4

National Automated Highway System Research Program

The key developments leading up to the creation of the National Automated Highway System Consortium (NAHSC), as well as its organization and its major accomplishments since its inception in late 1994, are discussed in this chapter. This review covers the steps taken by the U.S. Department of Transportation (DOT) to implement the National Automated Highway System Research Program—including the decision to concentrate this research in a consortium of government, industry, and academic organizations—and the mission, procedures, and achievements of NAHSC.

EARLY DECISIONS AND ASSESSMENTS

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) called on the Secretary of Transportation to develop an automated highway and vehicle prototype from which future fully automated systems could be developed (see Chapter 1 for the specific wording of this section of the Act). In doing so, ISTEA called upon DOT to investigate human factors issues pertaining to fully automated vehicles and highways, have a fully automated roadway or test track in operation by 1997, and develop a system that could accommodate the installation of automation equipment on new and existing vehicles. Beyond these stipulations, the legislation did not give DOT direction on how the research and demonstration activities should be undertaken or what was meant by the term "fully automated highway systems."

Program Initiation

Given latitude to determine the best means of fulfilling the legislative mandate, DOT elected to make the National Automated Highway System Research Program the longest-range component of its Intelligent Transportation Systems (ITS) program. DOT chose to go beyond the 1997 demonstration required by Congress by establishing a program that would (by the year 2002) specify, develop, and demonstrate a prototype fully automated highway system on which future systems would be based.

Among the first steps taken by DOT in establishing the research program was to identify several essential features of a fully automated highway system that could be used by researchers to begin examining these systems. The characteristics listed in Box 4-1 were identified as guiding assumptions for investigating fully automated highway systems.

Some of these system requirements—for instance, that existing vehicles have the capability to be retrofitted for fully automated driving—were developed in response to stipulations in ISTEA. Most, however, stemmed from DOT's own determinations about the characteristics that would make fully automated driving technically and commercially viable. These system requirements were used in work sponsored by DOT to develop more than a dozen alternative configurations of fully automated highway systems. These "representative system configurations" (RSCs) differed mainly in their physical and technical approaches to full automation—for instance, whether ded-

BOX 4-1: ESSENTIAL FEATURES OF AN AUTOMATED HIGHWAY SYSTEM (FHWA 1996, 11–12)

- All vehicle types (automobiles, buses, trucks) will be supported in a mature system, although initial deployment would be on automobiles.
- Automated vehicles will be instrumented, enabling them to operate automatically on instrumented segments of the roadway.
- Not all vehicles and roadways will be instrumented—instrumented vehicles will be able to operate on noninstrumented roadways, only instrumented vehicles will be allowed to operate on instrumented roadways, and noninstrumented vehicles will be instrumented on a retrofit basis.
- Automated operations will occur on freeway-type roads and will work in a wide range of weather conditions.
- Automated highways will perform better than today's roads and vehicles in terms of safety, throughput, user comfort, and environmental impact.
- The system will be practical, affordable, desirable, and user-friendly.
- The system will rely primarily on noncontact, electronics-based technology as opposed to mechanical or physical contact techniques—though the latter might be part of a backup subsystem.

icated lanes would serve fully automated traffic, where transition lanes would be located, whether vehicles and roadways would communicate with one another, and how much roadways would be instrumented to control vehicle speed, maneuvering, and spacing. Although the RSCs were not developed with reference to a specific application, it was generally assumed that they would permit fully automated driving on Interstate highways and other high-volume freeways.

Analysis Phase

Having identified these alternative configurations for fully automated systems, DOT embarked on the analysis phase of its research program. DOT planned three phases for the program (see Figure 4-1). The first two have been undertaken. The third, including operational tests of a fully automated highway system, was scheduled to begin in 2001.

The first phase, the analysis phase, consisted of several "precursor" studies conducted by teams of researchers and practitioners from government, industry, and academe over the course of 1 year. The precursor studies, undertaken during 1993 and 1994, covered various topics. The study teams conducted their work by several means, including workshops, computer

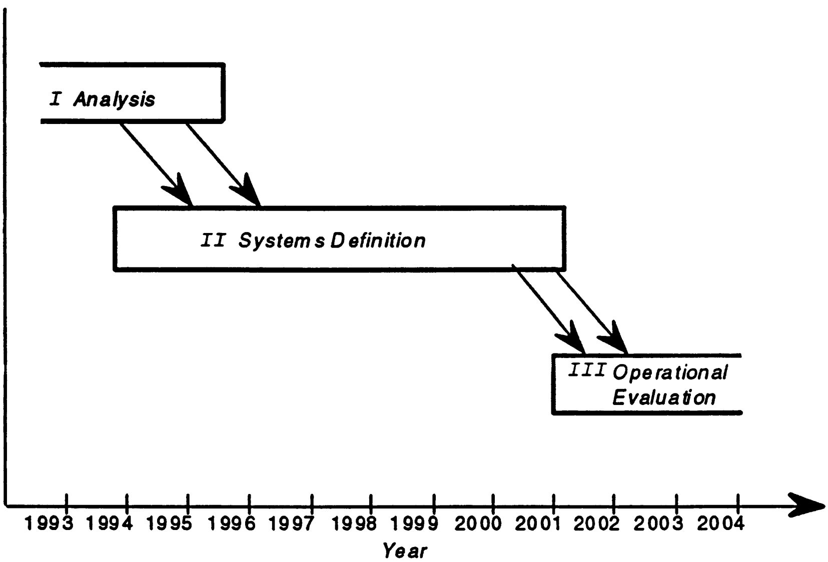

FIGURE 4-1 Planned phases of National Automated Highway System Research Program.

