2

Background

A review of the history of interest in fully automated vehicles and highways is important in helping to explain why the U.S. Department of Transportation (DOT) has been pursuing two different visions of how a fully automated system might one day emerge. One vision is of increasingly automated vehicles and highways evolving into a fully automated system relatively gradually through efforts to encourage developments in intelligent vehicle technologies and intelligent transportation systems (ITS) in general. The other envisions a fully automated highway system emerging sooner, facilitated by deliberate efforts to specify a system configuration and to encourage development and implementation of that system. Having pursued both visions during the past 5 years, DOT now has indicated its intention to consolidate its research efforts to realize a single vision.

INTEREST IN FULLY AUTOMATED VEHICLES AND HIGHWAYS

Fully automated driving has been an aim of engineers, planners, and technologists for decades. As early as 1939, the World's Fair in New York included a futuristic exhibit by General Motors (GM) on "driverless" cars (Shladover 1990, 158). During the 1950s, GM research engineers conceptualized and conducted preliminary tests of automobiles with steering and speed controlled by radio controls and other mechanical systems (DOT 1995, 73). GM's early work envisioned fully automated, hands-off, feet-off systems that would greatly increase driver convenience and comfort: Drivers were portrayed as relaxed, cruising in completely automated cars down the open freeways created by the newly established Interstate Highway System while they read the newspaper and drank coffee. Increased safety and highway capacity had yet to be emphasized.

By the 1960s, automation concepts were being explored not only as a means of enhancing driving comfort and convenience but also with other, more practical, applications in mind. For instance, researchers at Ohio State

University—motivated by the emerging network of modern freeways and advances in transistors and other radio and communications technologies—investigated vehicle and roadside communications devices that would assist motorists in performing some driving tasks and provide real-time traffic and navigation information.[1] Fully automated highway systems were increasingly being regarded as a way to increase throughput on increasingly congested urban and intercity highways. During the late 1970s, GM received DOT funding to examine fully automated highway system concepts and identify an optimal system configuration that could be developed and deployed before the end of this century (DOT 1980; DOT 1981). Although federal funding of these efforts was discontinued in 1980, this general approach—that is, the goal of early system specification and deployment—would be rejuvenated during the 1990s.

A new emphasis emerged, however, in the late 1980s. Although work on fully automated systems continued through the decade, increased attention was being given by the public and private sectors to intelligent, partially automated products and services.[2] Advances in electronics, sensor, and computing technologies—and burgeoning activity in ITS—generated commercial interest in products that might enhance driver perception as well as driving capabilities: for example, by sensing an impending collision, alerting the driver, and applying the brakes if necessary. Motorists might be aided further by traveler information and route guidance systems being developed as part of ITS. Full automation concepts—typically imagined as hands-off, feet-off driving on instrumented highways—were the subject of intermittent research but generally were viewed as long-range outcomes of the gradual development and expanded use of nearer-term intelligent vehicle and highway products.

ITS AND THE VISION OF INCREASINGLY AUTOMATED SYSTEMS

ITS is the collective term for a variety of advanced surface transportation technologies that are intended to aid driving, enhance the capacity and efficiency of the highway system, and assist transportation agencies in managing their facilities and controlling traffic. The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) substantially increased federal funding of

[1] The traveler information system that was the subject of research from the 1960s to the early 1970s was known as the Electronic Route Guidance System (Rosen et al. 1970).

[2] Efforts to coordinate ITS development at the national level began with Mobility 2000, a voluntary organization formed in the late 1980s to bring together advocates for intelligent vehicle and highway systems (IVHS) from the private and public sectors and from academe (Texas Transportation Institute 1990). Mobility 2000 was subsumed by IVHS America, later renamed ITS America.

ITS research, development, and implementation. There was a strong rationale for expanded funding. By the end of the 1980s, construction of the Interstate Highway System was nearly complete, yet traffic demands on the nation's highway network were continuing to grow at an extraordinary pace. Building more roads clearly was not the solution in many areas where costs and traffic disruptions would be prohibitive. Emerging technologies were regarded as critical tools for keeping pace with growing demands for system efficiency and safety (Saxton 1993). Among other benefits, these technologies promised to optimize traffic signal timing, advise motorists about traffic conditions, enable rapid detection and removal of accidents and other obstacles to traffic flow, and reduce waits at toll and weigh stations.

