmitted by satellite radio, on local traffic incidents, road closures, travel speeds, and delays. This information enables users to see traffic conditions superimposed on their in-vehicle map screens, allowing them to plan their routes and itineraries accordingly.

Such systems are currently available as an option only on the Cadillac CTS and Acura RL[34]. The traffic information is provided by the mapping firm NAVTEQ and transmitted to the vehicle via XM satellite radio through a partnership between the two companies[35]. The Acura RL service is free for the first year, then priced at $10 per month ($4 for those with an XM Radio subscription). The Cadillac option is structured similarly, though with only three months free. Other automakers – including Nissan, which joined in partnership with XM Radio to offer onboard navigation-linked traffic information[36] –are expected to use similar approaches and business models. Several aftermarket products are also available, with prices around $1,300 to $1,500 for equipment plus about $15 per month for subscription. These aftermarket navigation products are also linked to satellite radio transmissions of traffic information[37].

At present, the information provided by these services is mostly limited to the display of information on incidents, construction, and travel speeds on the major highways. The *Hansen Report* describes the next level of service as dynamic route guidance – i.e. not just displaying real-time traffic information, but automatically recalibrating the suggested A-to-B route based on this information in order to minimize travel time and delays. *Hansen* expects this kind of service to be available in about two years[38].

Electronic toll payment and border clearance is included here as a form of "communication" in the sense that it provides (generally short-range) communication between the vehicle and a tollbooth or border station, and thus by extension between the driver and the tolling authority or customs agency.

For a typical driver, especially in parts of the country where roadway tolls are common, electronic toll tags are likely one of the most familiar forms of in-vehicle ITS. The most common form is a toll tag using dedicated short-range communications (DSRC, though not the 5.9 GHz DSRC envisioned for the VII) to transfer information between vehicle and toll plaza. Approximately 15 million such tags are currently in use in the US. They are sometimes given free of charge by tolling authorities but are more commonly sold for $25 to $30 apiece[39]. A rival technology is the toll "sticker," a smaller tag that communicates in the 902-928 MHz range. About 250,000 of these stickers, made by TransCore under the name "eGo," have been issued for expedited US customs clearance; they are used at 22 specially equipped crossings along the US-Canada and US-Mexico borders as part of the Fast and Secure Trade Program (FAST)[40]. Similar sticker tags are also used for toll collection in Puerto Rico, where they sell for about $10 each[41].

Two major developments are on the horizon for electronic toll payment. The first is the potential for using the toll tags to pay for services other than tolls; already E-Z Pass can be used to pay for parking at LaGuardia, Kennedy, and Newark airports in the New York area. Legislators in New Jersey have debated the idea of allowing E-Z Pass as a form of payment at gas stations in the service areas along the Garden State Parkway and New Jersey Turnpike,[42] and it is not hard to envision many other applications.

The other major development is the potential advent of 5.9 GHz DSRC as the standard for communication to and from automobiles and wayside infrastructure, primarily for safety but also for mobility and other applications, as envisioned by the VII initiative. This would potentially replace the current toll tags with a multi-functional DSRC link. The four major firms in the US toll tag market (TransCore, Sirit, Mark IV, and Raytheon) are said to be taking a "wait and see" approach toward 5.9 GHz DSRC[43].

Deployment summary
Information and communication

Concierge services	W	Widely available via OnStar and ATX systems. US subscribers in 2004: OnStar, 2.5 million; ATX, 0.5 million. OnStar is standard equipment on one-third of GM vehicles. GM has announced that it will equip all of its vehicles with OnStar in the US-Canada market by 2007. Basic package of safety-related OnStar services priced at $199/year; other packages priced at $399 and $799/year. Hardware production cost is estimated at $350.
Remote diagnostics	L	Limited remote diagnostic capabilities available with OnStar and ATX-equipped vehicles.
Crash notification	W	Available through OnStar- and ATX-equipped vehicles, triggered by airbag deployment. More sophisticated notification system that sends alert even for minor crashes is available via OnStar on 2004 Chevrolet Malibu; similar systems available on other models.
Navigation systems	W	US market estimated at 850,000 units in 2004. Sales estimate for 2010: 3.57 million units. US figures for installed navigation systems: 2003: offered as standard or optional equipment on 20% of new models; actually installed on 3% of new vehicles sold 2004: c. 35% availability, c. 5% penetration 2008 projection: c. 50% availability and c. 10% penetration
Metropolitan area traffic and weather updates	W	Continuous traffic and weather updates available via satellite radio – dedicated channel for each metro area (XM: 21 cities, Sirius: 20 cities). WeatherData offers personalized weather information and warnings on GPS-linked map, delivered to PDA via satellite or wireless. Priced $1500-$1900 for software and hardware, plus $120/year for subscription.
Navigation with real-time traffic updates	L	Built into navigation system of 2005 Cadillac CTS and Acura RL using satellite radio link. Also available as aftermarket option linked to satellite radio. Aftermarket prices: c. $1300-1500 for equipment, plus c. $15/month for subscription. Acura RL pricing: free for one year, then $10/month for satellite radio and $4/month for traffic data. Partnership between Nissan and XM to use satellite radio-based traffic info on in-car navigation system. Truly dynamic route guidance is estimated to be 2 years away.
Electronic toll payment & border clearance	W	Approx. 15 million "DSRC" tags currently in use in US (prices: $25-30). Other system is 902-928 MHz sticker tags: 250,000 issued by US Customs for border crossings; also used in Puerto Rico ("Auto Expreso", price: $10).