simulations, literature reviews, and multidisciplinary brainstorming sessions. The main purpose of these studies was to provide an early assessment of important issues and problems that might arise in developing and implementing fully automated highway system concepts (see Box 4-2 for examples of key findings). The precursor study teams therefore focused their efforts on identifying major technical, environmental, and safety impacts from implementation of a fully automated highway system. On the basis of these assessments, none of the precursor studies found reason to question the aim of the follow-on "systems definition" phase of the National Automated Highway System Research Program, which would aim to specify, develop, and test a fully automated highway system.

BOX 4-2: KEY FINDINGS FROM PRECURSOR STUDIES (FHWA 1996)

Urban and Rural Settings [Battelle, Calspan, Delco, Partnership for Advanced Transit and Highways (PATH)]

- Urban travelers, particularly commuters to and from work, are potential early candidates for automated highway system applications. They are more likely to be willing to pay the added cost of vehicle instrumentation. High Occupancy Vehicle and transit users are the earliest candidates among urban travelers.
- Building new roads and adding rights-of-way will be problematic in urban areas. Using existing lanes for automated traffic may be necessary.
- Major urban design challenges will involve entry and exit lanes and controls for mixing of automated and nonautomated traffic.
- The system will need to support mixed automated and nonautomated traffic in rural areas.
- Alternative system configurations will be required for urban, suburban, and rural settings.

Traffic Operations and Impacts on Nonautomated Roads (Battelle, Calspan, Delco)

- Incidents on automated roadways may cause serious operational disruptions, requiring timely incident detection and removal.
- New jurisdictional organizations and cooperative mechanisms will be required to operate and maintain automated facilities.
- Transportation agencies will need to expand staffs and technical capacity, concentrating more on preventive maintenance of facilities.

BOX 4-2 (*continued*)

◆ Saturation of roads near automated facilities may require geometric design and signalization changes.

◆ Queueing of vehicles entering automated facilities may be required but can be handled effectively.

Exit and Entry and Check-in and Checkout (Battelle, Calspan, Delco, PATH, Raytheon)

◆ Vehicles may need to check into automated environments while in motion.

◆ Vehicles will need to be tested and monitored during operations, not only during exit and entry.

◆ Normal and emergency checkout systems will be required.

◆ Vehicle and driver readiness will need to be tested. A driver must actively engage the vehicle before checkout, rather than simply being handed the controls.

◆ Entry and exit designs will have an important effect on system throughput.

◆ AHS designs must recognize that many motorists travel on freeways for short distances; thus, entry and exit efficiency is critical to motorist acceptance and benefits.

◆ Multiple system configurations may be required to accommodate the many differences in street layouts and distances between exit and entry ramps.

Lateral and Longitudinal Controls [Calspan, Delco, Lockheed, Raytheon, Rockwell, Stanford Research Institute (SRI)]

◆ Sensors and controls must be able to perform under adverse weather conditions.

◆ Magnetic markers or overhead wires are the most promising lateral control technologies.

◆ Infrastructure-based systems have the potential to be most cost-effective.

◆ Communications among vehicles may not be required if sufficient headway is maintained.

Vehicle Operations (Calspan, Delco, Raytheon, Rockwell)

◆ Adding automation capabilities may decrease vehicle reliability by increasing the number and complexity of components that could

BOX 4-2 (*continued*)

fail. Preventive vehicle maintenance therefore will become even more important.

◆ Full automation of vehicles probably will occur in an evolutionary manner, from collision warning devices and emergency controls to automation of routine driving tasks.

◆ Software verification, validation, and monitoring in use must be an integral part of the vehicle design process.

Malfunction Management and Safety (Battelle, Calspan, Honeywell, Delco, PATH)

◆ Obstacles and nonautomated vehicles entering automated lanes may require barriers.

◆ Redundant systems will be necessary.

◆ Drivers must not be allowed to relax completely; systems that compensate for the complete inattention of the driver will be expensive.

◆ Automation could reduce crashes on urban Interstate highways by 26 to 85 percent, on suburban Interstate highways by 32.5 to 85 percent, and on rural highways by 45.7 to 85 percent.

Commercial Truck and Transit Applications (BDM, Calspan, Delco, Raytheon)

◆ It will be difficult for automated facilities to serve intracity trucks because they make frequent stops.

◆ The market for intercity bus travel is small.

◆ City transit buses, especially express buses, may be the best early candidates for automated applications.

Institutional and Societal Issues (Battelle, BDM, Calspan, Delco, Raytheon, SAIC)

◆ There appear to be no insurmountable institutional or societal barriers to automated highway systems.

◆ Many of the institutional issues related to automated highways are similar to those of road building in general.

◆ If lanes must be dedicated to automated vehicles and vehicle instrumentation is expensive, equity issues will arise.