Implicit in the ITS provisions of ISTEA was the need for the private and public sectors to work together in developing, demonstrating, and deploying intelligent transportation systems and technologies to accelerate their availability. ISTEA called upon DOT and the ITS research community to develop a strategic plan for embarking on an efficient and effective course of ITS development, deployment, and operations [ISTEA, Section 6054(a)]. The DOT and the ITS America[3] strategic plans foresaw an integration of ITS products and services (DOT 1992; ITS America 1992). Both DOT and ITS America expected that with the assistance of public and private partnerships, ITS would be implemented incrementally but in a coordinated manner that would facilitate systems compatibility among regions and the gradual integration of different ITS products and services. This thinking, sometimes called a "planned evolution," is typified in a passage from the strategic plan of ITS America: "As our base of knowledge and technology grows, as we find out what works best, what the market will support, and what prudent management demands, the systems will expand and mature, taking on a national character" (ITS America 1992, II-6).

The ITS America and DOT strategic plans identified five "functional areas"—essentially groupings of ITS products that would provide similar or compatible services. For example, one functional area, advanced vehicle control systems (AVCS), encompassed a broad range of products—including sensors, computers, and control systems—that would enhance driver perception and assist with driving tasks. Planners anticipated that different AVCS features and capabilities would be developed and deployed over different periods of time. Vehicle-based systems that give drivers warnings of impending dangers—such as products that provide blind-spot surveillance or improve night vision—were expected to be introduced first, followed by

[3] ITS America is a nonprofit association established to plan, promote, and coordinate ITS in the United States. It comprises researchers, producers, and users of ITS products and services from academe, industry, and government. One of its chartered missions is to provide advice to the federal government on ITS.

systems that take control of certain driving tasks, such as braking in an emergency or adjusting vehicle speed according to the driver's desire for distance following other vehicles ("adaptive cruise control").

Over time, such systems would become integrated with intelligent traffic control and management infrastructure to "serve as fundamental building blocks for future systems" (ITS America 1992, III-34). For instance, electronic transmitters in the pavement might detect the position of vehicles within a lane, providing information to traffic control centers while sending information to motorists about traffic levels and roadway conditions and helping them stay in their lanes (Euler 1990). The evolution and integration of these technologies into a system that could provide full vehicle control was conceived as a possible long-range outcome of these developments, potentially providing a solution to future safety and highway capacity problems.

ALTERNATIVE VISION: FULLY AUTOMATED SYSTEMS EMERGING IN AN ACCELERATED, PLANNED MANNER

By the late 1980s, DOT had initiated several research projects on advanced vehicle and traffic control systems. The Federal Highway Administration (FHWA) was concentrating its ITS-related efforts on advanced traffic management techniques and control systems (FHWA 1992, 12–14); its sister agency, the National Highway Traffic Safety Administration (NHTSA), was beginning to test vehicle-based radar systems to maintain headways in semiautomated traffic. NHTSA's efforts included making small grants for research on these and other vehicle-based technologies that later would be grouped under the AVCS heading (TRB 1990, 145).

Following passage of ISTEA in 1991, however, DOT added a new element to its research program. ISTEA called upon DOT to "develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed" [ISTEA 1991, Part B, Section 6054(b)]. This legislative provision called into question the notion of a fully automated highway system emerging gradually through efforts to encourage incremental advances in intelligent vehicle and traffic control and information technologies. By mandating the prototyping of an automated vehicle and highway from which a future fully automated system could be developed, Congress implied that a fully automated system might indeed emerge in a deliberate and accelerated manner. This mandate represented a vision similar to that of GM researchers in the 1950s and 1970s who sought to specify an optimal fully automated highway system for application before the turn of the century (DOT 1980; DOT 1981).

The effect of this provision is evident in the ITS strategic plans of ITS America and DOT. Both presented dual visions of how fully automated driving systems could emerge. ITS America's 1992 strategic plan, for instance, describes AVCS concepts that support automatic control as "long-term" while noting, "The goal is to have the first fully automated roadway or test track in operation by 1997" (ITS America 1992, I-12). Likewise, the 1992 DOT strategic plan calls for two distinctly different research paths on advanced vehicle and highway systems. One path, headed by NHTSA, would evaluate and investigate opportunities for implementing sensors, processors, and other technologies that could aid drivers in avoiding crashes. The focus would be on examining the need for, and the potential effects of, collision warning devices and other partially automated vehicle systems that could offer emergency control in near-collision situations (DOT 1992, 61–62). The second path, headed by FHWA, would develop and demonstrate a fully automated highway system that would serve as the basis for future developments (see Box 2-1). The evolutionary and accelerated research programs have coexisted within DOT during the past 5 years.

FEDERAL RESEARCH EFFORTS

DOT is not the only federal agency that supports work related to intelligent vehicles and highways. Within the U.S. government broadly, various efforts are under way to research and develop automation technologies that could have application to highway transportation. For example, as part of the robotics program of the U.S. Department of Defense, the Unmanned Ground Vehicles Program is working on relevant systems and technologies, such as obstacle detection, image processing, mapping, the Global Positioning System (GPS), and range finding. Likewise, various technologies and evaluation methods for automation controls, sensing systems, human factors, and other components and aspects of intelligent vehicle and highway systems are being investigated with federal funding by national laboratories (e.g., Sandia National Laboratory), the National Science Foundation, the National Institute for Standards and Technology, and the National Aeronautics and Space Administration. NHTSA and FHWA have tapped into the work of these other federal research and development programs.