W = widely available in US
L = limited commercial availability
R = still in research and development phase

Safety systems

Note that this section includes a number of systems that are sometimes labeled by the automakers as “convenience” features, simply because the line between safety and convenience is not always a clear one. One major sub-category of safety systems is **vision enhancement**, which includes a number of different technologies designed help the driver to gain a better view of the road and detect potential hazards. **Back-up camera** systems use a small rear-mounted video camera, with the image displayed on a screen near the driver (often on or near the central console). This allows the driver to gain an improved view of the area behind the vehicle. Because they are particularly useful with large minivans and SUVs, these systems are currently available on models such as the Acura MDX, Honda Odyssey, Toyota Sienna, Lexus RX330, and Lexus LS430[44].

Night vision systems use varying combinations of infrared and near-infrared light and cameras to enhance the driver’s vision during low-light conditions. The enhanced view is typically displayed over the windshield using a heads-up display. Such systems became available in the US with the model year 2000 Cadillac DeVille.[45] However, Cadillac reportedly discontinued the system after 2005 after disappointing customer experiences, and at present night vision is available only on some Lexus models.

BMW and DaimlerChrysler have been conducting research on night vision concepts and plan to bring night vision-equipped vehicles to the US market later this year as options on the BMW 7-Series and Mercedes S-Class. The BMW system is based on far-infrared sensors, while the Mercedes system is based on near-infrared[46].

Adaptive headlights (or adaptive front lighting systems) are motorized headlamps linked to sensors that measure the vehicle’s angle, pitch, steering direction and orientation; as such, they can adjust their direction and intensity to provide additional illumination on curves, turns, and hills. . They are available as options on a handful of high-end vehicle lines and became available on Range Rover models starting in model year 2006[47].

American automakers are reported to have relatively little interest in adaptive lighting systems at present. While this may change as consumers gain exposure to them and understand their benefits, current projections are that only about 1½ percent of North American vehicles sold in 2010 would be equipped with them[48].

Another related area of vision enhancement is ***blind spot monitoring***, which provides warnings to drivers that another vehicle is in one of the “blind” spots to the side and rear of the car. The first such system on the US market is Volvo’s Blind Spot Information System (BLIS), which makes use of digital camera-based sensors mounted on the exterior side mirrors and provides a visual warning when another vehicle is in the blind spot. BLIS is available on some 2006 Volvo models as an option priced around $500[49]. BLIS had earlier become available in Europe in 2004 on the V70, V50, and S40 models as an option priced around €750.[50] Other mirror-mounted blind spot detection systems are in development at GM (and possibly other automakers), though GM’s system is expected to use 24 GHz radar instead. Industry analyst Randy Frank believes that blind spot monitoring systems will be available in the US from several automakers by the 2007 model year[51]. Production costs for the 24 GHz system, installed on both side mirrors, is estimated at $400-$500[52].

The ***object detection systems*** that have been developed to date generally use a set of ultrasonic sensors on the vehicle's bumpers to detect nearby objects, translating this into a series of audible warnings to the driver as an object approaches. Such systems are typically designed for use in parking the vehicle in close quarters, and as such only operate when the vehicle is moving a low speed. These systems are now widely available under names such as Mercedes Parktronic[53]. A smaller number of vehicles, such as the Ford Expedition and Lincoln Navigator, supplement the ultrasonic sensors with 17 GHz radar in order to detect a wider range of objects and to better detect the presence of children[54].

Parking assistance of a more sophisticated form – one that might well be labeled as primarily a "convenience" rather than safety feature – has been available since 2003 as an option on the Toyota Prius sedans sold in Japan[55]. The car's "intelligent parking assist" system combines a rear-mounted camera with imagining and triangulation software and a forward display screen. When the system is activated, the driver can specify the outlines of a parking space on the screen and then have the vehicle calculate the precise trajectory needed. Via a connection to the steering control, the system then reverses the vehicle into the space automatically, with the driver controlling the brake. This system has proven popular in Japan, where about 80 percent of Prius buyers choose it as an option despite the $2,200 pricetag on the relevant option package[56]. The system may be expanded to other makes and models, though a Toyota executive stated at the 2004 Convergence conference that product liability issues remain a serious barrier to its introduction in the United States[57]. (As a practical matter, relatively fewer American drivers have a routine need to fit into tight parallel parking spaces, so consumer demand may also be an issue.)