◆ Moderate-income commuters may be the best early candidates for using automated systems.

In retrospect, it is now evident that too little attention was given at the analysis stage to examining the ultimate goal of the program—to specify a preferred system in less than a decade—as well as the way this next phase of the research program would be implemented (through a predetermined public-private consortium).

Systems Definition Phase

With the legislated 1997 deadline for a fully automated highway system approaching, DOT sought to establish a new kind of research and development program that could meet the deadline and continue with the specification, testing, and deployment of a fully automated highway system. DOT issued a Request for Applications in December 1993 seeking the creation of a public-private research consortium that could pool financial resources, technical expertise, and marketplace experience (DOT 1993). DOT anticipated that a national consortium committed to long-range research and drawn from industry, academe, and government agencies would bring continuity and visibility to the program and provide the leadership and insights needed to develop and deploy a fully automated highway system (Bishop and Lay 1997, 69).

DOT was specific in its intention, delineating the structure, methods, and work plan of the proposed consortium. Its Request for Applications prescribed what kinds of participants should be included in the consortium, how the consortium should be organized to involve members and elicit the participation of nonmembers, and how the program would be managed and overseen by the DOT. Emphasis was placed on ensuring the participation of at least one leading organization from various segments of the highway, vehicle, electronics, and communications industries; these "stakeholder" industries were expected to have an important role in the design, construction, deployment, and operation of fully automated systems. Having prominent organizations from these stakeholder groups in the consortium would aid DOT in building enthusiasm for the development and deployment of a fully automated highway system.

DOT outlined six milestones to provide direction for the work plan devised by the selected consortium (DOT 1993, 16):

1. *Establish performance and design objectives* (e.g., expected traffic operating speeds).
2. *Demonstrate proof of feasibility,* fulfilling the congressional mandate for a demonstration and establishing technical feasibility [but not demonstrating a prototype of a preferred system, which was scheduled to occur later in the program].

3. *Identify and describe multiple feasible system concepts,* including factors that should be used to evaluate them (such factors should include institutional and legal issues assessments, technology analyses, and system costs and benefits).
4. *Select a preferred system configuration,* using a thorough, objective process that involves the participation of major stakeholders.
5. *Conduct prototype tests* of major system functions such as steering, braking, lane changing, and malfunction management.
6. *Prepare documentation* of preferred system specifications, implementation standards, scenarios for evolutionary development and deployment, and projected costs and benefits.

The Request for Applications also called for an organization and management structure in which DOT would offer broad policy guidance and consortium participants would make decisions based on a consensus process in which no single stakeholder category would have a disproportionate influence. DOT also required an active outreach effort to elicit the views and involvement of nonmembers. A public relations program was encouraged to foster interest in the development and deployment of fully automated highway systems. Members of the consortium would be expected to pay at least 20 percent of the costs of the program; DOT would pay the remaining costs, which were budgeted at an average of approximately $20 million per year for 7 years.

Two consortia responded to the request. One was led by General Motors Corporation (GM) and the other by TRW, Inc. The nine-member GM team (Box 4-3) was considered better qualified largely because of the range of prominent stakeholders in its membership. After a period of negotiation, NAHSC began its work in the fall of 1994.

NATIONAL AUTOMATED HIGHWAY SYSTEM CONSORTIUM

Thus, NAHSC was formed with a set of milestones in place, an organizational and management framework outlined, and the results of precursor studies that could be built upon. Indeed, several organizations on the precursor study teams were members of the consortium. In accordance with the program goals established by DOT, NAHSC's stated mission was as follows:

> Specify, develop, and demonstrate a prototype automated highway system. The specifications will provide for progressive development that can be tailored to meet regional and local transportation needs. The Consortium will seek opportunities for early introduction of vehicle and highway automation technologies to achieve early benefits for all surface transportation users. The NAHSC will incorporate public and private stakeholder views to ensure that the AHS is economically, technically, and socially viable. (NAHSC 1997a, Appendix A)

BOX 4-3: CORE MEMBERS OF NAHSC AND THEIR SPECIALTIES

- Bechtel Corporation—infrastructure and environment
- California Department of Transportation (Caltrans)—infrastructure development and highway operations
- Carnegie Mellon University—vehicle robotics
- Delco Electronics—vehicle development
- General Motors—vehicle development
- Hughes Electronics—communications and systems engineering
- Lockheed Martin—system integration
- Parsons Brinckerhoff, Inc.—traffic engineering
- University of California Partners for Advanced Transit in Highways (PATH/UC Berkeley)—advanced vehicle control

Organization and Process

The consortium defined a series of tasks—accompanied by designated task leaders, teams, timelines, and detailed work plans—to achieve the six milestones assigned by DOT. Task teams were drawn from each of the member organizations. The consortium also instituted an organizational structure and a set of procedures to ensure that outreach efforts required by DOT were undertaken. NAHSC established an Internet site and published a newsletter to expand its reach to the general public. An associates program was established to provide an avenue for involvement by and input from a range of potential automated highway system users, industries, and transportation agencies; more than 125 organizations were listed as participants in the associates program by 1997. Associates were informed about NAHSC work in progress and, in turn, were expected to provide the consortium with constructive input and information about their own related research activities. Associates ranged from large multinational corporations to individual consultants and were drawn from state and local government, the motor vehicle and electronics industries, and public transit and commercial trucking, as well as other transportation system users, suppliers, and operators.

