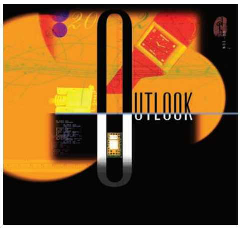
Expanding Automotive Electronic Systems



A vast increase in automotive electronic systems, coupled with related demands on power and design, has created an array of new engineering opportunities and challenges.

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The past four decades have witnessed an exponential increase in the number and sophistication of electronic systems in vehicles. Today, the cost of electronics in luxury vehicles can amount to more than 23 percent of the total manufacturing cost. Analysts estimate that more than 80 percent of all automotive innovation now stems from electronics. To gain an appreciation of the sea change in the average dollar amount of electronic systems and silicon components—such as transistors, microprocessors, and diodes—in motor vehicles, we need only note that in 1977 the average amount was $110, while in 2001 it had increased to $1,800.[1]

The growth of electronic systems has had implications for vehicle engineering. For example, today's high-end vehicles may have more than 4 kilometers of wiring—compared to 45 meters in vehicles manufactured in 1955. In July 1969, Apollo 11 employed a little more than 150 Kbytes of onboard memory to go to the moon and back. Just 30 years later, a family car might use 500 Kbytes to keep the CD player from skipping tracks.[2]

The resulting demands on power and design have led to innovations in electronic networks for automobiles. Researchers have focused on developing electronic systems that safely and efficiently replace entire mechanical and hydraulic applications, and increasing power demands have prompted the development of 42-V automotive systems.

IN-VEHICLE NETWORKS

Just as LANs connect computers, control networks connect a vehicle's electronic equipment. These networks facilitate the sharing of information and resources among the distributed applications. In the past, wiring was the standard means of connecting one element to another. As electronic content increased, however, the use of more and more discrete wiring hit a technological wall.

Added wiring increased vehicle weight, weakened performance, and made adherence to reliability standards difficult. For an average well-tuned vehicle, every extra 50 kilograms of wiring—or extra 100 watts of power—increases fuel consumption by 0.2 liters for each 100 kilometers traveled. Also, complex wiring harnesses took up large amounts of vehicle volume, limiting expanded functionality. Eventually, the wiring harness became the single most expensive and complicated component in vehicle electrical systems.

Fortunately, today's control and communications networks, based on serial protocols, counter the problems of large amounts of discrete wiring. For example, in a 1998 press release, Motorola reported that replacing wiring harnesses with LANs in the four doors of a BMW reduced the weight by 15 kilograms while enhancing functionality. Beginning in the early 1980s, centralized and then distributed networks have replaced point-to-point wiring.[3]

Figure 1 shows the sheer number of systems and applications contained in a modern automobile's network architecture.

Controller area network

In the mid-1980s, Bosch developed the controller area network, one of the first and most enduring automotive control networks. CAN is currently the most widely used vehicular network, with more than 100 million CAN nodes sold in 2000.