Another major subcategory of safety systems is ***steering and braking assistance***, which encompasses a variety of systems that aim to help motorists maintain safe control of their vehicles during difficult driving situations. What these systems have in common is that they employ a set of sensors, linked to a central processing unit, that monitor aspects of the vehicle's movement, such as speed, acceleration, braking force, pitch, yaw, and steering angle. When a potential instability is detected, these systems intervene by making calibrated adjustments to the braking, steering, and/or throttle in order to keep the vehicle on a safe course.

One familiar form of such assistance is the ***antilock braking system*** (ABS), which monitors wheel speed and modulates braking force during sudden stops to prevent wheel lock-up and skidding. ABS and other advanced braking systems are now widely available[58] and are found on about two-thirds of all new cars sold in the US, as well as almost all light trucks[59]. Mercedes and a few other automakers have expanded on ABS by introducing various forms of ***brake assist*** technologies, which detect sudden "panic" stops and apply the maximum braking force[60]. These systems can significantly reduce stopping distances, in part because they correct for many drivers' tendency to apply the brake pedal with insufficient force even in panic situations.

Traction control is a technology that is operationally analogous to ABS, except that its sensors work to detect wheel slippage during acceleration rather than braking. Traction control systems adjust the throttle and apply brake force as necessary to maintain adequate traction (friction) between the vehicle tires and roadway surface.

Electronic stability control (ESC) builds on the sensor networks used for ABS in order to detect and correct instabilities in the lateral (side-to-side) direction, for example on sharp curves. Specifically, ESC measures wheel speed, steering direction, brake pressure, yaw, and lateral acceleration in order to compare the lateral movement of the vehicle to the driver's intended direction. If a potential instability from "over-steering" or "under-steering" is detected, the ESC's processing unit then calculates the necessary intervention and applies the appropriate braking force (and in some cases, reduces engine torque) to one or more of the wheels individually to keep the vehicle on the intended path.

ESC was introduced in 1997 on some Mercedes and GM vehicles[61], and was offered on 73 North American vehicles during the 2004 model year.[62] GM's version of ESC, StabiliTrak, is currently offered on about one-fifth of its models as an option priced between $200 and $800. Last year the company announced its intention to install StabiliTrak on all SUVs and vans by 2007 and on all GM vehicles by 2010[63]. Other companies seem to be following suit: Ford has announced plans to add ESC to its Explorer and SUV models, and DaimlerChrysler plans to add ESC to its SUVs by 2007[64].

Automotive safety advocates have described ESC as a very important safety technology, with the Insurance Institute for Highway Safety (IIHS) estimating that an additional 7,000 fatalities per year could be avoided if all vehicles were equipped with ESC[65]. However, consumer awareness and interest appear to be relatively low. The IIHS estimates that, among purchasers of automobiles for which ESC is available as an option, only about 5 to 10 percent specifically request it[66].

Advanced versions of ESC are able not only to deliver braking force to individual wheels, but also, when necessary, to adjust the steering angle to prevent a skid. These systems are known as "active steering" because of the way they modify the driver's choice of steering wheel position.

Roll stability control is a variant of ESC that is specifically designed to prevent rollovers, particularly in large sport-utility vehicles. Roll stability control systems require the addition of sensors to monitor the vehicle's movement along its central axis so that potentially dangerous roll movements to the left or right can be detected. The system then counteracts these movements by applying brake force to the appropriate wheels. These systems are largely still in the early stages of deployment.

As of 2004 there no vehicles on the North American market that combined all of these steering and braking intervention functions into a single integrated system. However, Toyota in 2004 introduced a "vehicle dynamics integrated management system" (VDIM) on its Crown Majesta models sold in Japan[67]. VDIM brings steering, braking, stability, and traction controls into one system, with a coordinated set of sensors monitoring the vehicle during turns and adjusting steering, braking, speed, and/or throttle as necessary to maintain traction and the intended path[68]. Toyota has brought VDIM to the US market on the model year 2006 Lexus GS300 and GS430 models as standard equipment[69].