When NAHSC began its work in early 1995, it recognized the challenge involved in coordinating the work of organizations with varied interests, expectations, and corporate cultures. Based on guidance provided by DOT, the consortium organized its management into a three-tiered system (Figure 4-2). Broad policy guidance was to be provided by a Policy Steering Board consisting of a senior DOT representative (from the ITS program office) and top executives from each of the nine core members of the consortium. This board was intended to meet at least annually. A Program Management Oversight Committee was established to report to the steering board and to meet more frequently (about every two months) to address management issues. The oversight committee would consist of senior managers from each of the nine core members and nine independent members selected by associate participants; a DOT representative also would be appointed to the oversight committee. Most major decisions having to do with program direction, budgeting for specific tasks, and funding levels for individual members would be made by consensus of the oversight committee.

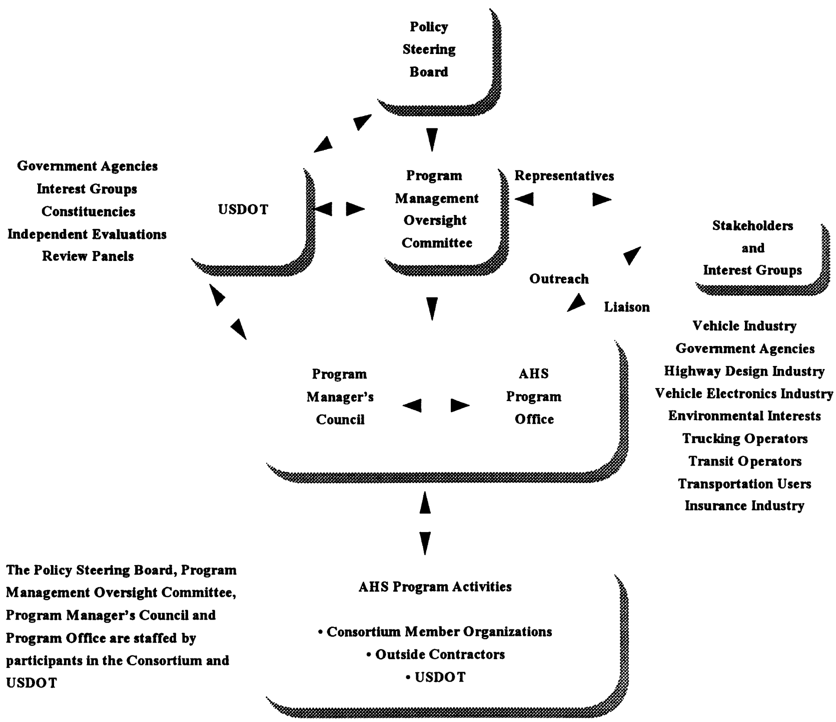

FIGURE 4-2 Management structure of NAHSC (NAHSC 1997a, 21).

Building a consensus often involved an iterative process that required frequent meetings and communications among program managers (Bishop and Lay 1997). To facilitate this process and provide day-to-day management, a Program Manager Council was formed; this council consisted of the NAHSC program manager, the FHWA program manager, and site managers from each of the core members (sometimes supplemented by associate participants). Task assignments, involving teams consisting of analysts from several member organizations, also were designed to foster consensus-building and cooperation. Additionally, the consortium sponsored numerous workshops and conferences in which outside experts and other interested parties were invited to participate. A stakeholder relations and public affairs program was established to develop consensus among stakeholders and include stakeholders in the development of automated highway system concepts; significant emphasis was placed on marketing the program through public and media relations (NAHSC 1997a, 54–55).

Activities

NAHSC had several tasks to pursue. The ultimate goal of most of these tasks was to identify a feasible full automation concept, culminating in the prototyping and testing of a fully automated highway system. Related to this goal, but a major goal in itself, was the successful undertaking of the congressionally mandated automated highway system demonstration in 1997. The demonstration (held in San Diego, California, in August 1997) raised the visibility of the program and gave NAHSC members a near-term objective (see Box 4-4 for a brief description). It also required much of the consortium's attention and resources, however. Figure 4-3 shows major funding items in the NAHSC budget for fiscal year 1997, when much of the organization's resources were dedicated to the demonstration. Although the demonstration

BOX 4-4: SUMMARY OF SCENARIOS PRESENTED DURING NAHSC'S 1997 PROOF OF TECHNICAL FEASIBILITY DEMONSTRATION IN SAN DIEGO, CALIFORNIA

NAHSC's August 1997 "Proof of Feasibility Demonstration" was held on a 7.6-mi (12-km) section of HOV lanes on Interstate 15 near San Diego. The lanes were separated from the main north- and southbound lanes of I-15 by concrete barriers. The most significant physical modification to the highway was the addition of several thousand magnets

BOX 4-4 (*continued*)

in markers embedded in the center of the lanes. Communications equipment was installed along the roadside.