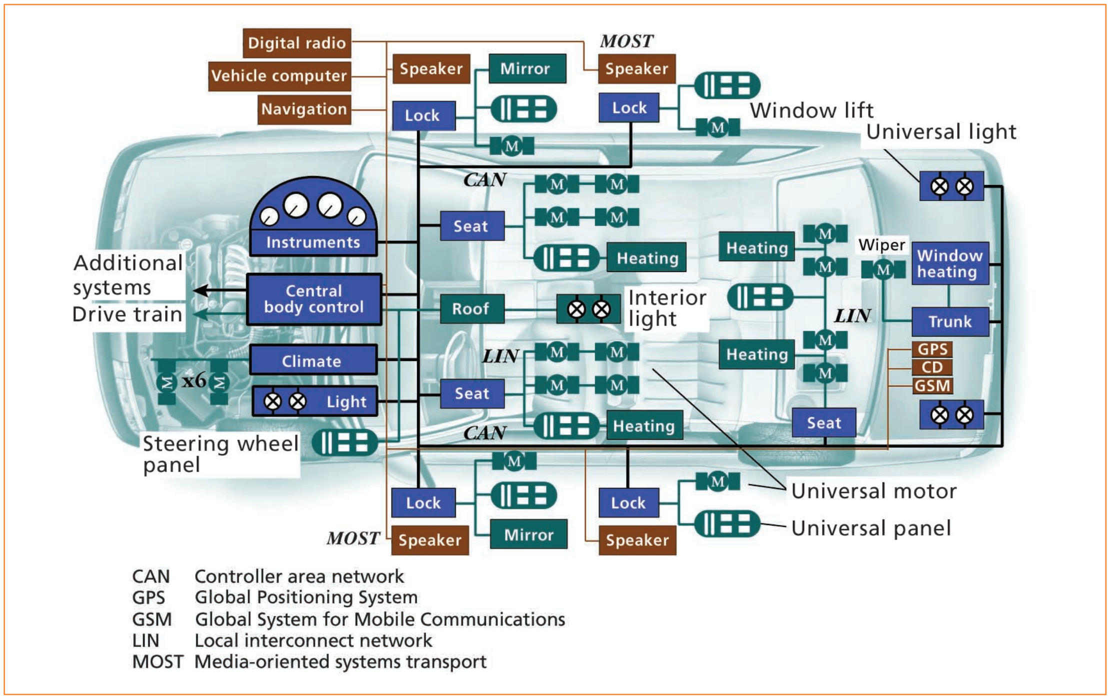


Figure 1. One subset of a modern vehicle's network architecture, showing the trend toward incorporating ever more extensive electronics.

A typical vehicle can contain two or three separate CANs operating at different transmission rates. A low-speed CAN running at less than 125 Kbps usually manages a car's "comfort electronics," like seat and window movement controls and other user interfaces. Generally, control applications that are not real-time critical use this low-speed network segment. Low-speed CANs have an energy-saving sleep mode in which nodes stop their oscillators until a CAN message awakens them. Sleep mode prevents the battery from running down when the ignition is turned off.

A higher-speed CAN runs more real-time-critical functions such as engine management, antilock brakes, and cruise control. Although capable of a maximum baud rate of 1 Mbps, the electromagnetic radiation on twisted-pair cables that results from a CAN's high-speed operation makes providing electromagnetic shielding in excess of 500 Kbps too expensive.

CAN is a robust, cost-effective general control network, but certain niche applications demand more specialized control networks. For example, X-by-wire systems use electronics, rather than mechanical or hydraulic means, to control a system. These systems require highly reliable networks.

Emerging automotive networks

X-by-wire solutions form part of a much bigger trend—an ongoing revolution in vehicle electronics architecture. Multimedia devices in automobiles, such as DVD players, CD players, and digital TV sets, demand networks with extensive synchronous bandwidth. Other applications require wireless networks or other configurations. To accommodate the broad and growing spectrum of vehicle network applications, research engineers are developing many specialized network protocols, including the following.

Domestic Data Bus. Matsushita and Philips jointly developed the Domestic Data Bus (D2B) standard more than 10 years ago, which the Optical Chip Consortium—consisting of C&C Electronics, Becker, and others—has promoted since 1992. D2B was designed for audio-video communications, computer peripherals, and automotive media applications. The Mercedes-Benz S-class vehicle uses the D2B optical bus to network the car radio, autopilot and CD systems, the Tele-Aid connection, cellular phone, and Linguatronic voice-recognition application.

Bluetooth. Bluetooth is an open specification for an inexpensive, short-range (10–100 meters), low-power, miniature radio network. The protocol provides easy and instantaneous connections between Bluetooth-enabled devices without the need for cables. Potential vehicular uses for Bluetooth include hands-free phone sets; portable DVD, CD, and MP3 drives; diagnostic equipment; and handheld computers.

Mobile media link. Designed to support automotive multimedia applications, the mobile media link network protocol facilitates the exchange of data and control information between audio-video equipment, amplifiers, and display devices for such things as game consoles and driver navigation maps. Delphi Packard Electric Systems developed the MML protocol based on a plastic fiber-optic physical layer. Delphi has installed the system in the Network Vehicle, an advanced concept vehicle developed in conjunction with IBM, Sun Microsystems, and Netscape.

Media-oriented systems transport. The applications of MOST, a fiber-optic network protocol with capacity for high-volume streaming, include automotive multimedia and personal computer networking. More than 50 firms—including Audi, BMW, DaimlerChrysler, Becker Automotive, and Oasis SiliconSystems—developed the protocol under the MOST Cooperative (http://www.mostnet.de/main/index.html).