Each of the steering and braking systems mentioned above entails some intermediation of vehicle control. In other words, the driver's movements of the pedals and steering wheel do not always move the car directly, but instead can be modified by electronic systems. Due to the growing number and popularity of such systems, it has been suggested that future vehicles may become ***drive-by-wire*** – with electronic intermediation of all vehicle control functions, and the traditional controls replaced with something akin to a joystick. This is a technology that has been proven in a number of concept cars, including Bertone's FILO, Saab's NOVANTA, and GM's Hy-Wire[70]. However, there appears to be little prospect of entirely drive-by-wire cars coming onto the market in the near term, as automakers do not envision much customer acceptance for that kind of radical change to vehicle controls[71].

The various **monitoring and warning systems** that have been developed can be considered another sub-category of safety systems, though they cover many different areas. ***Adaptive cruise control*** (ACC) is a good example of a technology combining elements of both convenience and safety. As with conventional cruise control, drivers can engage ACC in order to keep the vehicle at a constant cruising speed, without the need for repeated fine-tuning via the brake and accelerator pedals. Unlike conventional cruise control, however, ACC also maintains a safe, pre-set following distance (or time interval) behind other vehicles, making use of radar-, lidar-, or microwave-based sensors linked to a processing unit that adjusts engine throttle and braking as necessary.

ACC first became available in Japan in the late 1990s.[72] In the US market, ACC is now available on a number of high-end vehicles, including models from Jaguar, Lexus, Infiniti, and Mercedes[73]. The production costs of the system have been estimated at about $3,000 per vehicle (for the Mercedes version[74]). Prices to the consumer tend to fall in a similar range

ACC systems were initially designed to function only at highway-type speeds, so the most recent round of innovation has brought ACC systems capable of working at a wider range of speeds. Nissan has developed an advanced form of ACC that can function at speeds under 40 kph;[75] this was first introduced in the Japanese market and is expected to be brought to Infiniti models in the US in a few years. Toyota, for its part, is also developing "stop-and-go" and low-speed ACC systems[76]. Another development in ACC is linkage to the vehicle's navigation and mapping software, so that the speed control functions can be tied to information on the characteristics of upcoming roadway segments, such as turns and curves.

Lane departure warning systems use vehicle-mounted cameras and image processing software to recognize lane markings, processing this information along with vehicle trajectory data (speed, steering angle). The systems provide an audible and/or visual warning to the driver when the vehicle begins to leave the lane, unless deactivated by the use of the turn signal. Different types of haptic (tactile) warnings have also been developed and may be used on future versions of LDW; for example, haptic feedback on one side of the driver's seat cushion could serve as a warning.

LDW was originally developed for heavy-duty trucks – it is currently installed on about 12,000 trucks in Europe and North America[77] – but has also been making the transition to passenger cars. LDW has been available in Japan for a few years now: starting in 2002, Honda Accords sold in Japan have offered the Honda Intelligent Driver Support System (HIDS), which combines lane-keeping assistance and ACC, as an option priced around $6000[78]. By 2003, three Japanese Toyota models had a Lane Monitoring System, with the total production volume of equipped vehicles around 80,000 per year[79]. The first vehicle to offer LDW to the US market is the 2005 Infiniti FX, which uses a camera-based system[80]. The system, which has been expanded to the Infiniti M series for the 2006 model year, was developed by the supply firms Valeo and Iteris[81]. The price of LDW as an option to Infiniti buyers is difficult to state succinctly; it requires the purchase of another options package priced around $2,750, then an additional $4,200 for a "technology" package that includes LDW and an assortment of other options. Sales volumes of LDW-equipped vehicles in North America were essentially nil in 2004 because of the lack of equipped vehicles on the market.

Forward collision warning is conceptually similar to LDW in that it provides the driver with warnings of potentially dangerous situations. In this case, of course, the cameras and/or radar are used to detect objects in the vehicle's forward path, rather than deviations from lane markings. In addition to warnings, FCW systems often also incorporate one or more elements of corrective action – amplifying the driver's braking force when needed, or even applying the brakes independently when an imminent collision is detected. FCW is also closely related to ***pre-crash detection and mitigation systems***, which use forward-looking sensors (generally radar-based) to detect imminent collisions and prepare the passenger cabin to mitigate the impact of the crash – for example by adjusting the seats, tightening the seat belts, closing the sunroof, and priming the airbag system. Such systems have been available in Japan for some time and are available on some Mercedes and Lexus models sold in the US[82]. The Lexus version, called Pre-Collision Safety (PCS), also makes adjustments to the braking and steering system; it is offered as an option costing $2,850 on Lexus GS models and as part of an options package on the LS430[83]. Toyota is reportedly working on refinements to PCS that would improve the system's ability to detect "softer" objects such as pedestrians and animals[84]. The Mercedes version, called PreSafe, is standard equipment on the company's line of S-class sedans, M-class SUVs, and on some other models.