The following scenarios (among others) were presented not as prototypes of an automated highway system but to demonstrate alternatives for providing automated highway travel. Rides on the demonstration vehicles were offered to the public. Riders were surveyed for reactions and feedback, intended to be used by NAHSC in its subsequent efforts to select a preferred system.

Free-Agent, Multi-Platform Scenario
Carnegie Mellon University teamed with the Metropolitan Transit Authority of Harris County (Houston Metro) to demonstrate vehicle-based automation technologies in multiple vehicle platforms (bus and passenger car). Obstacle avoidance, collision warning, and automated lane-change and passing maneuvers were demonstrated using side- and rear-looking sensors.

Platooning Scenario
University of California researchers teamed with Delco Electronics, General Motors, and Hughes to equip eight Buick LeSabres with computers, actuators, sensors, and other instruments to demonstrate the feasibility of automated vehicles operating in platoons to maximize highway throughput. The vehicles traveled in a single-file formation guided by magnets embedded in the pavement. The vehicles accelerated, decelerated, and performed passing maneuvers and coordinated stops to avoid obstacles.

Alternative Technology Scenario
Researchers from Ohio State University equipped four miles of the demonstration lanes with radar-reflective tape. Radar and camera-based vision systems were used to provide longitudinal and lateral control of two automated cars, which performed passing maneuvers using the system.

Evolutionary Scenario
This scenario was intended to show how full automation could evolve from partial-automation technologies and other intelligent vehicle features. Toyota equipped vehicles with sensor and surveillance features that gave the driver obstacle, lane-departure, and blind spot warnings. These features were then combined with adaptive cruise control and other systems to coordinate fully automated driving by two vehicles.

accounted for approximately 15 percent of the consortium's total expenditures over the three full years of the program, it was a particularly significant expense item in view of shortfalls in federal funding. Figure 4-4 shows the original budget for federal funds, including the funding shortfalls that occurred in two of the three years following program inception.

Apart from the demonstration, the consortium's activities centered on identifying and evaluating alternative fully automated highway system concepts. NAHSC planned to examine alternative concepts from a broad perspective first, then narrow its attention to the most promising concepts. Some of the technical and practical issues associated with fully automated highway systems had been explored in the precursor studies; the consortium expected to build on these efforts by employing similar methods, including simulations, modeling, and workshops with outside experts and stakeholders.

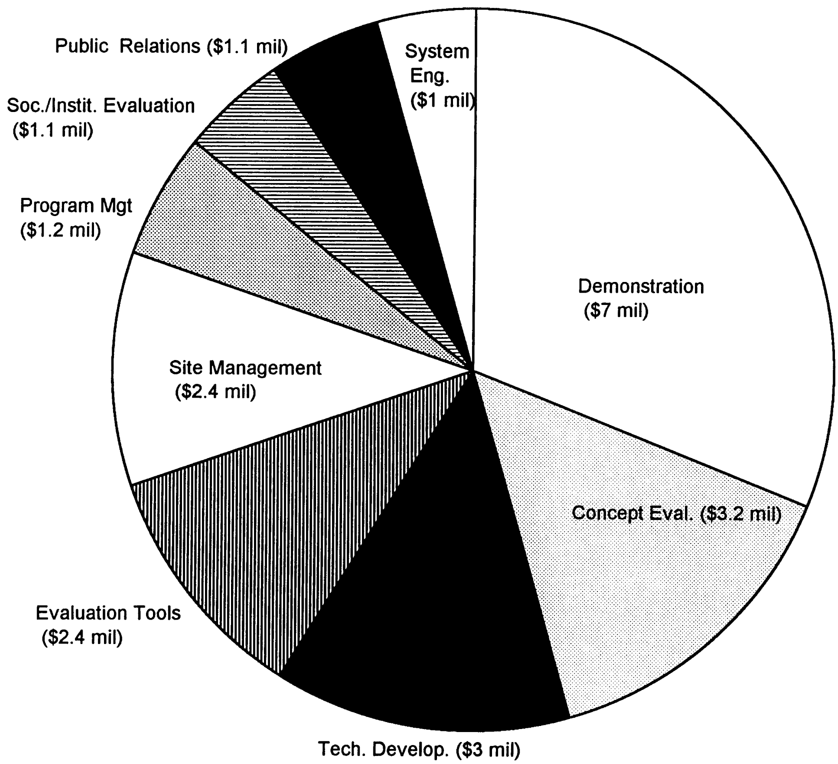

FIGURE 4-3 NAHSC FY 1997 budget by major activity using federal funds.

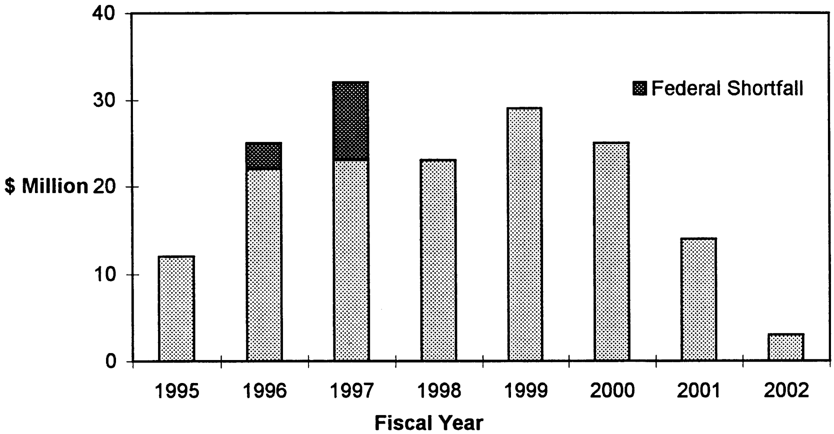

FIGURE 4-4 NAHSC original program budget, federal share (data provided by NAHSC).