Time-triggered protocol. Designed for real-time distributed systems that are hard and fault tolerant, the time-triggered protocol ensures that there is no single point of failure. The protocol has been proposed for systems that replace mechanical and hydraulic braking and steering subsystems. TTP is an offshoot of the European Union's Brite-Euram X-by-wire project.

Today's vehicle networks are transforming automotive components into truly distributed electronic systems.

Local interconnect network. A master-slave, time-triggered protocol, the local interconnect network is used in on-off devices such as car seats, door locks, sunroofs, rain sensors, and door mirrors. As a low-speed, single-wire, enhanced ISO-9141-standard network, LIN is meant to link to relatively higher-speed networks like CAN. LIN calms fears about security of serial networks in cars. Because LIN provides a master-slave protocol, a would-be thief cannot tap into the network's vulnerable points, such as the door mirrors, to deactivate a car alarm system. Audi, BMW, DaimlerChrysler, Motorola, Volcano, Volvo, and Volkswagen created this inexpensive open standard.

Byteflight. A flexible time-division multiple-access (TDMA) protocol for safety-related applications, Byteflight can be used with devices such as air bags and seat-belt tensioners. Because of its flexibility, Byteflight can also be used for body and convenience functions, such as central locking, seat motion control, and power windows. BMW, ELMOS, Infineon, Motorola, and Tyco EC collaborated in its development. Although not specifically designed for X-by-wire applications, Byteflight is a very high performance network with many of the features necessary for X-by-wire.

FlexRay. FlexRay is a fault-tolerant protocol designed for high-data-rate, advanced-control applications, such as X-by-wire systems. The protocol specification, now nearing completion, promises time-triggered communications, a synchronized global time base, and real-time data transmission with bounded message latency. Proposed applications include chassis control, X-by-wire implementations, and body and powertrain systems. BMW, DaimlerChrysler, Philips, and Motorola are collaborating on FlexRay and its supporting infrastructure. FlexRay will be compatible with Byteflight.

Time-triggered CAN. As an extension of the CAN protocol, time-triggered CAN has a session layer on top of the existing data link and physical layers. The protocol implements a hybrid, time-triggered, TDMA schedule, which also accommodates event-triggered communications. The ISO task force responsible for the development of TTCAN, which includes many of the major automotive and semiconductor manufacturers, developed the protocol. TTCAN's intended uses include engine management systems and transmission and chassis controls with scope for X-by-wire applications.

Intelligent transportation systems data bus. Enabling plug-and-play in off-the-shelf automotive electronics, the intelligent transportation systems data bus eliminates the need to redesign products for different makes. The Automotive Multimedia Interface Collaboration, a worldwide organization of motor vehicle makers, created the specification, which supports high-bandwidth devices such as digital radios, digital videos, car phones, car PCs, and navigation systems. The specification's first release endorses IDB-C (CAN) as a low-speed network and optional audio bus, and two high-speed networks, MOST and IDB-1394b. IDB-1394b is based on the IEEE 1394 FireWire standard.

X-BY-WIRE SOLUTIONS

Today's vehicle networks are not just collections of discrete, point-to-point signal cables. They are transforming automotive components, once the domain of mechanical or hydraulic systems, into truly distributed electronic systems. Automotive engineers set up the older, mechanical systems at a single, fixed operating point for the vehicle's lifetime. X-by-wire systems, in contrast, feature dynamic interaction among system elements.

Replacing rigid mechanical components with dynamically configurable electronic elements triggers an almost organic, systemwide level of integration. As a result, the cost of advanced systems should plummet. Sophisticated features such as chassis control and smart sensors, now confined to luxury vehicles, will likely become mainstream. Figure 2 shows how dynamic driving-control systems have been steadily adopted since the 1920s, with more on the way.[4,5]

Highly reliable and fault-tolerant electronic control systems, X-by-wire systems do not depend on conventional mechanical or hydraulic mechanisms. They make vehicles lighter, cheaper, safer, and more