FCW itself was first made available in 2003 in Japan on the Honda Inspire and Odyssey models and on some Nissan models. The Honda system, called "collision mitigation brakes," is based on millimeter-wave radar and gives drivers audible, visual, and tactile warnings of forward collision hazards. When an impending collision is detected, the system is designed to apply extra braking pressure and to pre-tension the safety belts[85]. While FCW systems are reportedly under development at all of the major Japanese automakers, there have also been reports that they are reluctant to bring the technology to the US market until product liability issues are resolved[86]. However, at least one Japanese vehicle sold in the US, the 2006 Acura RL, will feature this technology. Like its Honda predecessor, Acura's system includes audible and visual alerts, and when necessary will also apply braking force and pre-tension seatbelts[87]. DaimlerChrysler began offering a very similar system, called Brake Assistant Plus and based on 24 GHz radar, on S-class sedans last autumn[88]. These two vehicle models appear to be the first on the US market to offer any form of FCW.

Rear-end impact warning is akin to forward collision warning, except that it provides warnings when the driver's vehicle is at risk of being struck in the rear. As it happens, these systems are less well-developed than FCW, with no production vehicles offering this as an option. It is a concept under development at Volvo[89] and potentially other automakers but this research did not uncover any examples of rear-end impact warning in production. Another technology that is still squarely in the research and development phase is ***traffic control device compliance*** – systems that "read" traffic signs and signals and provide warnings as necessary. DaimlerChrysler is conducting research on this technology,[90] as are other carmakers.

Tire pressure monitoring systems (TPMS) are likely to become standard equipment on almost all new passengers vehicles in the US, due to the requirements of the federal TREAD Act and subsequent rulemaking by NHTSA. This regulation came from a growing understanding of the safety risks of under-inflated tires, which include longer stopping distances, a greater propensity to hydroplane or skid, and a greater risk of tire failure.

NHTSA's rule calls for this threshold to be set at 25 percent below the recommended cold inflation pressure. The Tire Industry Association believes this threshold to be too high to protect motorists, as serious problems can occur at lower levels of under-inflation. As of this writing, the TIA had joined major tire manufacturers in a lawsuit challenging the NHTSA rule[91]. NHTSA's final rule creates a phase-in period for the new requirements, but by model year 2008 all vehicles sold in the US will be required to have direct tire pressure monitoring systems. This directive will make TPMS "the fastest growing automotive electronic system" during this time period[92]. NHTSA estimates that this requirement will cost between \$48 and \$70 per vehicle but will save approximately 120 lives per year[93].

As the previous sections have illustrated, there are an increasing number of warnings and alerts that a driver would be expected to keep track of, to say nothing of the dramatic rise in mobile telephones, navigation systems, in-car entertainment, and other newer features of the automobile interior. There is a risk that all of these may distract motorists from the core function of safe driving, and therefore have an offsetting detrimental effect on safety. ***Workload managers*** are designed to address this problem by filtering and prioritizing the information made available to the driver. They work by using a "workload estimator," which uses information from vehicle sensors (such as speed, braking, and headlight and windshield wiper usage) to assess the potential difficulty of the driving situation. When challenging situations are detected, the workload manager then postpones or cancels certain distractions, such as non-urgent vehicle warnings or mobile telephone calls.

Since 2003, most Saab 9-3 and 9-5 models have had a rudimentary form of workload manager called a "dialogue manager," which suppresses certain information displays during demanding driving conditions. For example, the system "will postpone a reminder for the 30,000-mile checkup that otherwise might be presented while driving in a torrential downpour, an inopportune time to distract a driver."[94] A similar system, called the Intelligent Driver Information System (IDIS), is available on Volvo S40s and V40s sold in Europe. IDIS blocks telephone calls and text messages during times when the driver is turning, changing lanes, or conducting similar maneuvers[95].

A number of other automakers and suppliers are working on workload managers, in large part due to the growing realization that use of telematics and other in-vehicle electronics can lead to serious driver distraction. At present, the development of workload managers appears to be hindered by the difficulty in creating a sophisticated and reliable workload estimator. The actual difficulty of a driving situation is determined by many different factors, some of them subtle and not easily modeled using vehicle data.[96] Other potential sources of data include map-linked information on road geometry and crash frequency and severity.

Another means of managing driver attention is through the monitoring the driver's own mental and physiological condition, particularly for signs of drowsiness, inattention, or distraction[97]. Indeed, ***driver condition monitoring*** is in development at a number of automakers and aftermarket providers, though no factory-installed products were available as of 2004. While a driver's degree of alertness can be assessed through a number of metrics, many experts in the field of human factors believe that the direction of the driver's gaze is the best measure of distraction[98]. Toyota, for one, has been conducting research on the potential for using cameras to monitor drivers' eye movements.[99] The company has recently developed a system that uses a dashboard-mounted camera and image processing software to detect when the drivers' eyes have strayed from the road. It uses flashing lights and audible beeps to alert the driver, then eventually applies the brakes if there is no response. This safety system was expected to be available this year on Lexus models sold in Japan[100].