(Workshops and conferences sponsored by NAHSC, with issues covered, are listed in Box 4-5.)

Key Findings

NAHSC reported the results of these efforts in June 1997, just before the San Diego demonstration (NAHSC 1997b). The consortium provided analyses of several fully automated highway system concepts (e.g., fully automated vehicles operating on dedicated lanes, in mixed traffic, and in platoons on dedicated lanes) with respect to their effects on highway throughput and travel time, safety, and infrastructure costs. Results from preliminary assessments of societal and institutional issues also were offered, as were perspectives from transportation agencies, users, and industry experts consulted in conferences and workshops.

Throughput

Computer models were developed to determine the effect of alternative fully automated highway system concepts on vehicle throughput and travel times. Automated systems were compared with nonautomated (manual) systems. Different scenerios were developed to vary vehicle spacing, speed, levels of vehicle cooperation, and other characteristics of automated systems.

BOX 4-5: WORKSHOPS SPONSORED BY NAHSC, 1995–1997

Opportunities for Participation Workshop, Sterling Heights, Michigan, March 1995

This public workshop sought to identify people and organizations interested in the research program and provided information about opportunities to participate. The consortium organization and process were explained.

AHS Objectives and Characteristics Workshop, Fort Lauderdale, Florida, April 1995

The purpose of this workshop was to clarify the consortium's objectives and elicit the perspectives of stakeholders from transportation agencies, industry groups, and users.

Systems Concepts Evaluation Workshop, San Diego, California, October 1995

This workshop provided an overview of AHS program status and system concepts and objectives being developed. The consortium presented candidate concepts. Stakeholder participation was encouraged to ensure that the process included appropriate evaluation criteria and concepts that addressed needs.

NAHSC Stakeholder Concept Downselection Forum, Boston, Massachusetts, May 1996

Participants were invited from several stakeholder groups to select associate representatives to serve on the NAHSC Program Management Oversight Committee. Opportunities for actively involving associates and other nonmembers were explored.

Develop Initial Suite of Concepts Workshop, San Diego, California, June 1996

This workshop presented the consortium's initial assessment of alternative AHS concepts, along with concepts independently developed by contractors, to state and local highway and transit agencies; metropolitan planning organizations; electronics, vehicle, and highway design firms; insurance and financial organizations, and environmental interest groups. Participants provided feedback on each concept.

BOX 4-5 (*continued*)

AHS and Land Use Conference, Pittsburgh, Pennsylvania, August 1996
Several commissioned papers were presented. These papers discussed automated highway systems and the local planning process, impacts on urban land use and metropolitan form, and the practical effects of automated highway systems on urban traffic patterns.

Downselect System Configurations Workshop, Minneapolis, Minnesota, September 1996
This workshop was designed to begin the process of refining AHS concept definitions. Attributes of alternative configurations were examined with respect to meeting stakeholder needs. Participants were more interested in discussing the value of automated highway systems in general than the relative value of alternative configurations. Developments in partial automation technologies also were of greater interest than the plan for full automation.

Joint Workshop on Liability Issues, Washington, D.C., February 1997
This 2-day workshop, cosponsored by the American Association of State Highway and Transportation Officials, examined liability issues associated with automation of vehicles and highways. Federal and state transportation officials, vehicle and product manufacturers, and plaintiff and defense attorneys participated in an effort to identify critical liability issues that could hinder AHS development and deployment.

NAHSC Stakeholder Needs and Services Forum Report, Washington, D.C., June 1997
Conducted in conjunction with the ITS Annual Meeting, this workshop involved technical breakout sessions organized to explore the needs and perspectives of consumers, commercial vehicle operators, transit providers, and highway system operators. Crosscutting issues also were discussed.

(Designed as a preliminary assessment, the models assumed light-duty vehicle traffic only and no intermediate entrance and exit points between the origin and destination of traffic flows). Results from the models suggested that platooning vehicles operating on dedicated travel lanes offered the greatest potential for throughput gains (NAHSC 1997b, 3–4). The maximum throughput of platooned vehicles operating on dedicated lanes was found to vary from 2,300 to 11,000 vehicles per hour per lane (vphpl) (the highest values were for larger platoons). These figures are 1 to 5 times the throughput assumed for manual traffic (assumed to be 2,200 vphpl). By comparison, the maximum throughput for nonplatooned (automated) vehicles operating on dedicated lanes ranged from 1,500 to 5,000 vphpl (0.7 to 2.3 times the flow rate of nonautomated highways). Other concepts, such as automated (nonplatooned) vehicles operating in mixed traffic with manually driven vehicles, suggested little potential for throughput gains. Additional work was being undertaken at the time of this study to determine how the inclusion of truck traffic and merging and maneuvering at intermediate freeway exits and entries would affect throughput capacity.