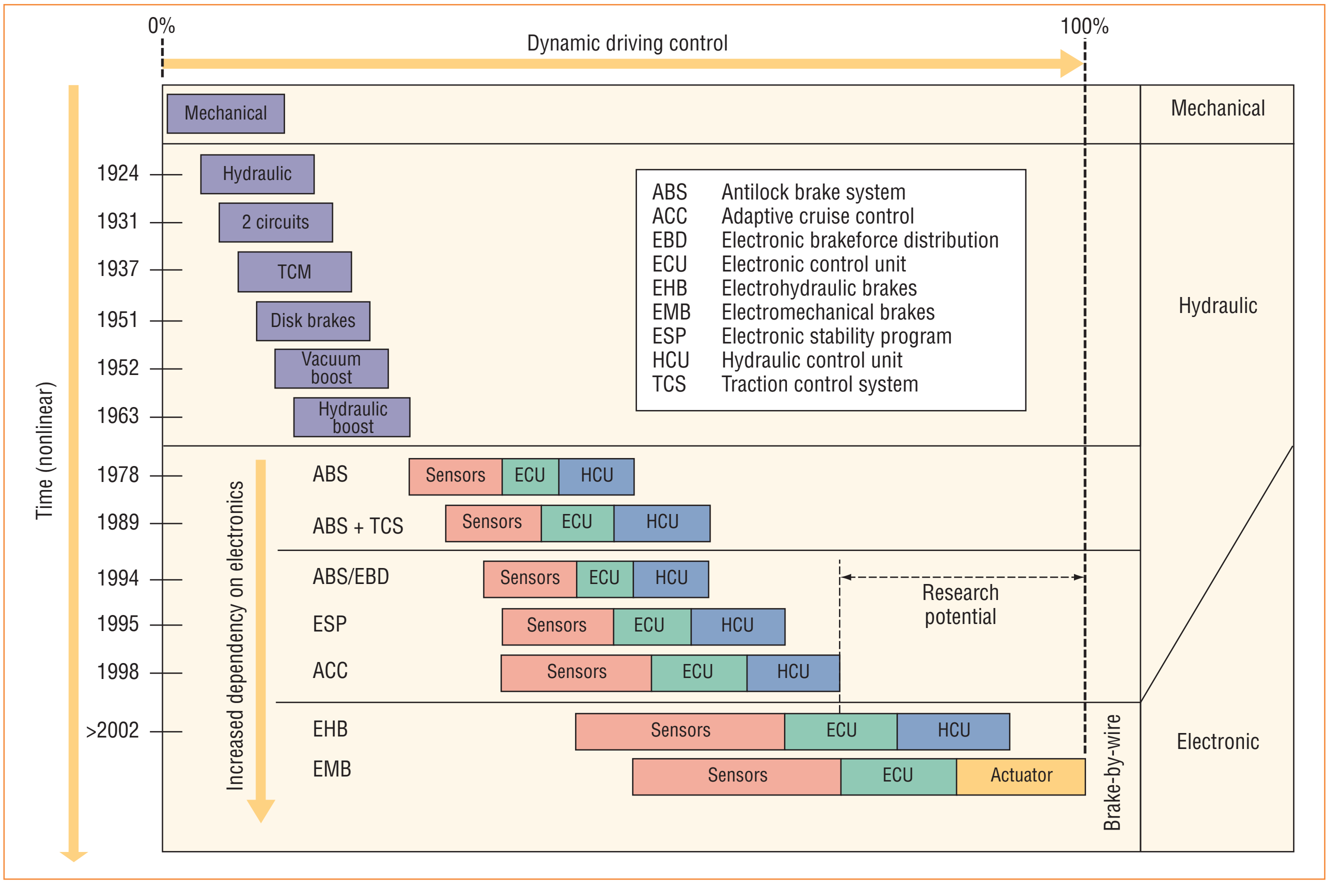


Figure 2. Past and projected progress in dynamic driving control systems. As the cost of advanced systems plummets, sophisticated features are likely to become mainstream components.

fuel-efficient. These self-diagnosing and configurable systems adapt easily to different vehicle platforms and produce no environmentally harmful fluids. Such systems can eliminate belt drives, hydraulic brakes, pumps, and even steering columns.

Indeed, by 2010 one in three new cars will feature electronic steering. X-by-wire steering systems under development will replace the steering column shaft with angle sensors and feedback motors. A wire network will supply the control link to the wheel-mounted steering actuator motors. Removal of the steering column will improve driver safety in collisions and allow new styling freedom. It will also simplify production of left- and right-hand models.

It is natural to add advanced functions to such electronic systems. For example, consider systems that reduce steering-wheel feedback to the driver. In mechanical steering systems, the driver actually feels the vehicle losing control in unstable conditions and can react appropriately. Today, such electronic features as antilock braking may let the vehicle approach or surpass this control-loss edge without providing warning. To accommodate this, X-by-wire systems can include motors on the steering wheel that provide artificial feedback to the driver.