Saab is also developing a distraction monitor based on infrared cameras that monitors the driver's head and eye movements. It is designed so that when the driver's gaze leaves the "primary attention zone" for more than a certain amount of time (the exact time varies according to the travel speed of the vehicle), an alarm is sounded and/or the brakes briefly applied[101]. The technology has been demonstrated in a Saab test vehicle but no decision has been made about bringing it to market.[102]

Ford reports that it is conducting simulator-based research on driver drowsiness, and that it expects to bring systems to Volvo vehicles "late in the decade."[103] One early version of driver condition monitoring that may become available is Volvo's "CoDriver" system, which is an extension of IDIS that was developed on a concept vehicle. Like IDIS, CoDriver manages the messages and alerts that the driver receives based on its measurement of driving conditions, but it also calls up certain help functions when it detects indications of driver fatigue or distraction[104] via measurements of eyelid movement and position[105].

Vehicle-to-vehicle and vehicle-to-infrastructure communications are another means of promoting road safety. Communications of the sort envisioned by the VII initiative (i.e. using 5.9 GHz DSRC and a standardized message protocol) would allow vehicles to share information about their location, speed, and direction with each other and with traffic signals and the wayside, triggering warnings or even intervention where a crash was imminent. (These communications would also have significant mobility benefits by, among other things, using vehicles as "probes" to gather traffic and weather data.)

There is a substantial amount of research being conducted in this area, with one market research firm noting that the automakers are "investing heavily in systems that can detect the speed of surrounding vehicles and road conditions, and have each vehicle simply transmit its telemetry data to surrounding vehicles."[106] However, nothing is currently on the market. This makes sense given that the scale and nature of the investment are such that this will almost certainly be pursued on an industry-wide basis in cooperation with the public sector (or not at all) rather than in piecemeal developments by different automakers. Most observers expect this decision point to come around 2008 or 2009. Within the automotive community, it is also generally expected that the initial applications would involve vehicle-to-infrastructure communications, since vehicle-to-vehicle applications would require a much greater share of the vehicle fleet to be equipped before any individual user obtained significant benefits[107].

As the previous sections have made clear, today's cars generate and process a large amount of data about the status and movement of the vehicle. ***Event data recorders*** are the "black boxes" that store some of this data for later retrieval. EDRs have been around since as early as 1974, when some GM vehicles were equipped with devices that recorded airbag deployment[108]. Since then they have grown both more common and more complex, with some EDRs recording various aspects of vehicle speed, throttle and brake status, airbag deployment, and seat belt usage, often with a five-second memory[109].

Because they provide information on the state of the vehicle just before a crash, EDRs are useful to police, the insurance industry, and safety researchers. Approximately 30 to 40 million vehicles in the US are equipped with EDRs, including about two-thirds of the new vehicles sold in 2004, though many vehicle buyers are unaware of their presence.[110] The National Transportation Safety Board has recommended that NHTSA require the installation of EDRs in all new vehicles, but so far NHTSA has only proposed common data standards for them[111].

Several aftermarket products (with names like CarChip and TripSense) are available to harvest data from a vehicle's EDR and then transfer it to a personal computer. This allows for subsequent analysis of detailed data on the car's speed, braking, and acceleration. As such, these devices have proven popular with some parents of young drivers, who can study their children's actual (rather than reported) driving habits[112]. They have also been used in programs offering "safe driver" discounts on car insurance[113]. Despite these benefits, EDRs have raised a number of concerns regarding privacy and data ownership. North Dakota and other states are considering regulating their usage, for example by barring their use in the setting of insurance rates.