Safety

Computer analyses of various braking scenarios (such as when the lead vehicle in a platoon fully engages its brakes and the following vehicles respond) found that cooperating automated vehicles (i.e., fully automated vehicles communicating and interacting with one another) would be significantly safer than vehicles driven manually under the same circumstances (i.e., at similar speeds and following distances) (NAHSC 1997b, 4). One analysis indicated that a nonplatooned but highly cooperative automated vehicle would be several times less likely than a manually driven vehicle to collide with a lead vehicle. Moreover, collisions involving these automated vehicles would tend to occur at lower speeds, thereby reducing the potential for severe collisions. The relationship between speed, safety, throughput, and the degree of intervehicle cooperation (e.g., platooning or nonplatooning) also was investigated. Though only a few parameters and assumptions could be varied, results from the models suggested several trade-offs between throughput and safety. At most throughput levels, cooperating (nonplatooned) fully automated vehicles collided less often than did platooned vehicles. Platooned vehicles, on the other hand, experienced fewer high-speed collisions. Combining collision probability and speed at collision, these preliminary analyses suggested that platooned vehicles would offer the greatest safety potential at the highest throughput levels (i.e., when throughput exceeds 3,500 vphpl).

Infrastructure Costs

Estimates of automated highway system infrastructure requirements in urban areas suggested that the costs involved in constructing dedicated travel lanes for automated vehicles would vary greatly from site to site but would be similar in magnitude to the cost of building high-occupancy-vehicle

(HOV) lanes. Separate entrance and exit ramps would be required to accommodate automated vehicles; in comparison with conventional highways, however, less overall right-of-way would be needed because fewer lanes would be required to carry comparable traffic volumes (assuming that fully automated systems can carry twice the traffic of conventional lanes, thereby requiring construction of half as many lanes (NASHSC 1997b, 5).

Societal, Environmental, and Institutional Aspects

In evaluating alternative public- and private-sector roles in owning and operating fully automated highway systems, as well as the environmental and tort liability issues that are likely to arise, NAHSC concluded that many of these issues are not unlike those now faced by the public and private sectors with regard to building conventional highways and vehicles and that many of these issues would be resolved through similar political, legal, and market processes. Others would need to be examined more carefully and thoroughly as the NAHSC program proceeded. National standards would be needed in areas such as sensing, communications, and driver interfaces to foster development and commercial introduction. Discussions in a workshop of land use experts led NAHSC to conclude that fully automated highway systems would have only marginal effects on land use because transportation infrastructure and land use patterns already are well established. A study sponsored by NAHSC estimated that platooned vehicles would reduce fuel use by up to 25 percent per vehicle mile; aggregate fuel and emissions impacts from changes in total vehicular travel were not reported (NAHSC 1997b, 6).

Study Committee Conclusions

The study committee would have benefited from more objective syntheses and summary evaluations of the consortium's technical and analytical findings. In the absence of such information, it was not possible in this study to assess the consortium's findings and conclusions in a comprehensive way. Even a cursory review of the consortium's work, however, raises questions about objectivity. The conclusion that tort liability, environmental, and transportation infrastructure issues associated with automated highways would be similar to those associated with conventional highway systems seems especially optimistic and highly conjectural based on workshop discussions. Close examination of the workshops sponsored by the consortium (Box 4-5), fails to reveal how such conclusions were reached. Experts participating in a 2-day workshop on land use impacts, for instance, are described by the consortium as concluding that automated highway systems "would have minimal impact on land use since it will be a relatively small part of a well-established surface transportation system" (NAHSC 1997b, 6). The draft report on this activity, however, does not offer such a summary assessment or any other indication that such a consensus had been reached (NAHSC 1997c). Thoughout, the consortium's work tends to selectively emphasize findings that are favorable to early development and deployment of automated highway systems and minimize those that are not.

At a more fundamental level, however, it is questionable whether NAHSC could have provided an objective and thorough assessment in light of its dual role as evaluator and promoter of fully automated highway systems. Not only was the consortium directed to identify a preferred fully automated highway system from technical and societal standpoints, it also was expected to build support for and ultimately select a system for development and implementation. Separating and balancing these two often conflicting roles proved difficult. For instance, NAHSC recognized early on that one of the important issues it would need to address was whether fully automated vehicles could share travel lanes with manually driven vehicles. The consortium's traffic throughput and safety assessments suggested that fully automated vehicles operating in mixed traffic would provide little, if any, gains in highway capacity and safety (NAHSC 1997b, 8). On the other hand, many state transportation officials and other stakeholders had expressed concern about the cost and practicality of building or converting lanes to accommodate fully automated traffic (NAHSC 1996). NAHSC therefore was reluctant to eliminate the mixed-traffic concept (the concept with minimal infrastructure requirements), despite its early technical findings (NAHSC 1997b, 7–9).