NHTSA Research on Intelligent Vehicles

NHTSA's research on vehicle automation has been headed by its Crash Avoidance Office. The emphasis to date has been on establishing the knowledge and research tools needed to develop collision warning and driver assistance technologies (NHTSA 1997). Crash data are being examined to identify problems warranting attention, and preliminary human factors

BOX 2-1: FHWA PLANS FOR FY 1993 HIGH-PRIORITY RESEARCH ON ADVANCED VEHICLE CONTROL SYSTEMS (FHWA 1992, 28)

The following quotation from FHWA describes the agency's initial plans for an automated highway system (AHS) research program.

> In response to the Congressional mandate in the ISTEA to demonstrate a prototype automated highway system on a test track by 1997, the FHWA and the NHTSA have jointly developed a long-term program with the goal of generating a performance specification of an AHS, through extensive system development and testing. This performance specification will then be used by automotive product developers and transportation agencies to deploy AHS's late in the next decade. The 1997 demonstration is a major milestone in this overall program and will provide proof-of-concept feasibility of an AHS system. The AHS vision can be summarized as a system of instrumented vehicles and highways that provides fully automated (i.e., "hands-off") operation at better levels of performance (safety, efficiency, comfort) than today's highways and is financially affordable, where vehicles can operate in both urban and rural areas on highways that are both instrumented and noninstrumented. Acquisition planning for this major program is not final; however, two efforts are envisioned for fiscal year 1993: a broad agency announcement is planned to perform precursor system analyses relating to an AHS. Multiple parallel analyses are desired to provide the DOT and others in the IVHS community with a realistic range of AHS configurations and a better understanding of the issues dealing with AHS applications, technology, design, deployment, operation, and practicality; and a solicitation for a consortium to design and develop the prototype system for the 1997 demonstrations is planned. The consortium would use the results of the precursor systems analyses as a technical foundation in beginning prototype development. At a minimum, this consortium would consist of automobile manufacturers and transportation agencies, as these entities are key stakeholders in the future widespread deployment of AHS systems.

guidelines have been developed for the design of crash-warning devices and in-vehicle displays. NHTSA anticipates that the National Advanced Driving Simulator, scheduled for completion in 1999, will aid human factors research in this area (NHTSA 1997). To assess various crash-avoidance measures, including automated controls, NHTSA also is sponsoring work to develop a portable device that can be installed in test vehicles to monitor and record driver and vehicle information, such as vehicle speed and driver orientation.

NHTSA has formed partnerships with several automotive companies and suppliers to accelerate the development of collision-avoidance systems. NHTSA expects these partnerships to spur the commercial introduction of the safest and most effective of these systems.

FHWA and National Automated Highway System Research Program

Following passage of ISTEA, DOT established the National Automated Highway System Research Program, housed within FHWA. DOT initiated the program by sponsoring "precursor" studies aimed at identifying and understanding potential obstacles to the development and deployment of fully automated highway systems. These year-long studies (which are discussed in more detail in Chapter 4) were conducted by teams of researchers from universities, aerospace and automotive industries, and several defense, communications, and aerospace firms. Concurrent with these assessments, DOT sponsored separate human factors studies of automated highway systems—an area of inquiry specifically identified in ISTEA.

As the precursor studies were nearing completion—and no major obstacles to the development and deployment of a fully automated highway system were identified—DOT moved forward to the next phases of its research program: undertaking the congressionally mandated demonstration and selection of a preferred fully automated highway system. In doing so, DOT chose to concentrate funding on a national research consortium consisting of the kinds of organizations that were ultimately expected to design, build, deploy, and operate a fully automated highway system (DOT 1993, 3).

By involving such "stakeholders" at the outset, DOT hoped to expand program resources (funds, equipment, and skills) and prompt the automotive and highway industries to begin working cooperatively in this area and to agree on a fully automated highway system that would serve as the basis for future developments. Building such early support entailed many challenges that would require concerted public- and private-sector effort. Consortium members would be expected to contribute 20 percent of the funds for the research program effort, which would "provide the basis for, and transition to, the next major performance upgrade of the U.S. highway system through the use of automated highway technology" (DOT 1993, 4). After a competitive process, a team headed by GM was selected in late 1994 to form the National Automated Highway System Consortium (NAHSC). (The organization, procedures, and accomplishments of NAHSC are briefly reviewed here for background purposes; they are described in more detail in Chapter 4.)