Summary chart
Safety

Back-up camera	W	Available in 2004 on Acura MDX, Honda Odyssey, Toyota Sienna, Lexus RX330, Lexus LS430, and other models.
Night vision	L	Discontinued by Cadillac. Available on some Lexus models and upcoming on BMW 7-Series and Mercedes S-Class.
Adaptive headlights	L	Available on MY 2006 Range Rovers and a few other high-end vehicles.
Blind spot monitoring	L	Digital camera-based system available on some 2006 Volvo models as $500 option. Expected to be offered in the US by other makers in model year 2007 (Cadillac DeVille, STS, Escalade; Buick LeSabre). Production cost is approximately $400 to $500 for 24 GHz radar system in both side mirrors.
Object detection	W	Ultrasonic systems for parking assistance widely available (e.g. Mercedes Parktronic); also some radar-based systems.
Parking assistance	L	Toyota "intelligent parking assist" on 80% of Priuses sold in Japan ($2,200 option).
Antilock braking; brake assist	W	ABS widely available and offered on 65% of new cars sold in 2004. More advanced brake assist systems on some models, including Mercedes.
Traction control	W	Widely available.
Electronic stability control	W	ESC offered on 73 vehicles in North America in 2004 model year. GM: StabiliTrak ESC system available now on one-fifth of models (priced $200-800 as option), with plans to install on all SUVs and vans by 2007, and on all GM vehicles in North American market by 2010. Ford is adding ESC to Explorer and SUV models; DaimlerChrysler to add ESC on all Chrysler SUVs by 2006.
Roll stability control	L	Introduced on 2004 Volvo SUV and now available on 5 Ford models.
Drive-by-wire	R	Used in concept cars -- Bertone FILO, Saab NOVANTA, GM Hy-Wire – but unlikely to appear on the market in near term.
Adaptive cruise control	W	Option on models from Mercedes-Benz, Infiniti, Jaguar, Lexus and a few other makers. System cost is estimated at $3,000 for Mercedes version. Nissan and Toyota developing ACC variants with stop-and-go/low-speed modes.
Lane/road departure warning	L	3 Japanese Toyota models, with production volume about 80,000, have Lane Monitoring System. First US vehicle with Lane Departure Warning is 2005 Infiniti FX (camera-based system). PSA Peugeot Citroen will offer LDW on 2005 C4 coupe. From 2002, Honda Accords sold in Japan offer HIDS (Honda Intelligent Driver Support system), a radar- and camera-based system providing both lane-keeping assistance and adaptive cruise control. Option priced around €5000.
Forward collision warning	L	2006 Acura RL and MY 2007 Mercedes S-class will have collision mitigation brake systems. Since 2003, Honda Inspire and Odyssey models sold in Japan have optional "collision mitigation brakes."
Pre-crash safety	W	Available on Mercedes (PreSafe) and Lexus (Pre-Crash Safety) models and in development at many other automakers.
Rear-end impact prevention	R	Concept in development at Volvo; nothing on market yet.

Tire pressure monitoring	L	As of MY04, available on several Mercedes models and a handful of Audi, Ford, VW models. All new US-sold vehicles to be equipped by 2008 to comply with federal law. NHTSA estimates cost at $48-$70 per vehicle.
Workload managers	L	Saab "Dialogue Manager" suppresses certain info displays under demanding driving conditions. First introduced on 9-5 sedan in 1997-98; standard on 9-3 beginning 2003. Volvo IDIS (Intelligent Driver Information System) delays incoming messages during certain driving conditions. In development at other OEMs, including BMW, Daimler Chrysler, Fiat, and Toyota, and among suppliers Delphi and Motorola.
Driver condition monitoring (fatigue, distraction)	R	Not currently available in North America, but expected on Lexus models in Japan in 2006. Volvo's "co-driver" (in development) may include fatigue monitor measuring eyelid movement/position. Saab developing distraction monitor using infrared cameras, possibly linked to mapping software – no decision yet on putting into production.
Vehicle-to-vehicle and vehicle-to-infrastructure safety systems	R	Nothing on market yet. OEMs pursuing research in advance of decision point, circa 2008, about whether to proceed with public-private partnership. Japanese government plans to install sensors in expressways that can communicate with in-car GPS systems to warn of dangerous conditions (fiscal 2007). Also developing vehicle-to-vehicle communication systems.
Event data recorders	W	30-40 million US vehicles equipped, including 65% of new cars sold in 2004. Aftermarket systems ($140-$425) connect to EDR for analysis and/or driver feedback.

W = widely available in US
L = limited commercial availability
R = still in research and development phase

Discussion

This section draws on the data and findings presented above to briefly discuss some of the broader trends and developments in the market for in-vehicle ITS and related technologies.

Overall Market Trends

Over the past decade or so, adoption of in-vehicle technologies has contributed to a number of far-reaching changes in the automotive market. These include:

- *Vast increases in the level of telecommunications "connectivity" between the vehicle and the outside world*. Motorists had earlier been essentially un-reachable, and AM/FM radio was the only medium for transmitting information to the vehicle. Drivers now routinely make use of mobile telephones and telematics for personal communication, concierge services, and emergency response. GPS-equipped navigation devices, toll tags, satellite radio, and other technologies have made the vehicle into something of a hub for information exchange and communication, and more innovations are likely on the way, such as wireless internet connections. Perhaps more important than the specific components, however, is the extent to which these technologies have altered drivers' expectations about the degree of "connectivity" they can experience in the car.
- *The idea of the car as a mobile entertainment center*. This is arguably just the latest chapter in a history that goes back to the early days of specially fitted gramophones, though the pace of change seems to have accelerated in the past few years. Technologies such as DVD players that were only recently considered to be somewhat esoteric aftermarket products are now available as factory options on almost all of the major manufacturers' models.
- *Increasing electronic intermediation of vehicle control*, with numerous systems employing vehicle sensors and microprocessors to adjust steering and braking input and improve safety. Again, this might be considered to be merely the continuation of a long series of engineering innovations, from automatic transmissions and power steering to cruise control and anti-lock braking.
- *Evolution and integration of previously separate information and safety systems*, such as combined Adaptive Cruise Control-lane keeping systems, and onboard navigation units that are tied to real-time traffic information.