All major automakers are developing prototype or production X-by-wire systems. TRW's electronic power-assisted steering system improves fuel economy by up to 5 percent. Delphi Automotive Systems claims similar improvements from its E-Steer system. Companies such as Bosch, Continental AG, Visteon, Valeo, and most other original equipment manufacturers have either developed or plan to develop X-by-wire technologies and components.

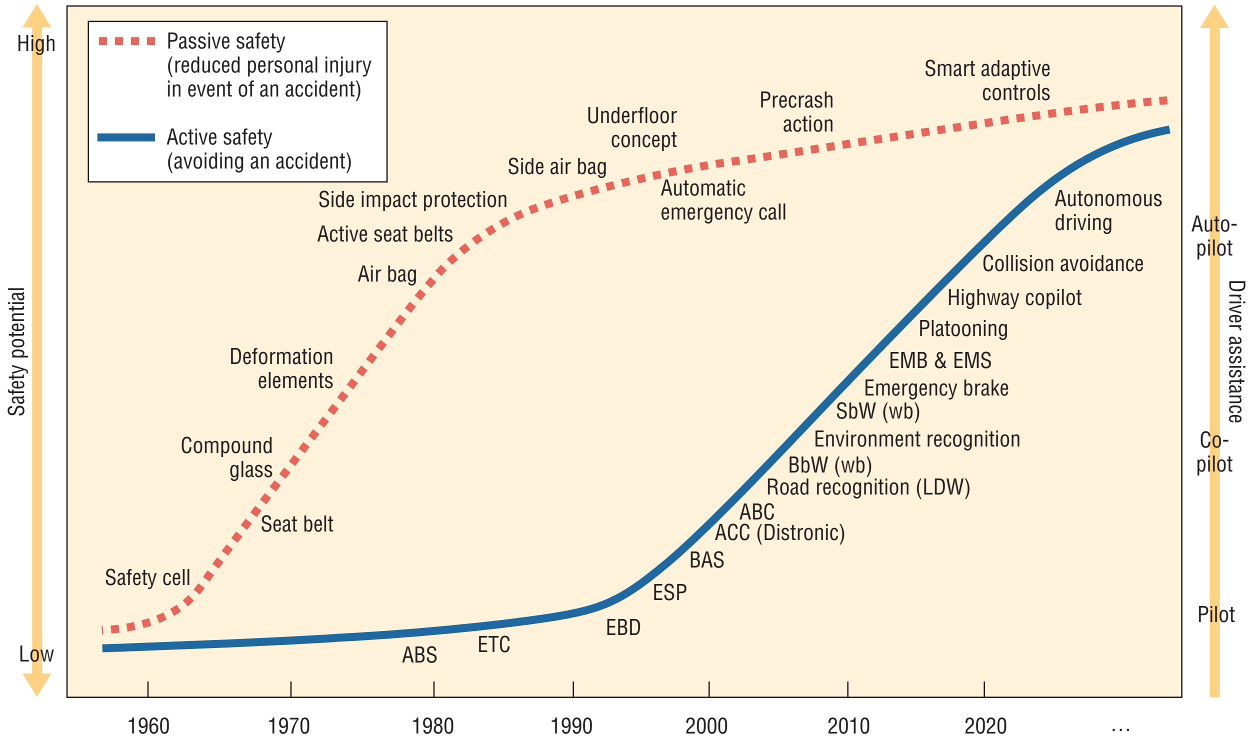
Several protocols are suitable for X-by-wire applications. TTP, for example, is a promising and available protocol geared toward improving driving safety. However, the FlexRay and TTCAN protocols will start to compete with TTP when manufacturers look for more flexibility and lower cost.

Figure 3 shows the past and potential future improvements from active and passive safety systems such as air bags and road-recognition sensors.[6] Advanced electronic systems and the X-by-wire infrastructure will enable most potential active safety improvements.

ELECTRICAL POWER DEMAND

Vehicular battery management systems continuously check the condition of the car's battery, monitoring the charge to ensure the auto will start and have enough power to maintain critical systems. Even with the engine switched off, some systems—real-time clocks, keyless entry and security devices, and vehicle control interfaces such as window switches and light switches—still consume power.