NAHSC comprised nine contributing organizations, known as core members. In addition to GM, the core membership consisted of Bechtel Corporation, the California Department of Transportation (Caltrans), Carnegie Mellon University, Delco Electronics Company, Hughes Electronics Corporation, Lockheed Martin Corporation, Parsons Brinckerhoff, Inc., and the University of California at Berkeley. These core members had expertise in areas ranging from electronics and vehicle manufacturing to highway construction and operations, all of which were considered central to the eventual development and deployment of fully automated highway systems. DOT also served as a member of the consortium and was responsible for representing the interests and perspectives of transportation users.

NAHSC was given several milestones to reach in achieving the goal of identifying a preferred fully automated highway system. It focused its early efforts on achieving three milestones: gaining an understanding of the basic requirements of an automated highway system from the perspective of transportation users, providers, and other "stakeholders"; characterizing the general concepts, or kinds of systems, that are candidates for achieving these requirements; and undertaking a public demonstration of automated highway system technologies, as mandated by Congress. To pursue the first of these goals, the consortium sponsored several workshops and outreach activities for transportation users, automobile makers and their suppliers, the highway community, and other interest groups. An associates program was established to bring in the views and expertise of individuals and organizations from outside the core membership.

Work on the second milestone led to the identification of several potential configurations for a fully automated highway system, grouped into "concept" families. According to one concept, for example, vehicles would operate automatically through independent means using on-board computers and sensors; according to another, vehicles would operate in synchronized platoons governed by a combination of vehicle- and infrastructure-based sensors, computers, and communications systems. In the NAHSC work plan, each concept was to be evaluated with regard to technical feasibility and safety, traffic throughput, and infrastructure cost impacts, as well as societal, institutional (e.g., jurisdictional or legal), and environmental implications. Those concepts showing the greatest promise would be evaluated further, leading to the eventual identification of a system configuration most suitable for prototype development and testing.

A public demonstration of several automation technologies was held in San Diego, California, in August 1997, fulfilling the mandate in ISTEA.

Next Steps in DOT's Program

The 1997 demonstration originally was planned as the precursor to achieving the next major step in the consortium's work plan: specifying a preferred automated highway system for prototype development, testing, and demonstration. This follow-on phase coincided, however, with the scheduled reauthorization of surface transportation legislation—a time when DOT budget and program priorities are scrutinized by the administration and Congress. Having complied with the congressional mandate for a 1997 demonstration, DOT turned its attention to the future of NAHSC.

Before the San Diego demonstration, DOT had indicated that the consortium's mission was not well suited to more immediate program goals. The administration's surface transportation bill (NEXTEA), submitted to Congress in the spring of 1997, included no explicit provisions prolonging NAHSC funding. Concurrently, DOT notified the consortium of preliminary plans to de-emphasize specification of a fully automated highway system and to give greater attention to the development of nearer-term intelligent vehicle technologies with the potential to attain early safety benefits.

According to a DOT draft, the new Intelligent Vehicle Initiative (IVI) program would focus on the development of systems that warn drivers of unsafe situations, recommend evasive actions, and take temporary control of driving during hazardous or near-collision situations (DOT 1997). Essentially, IVI would expand the intelligent vehicle research program already under way within NHTSA. In its early draft, DOT outlined plans to collaborate with industry to develop and evaluate intelligent vehicle technologies that show the potential to be deployed over the next decade. This collaboration would focus primarily on the automotive industry because most nearer-term driver assistance and partial-control products are expected to be vehicle-based. Automobile makers and their suppliers, for example, would be encouraged to equip a small number of cars with collision warning systems, adaptive cruise controls, and blind-spot surveillance systems (DOT 1997, 1). Industry was expected to work with DOT and other research organizations to evaluate and improve the performance of these technologies and find ways to integrate them into safe and effective crash-avoidance systems that could be offered to consumers (DOT 1997, 9). The goal of the IVI program would be "to accelerate the development, introduction, and commercialization of driver assistance products to reduce motor vehicle crashes and incidents" (DOT 1997). In effect, DOT moved toward the vision of individual ITS products leading to the eventual emergence of automated systems, thereby casting into doubt the future of the NAHSC program.

The next major milestone in the consortium's original agenda was to select a preferred automated highway system configuration, leading to the development of a final system for prototype design and testing by 2002. When presented with DOT's new plans, NAHSC sought to modify its work plan to better align it with the new emphasis. Doing so proved difficult, however, in light of the consortium's original mission, structure, and decision-making and management processes.

The issue became moot in December 1997, when DOT—citing changed priorities and budgetary constraints caused by the temporary extension of ISTEA—informed NAHSC of its decision to reduce funding for the program, withdrawing all financial support as of September 30, 1998.

REFERENCES

ABBREVIATIONS

DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration
NAHSC	National Automated Highway System Consortium
NHTSA	National Highway Traffic Safety Administration
TRB	Transportation Research Board

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