These trends mean that several of the elementary building-blocks of the federal ITS initiatives have already taken hold in the private vehicle market, albeit not necessarily in the same forms as envisioned by the federal initiatives. These components include robust communication links to and from the vehicle; in-vehicle screens for the display of information, such as weather alerts; onboard GPS and vehicle sensors; and the ability to intermediate control of the vehicle. At the same time, most observers of the automotive industry note that significant challenges remain to deploying a project along the lines of Vehicle-Infrastructure Integration, including issues of investment timing and coordination, data ownership and privacy, rival telecommunication standards, legal liability issues, and consumer acceptance. A full treatment of these issues is beyond the scope of this report, but executives at General Motors have highlighted privacy and liability as the most difficult of these to address[114].

Current Marketplace Issues

In addition to these larger trends, there are a number of specific qualitative issues in the current automotive marketplace that may affect the deployment of relevant ITS technologies. Among the ones that have been identified by this research, and which could be explored in greater detail in future work, are the following:

- *Limited consumer awareness* of some important safety technologies. Electronic stability control, in particular, has been described in market reports as suffering from fairly limited consumer awareness – that is, many potential car-buyers either have not heard of technologies like ESC or have little understanding of what benefits they provide. This situation is exacerbated, in many cases, by limited dealership support for technologies such as ACC and ESC, meaning that many salespeople are not familiar enough with the systems to promote them as vehicle options.

- *Pricing and bundling issues* may also be curbing purchases of advanced safety systems. As noted above, for example, Lane Departure Warning is an option on some Infiniti vehicles, but only as part of a package that also includes such disparate elements as a navigation unit, upgraded audio system, and satellite radio. This package, in turn, can only be purchased alongside another package, which includes climate-controlled front seats, adaptive headlights, a rear-view monitor, and a pre-crash safety system. This bundling approach, which is typical of other automakers as well, combines safety technologies with unrelated comfort, convenience, and entertainment features. As a result, consumers who might be interested solely in the safety elements face a much more complicated purchase decision than if the safety systems were offered separately; many who might otherwise be willing to pay the approximate cost of LDW or ACC may choose to forego these options rather than pay for a number of other unwanted features.

- The growing popularity of *GPS-equipped handheld devices* has the potential to erode interest in OEM-installed vehicle navigation systems. A number of new GPS-equipped handhelds have recently come onto the market, and (as with most consumer electronics) prices have fallen as production and sales volumes have increased. These devices can easily be attached to the vehicle interior and used for roadway navigation, but unlike OEM-installed units, they also offer the advantage of portability for use on hiking and camping trips, for boating, and for other recreational activities. As standalone units, however, they are not linked to the vehicle or its software. Therefore, if the advantages of price and portability lead consumers to choose these handhelds over OEM-installed navigation systems, this could raise complications for the deployment of other automotive ITS technologies – namely those that rely on a link between onboard GPS and other vehicle systems, such as map-linked adaptive headlights.

- General Motors has announced plans to *install OnStar in all of its vehicles by 2007,* which will greatly increase the reach of basic telematics services in the American market and facilitate the growth of related ITS such as collision notification. It remains to be seen whether this development will shake up the market and lead to similar announcements from other manufacturers. So far, the trend has been in the opposite direction – at least three automakers that formerly offered OnStar through an arrangement with GM have decided to discontinue the service due to lack of customer interest.

- While new in-vehicle technologies typically come first to the luxury segment and then cascade down to the rest of the market, *hybrid vehicles* are one exception to this trend. Since they are designed essentially from scratch rather than via incremental improvements to existing vehicles, hybrids tend to offer more advanced features than other vehicles of the same price[115]. Interest in hybrids has grown as gasoline prices have risen, and continued sales growth would tend to raise consumer awareness of in-vehicle ITS.

- At the same time, there are indications of *consumer resistance to more electronic sophistication* in vehicles, largely because of concerns about reliability. To give just one example, one otherwise favorable review of the Acura RL noted that the adaptive headlights malfunctioned, requiring the car to be turned off and re-started. "The reboot worked … but the incident raised a concern that remained throughout my six-day test drive: has Acura injected too much complexity into a machine that most people will use on the same commute each day? Would I be better off with my 10-year-old Civic, a beater that never needs rebooting?"[116]

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