In addition to these conventional electrical systems, emerging applications as diverse as in-car computers and GPS navigation systems consume enough power to raise the total energy load to more than



ABC	Active body control	EBD	Electronic brakeforce distribution
ABS	Antilock brake system	EMB	Electromechanical brakes
ACC	Adaptive cruise control	EMS	Electromechanical steering
BAS	Brake assist system	ESP	Electronic stability program
BbW	Brake by wire	ETC	Electronic traction control
CA	Collision avoidance	SbW	Steer by wire
DbW	Drive by wire	(wb)	with mechanical backup

Figure 3. Past and future active and passive safety systems. Advanced electronic systems and the X-by-wire infrastructure will enable active safety improvements.

2 kW. If historical trends continue, internal power demand will grow at a rate of 4 percent a year. Conservative estimates put the average electrical power requirements for high-end vehicles at 2.5 kW by 2005.[7] These increases place strains on conventional power equipment. For example, at a 3-kW load, bracket-mounted, belt-driven alternators generate unpleasant noises and require liquid cooling.

Table 1 shows some anticipated electrical loads for key emerging systems.[8] Analysts expect the loads to reach the listed levels by 2005. Electromechanical valves that will replace the camshaft and inlet and exhaust valves offer one exception—they probably won't be produced until 2010.

Given the benefits they offer, such systems and their greater power loads are necessary. Electromechanical valves, for example, should provide a 15 percent improvement in fuel consumption. Preheated catalytic converters will decrease exhaust emissions by 60 to 80 percent.

THE 42-V SOLUTION

To meet the increasing demand for power, a beltless engine with an integrated alternator-starter on the flywheel operating at a 42-V potential offers the most promising proposed solution. The motive for the new 42-V system is clear: 79 percent of the energy entering a conventional engine does not make it to the driveline.[2] The standard Lundell claw-and-rotor alternator is itself only 30 percent efficient at high speeds and 70 percent efficient at low speeds. Thus, generating a watt of electrical power requires about 2 watts of mechanical power, with the lost watt turned into heat.

The integrated system is expected to be 20 percent more efficient, providing a benefit of roughly 0.2 km/liter, or 0.4 mpg. Its "lite hybrid" alternator-starter will operate the vehicle in start-and-stop mode, in which the engine can be restarted in 200 ms for even more fuel savings. In addition, removal of the front-end accessory drive—running the alternator and power-steering pump—will mean enhanced car styling. The new 42-V systems are expected in new autos by 2003.

Within the electrical system, boosting the voltage proportionally reduces the required current for a given delivered power. Smaller currents will use smaller and lighter-gauge cables, allowing an expected 20 percent reduction in cable bundle size. Further, the carrying capacity of semiconductor switches for electrical currents relates directly to silicon area size, while operational voltage levels are a function of device thickness and doping profile. With less silicon area required, these systems

Table 1. Predicted electrical loads of advanced electronic systems.

System	Peak load	Average load
Electromechanical valves	2,400	800
Water pump	300	300
Engine cooling fan	800	300
Power steering (all electric)	1,000	100
Heated windshield	2,500	200
Preheated catalytic converter	3,000	60
Active suspension	12,000	360
Onboard computing, navigation		100
Total average		**2,220**

will achieve a significant cost reduction in solid-state load-switching devices.[1]

The 42-V systems will require a 36-V battery and produce a maximum operating level of 50 V, with a maximum dynamic overvoltage of 58 V. Engineers regard a 60-V limit as the safe maximum for cars; greater voltages can generate shocks.[9]

Despite the obvious advantages of 42-V systems, challenges loom. Transition costs—reengineering of products and production processes—will be extremely high due to the legacy of a half century of 12-V systems. The upgrading of service and maintenance equipment will provide other obstacles. Still, annual power consumption increases of 4 percent will simply overload present-day 14-V systems, making 42-V alternatives inevitable.

Reducing wiring mass through in-vehicle networks will bring an explosion of new functionality and innovation. Our vehicles will become more like PCs, creating the potential for a host of plug-and-play devices. With over 50 million new vehicles a year, this offers the potential for vast growth in automotive application software—much like that of the PC industry over the past decade.

On average, US commuters spend 9 percent of their day in an automobile. Introducing multimedia and telematics to vehicles will increase productivity and provide entertainment for millions. Further, X-by-wire solutions will make computer diagnostics a standard part of mechanics' work. The future could even bring the introduction of an electronic chauffeur. ■

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