The conflict inherent in this dual role as evaluator and promoter also was evident in the consortium's uneven attention to issues. NAHSC focused much of its effort on investigating the technical means of automating driving, such as technologies that could support obstacle detection, platooning, and lane-keeping. Transportation agencies and other stakeholders emphasized the need to better understand the many nontechnological issues associated with development and deployment of fully automated systems—such as liability issues, the role of the public and private sectors in deployment, environmental effects, and other socioeconomic considerations (NAHSC 1996). Although the consortium had planned to address these issues early on, its initial work proved cursory. The breadth and complexity of these nontechnological issues became increasingly evident, but the consortium did not develop insights into how these issues might be better understood and addressed to facilitate the early specification of a fully automated highway system.

These early analytical difficulties, along with the mixed responses received from stakeholders, were indicative of the challenges that would lie ahead in identifying and reaching consensus on a preferred fully automated highway system. Moreover, although DOT program managers were active in the day-to-day operation of NAHSC, they may have lacked the distance needed to reflect on the consortium's early findings and experiences. This problem is not uncommon; it is the reason that other public-private consortia—most notably the Partnership for a New Generation of Vehicles (PNGV)—have been subjected to, and benefited from, periodic third-party reviews of program plans, accomplishments, and management procedures.[1]

An example of a research gap that is apparent in the consortium's work—and one that might have been underscored by an outside review—is the absence of human factors assessments. This gap is explained in part by DOT's early decision to undertake a separate human factors study during the precursor phase of the National Automated Highway System Research Program. Congress had mandated in ISTEA a study of the "human-machine relationship" as it relates to fully automated vehicles and highways. DOT funded a 3-year human factors study by Honeywell, Inc.; most of Honeywell's work was completed before NAHSC began its work, however. Incorporating this early human factors work into the subsequent efforts proved problematic because the kinds of fully automated highway system design concepts being investigated by the consortium changed over time (Neale et al. 1996, 3–4). Thus, the human-machine relationship received limited attention under the NAHSC program.

RECENT DEVELOPMENTS

The ISTEA reauthorization process compelled DOT to examine critically the experience of the NAHSC program and its prospects for achieving its mission. In early 1997, DOT indicated its intention to focus on the implementation of nearer-term, partial automation technologies, significantly de-emphasizing the selection of a preferred system for full automation.

When NAHSC was informed of this change of direction in the spring of 1997, it faced a significant challenge: to substantially revise its work plan and procedures to conform with the new emphasis on evolutionary development and implementation of nearer-term, partial-control technologies. The consortium's composition, internal allocation of funds, outreach programs, and decision-making process were devised for a much different mission—one that would require consensus building to identify and build stakeholder sup-

[1] The PNGV research program, initiated in 1993, is a collaboration between major U.S. automobile makers and the federal government to develop a vehicle prototype that can achieve up to three times the fuel economy of current vehicles. A National Research Council committee has conducted three reviews of the program and is undertaking a fourth.

port for the deliberate advent of a fully automated highway system. Moreover, the consortium was engrossed in planning for a demonstration of fully automated vehicle and highway technologies, as originally instructed by DOT in response to the congressional mandate. Consequently, the consortium responded slowly, and with some reluctance, to DOT's revised priorities. By the summer of 1997, NAHSC had elected to postpone its original plan to select a fully automated highway system, focusing instead on potential candidates for early application of fully automated systems, such as express buses, snowplows, and truck convoys (see Box 4-6). NAHSC has since assisted in staging additional, smaller-scale automated highway technology demonstrations in Arizona (on a test track) and in Houston, Texas, on transit buses.

The study committee review was conducted in the midst of these developments. In December 1997, however, DOT indicated its intention to withdraw funding for NAHSC.

BOX 4-6: EARLY AUTOMATED HIGHWAY SYSTEM APPLICATION SCENARIOS DEVELOPED BY NAHSC

Automated Bus Movement in Maintenance Areas
Before automated buses were used on passenger routes, they would first operate automatically in the maintenance yards, which would offer a low-speed, controlled environment for evaluation and experience. A fixed route could be marked (e.g., by magnetic markers, magnetic stripes, or painted lines) within maintenance stations. The specially equipped buses would follow the route at low speed, stopping at different stations for maintenance tasks.

Automated Snowplows
Sensors would allow snowplows to sense the edge of the road and parked cars in heavy snow and automatically maintain a proper distance from them. The sensors also would keep plows on the road, guided by signals fed from lane sensors and side vehicle detectors. Problem roads could be instrumented with markers that could be detected through heavy snow. The driver could maintain longitudinal (throttle and brake) control, while the automated system would maintain lateral control (steering). This approach would offer a low-speed, controlled environment (lone vehicle and specially trained driver) for early evaluation and experience.

BOX 4-6 (*continued*)

Truck Convoy with Driver in Leading Truck
This possible precursor to platooning systems would involve a lead truck driver, with assistance from automation technologies, controlling the driving of several trucks in a convoy. The application would be appropriate for fleets, in which a team of drivers could take turns in leading the convoy and resting. The lead driver would be subject to alertness monitoring and awakened by an alarm if drowsy. Failure to respond would bring the vehicle and convoy to a stop. Also, all vehicles in the convoy could have sensors and logic to determine whether a lane change is safe, and the results would be communicated to the lead vehicle. Before the convoy could change lanes, the lead driver would activate the signal; all vehicles in the convoy would have to respond that it was safe to change lanes.

Precision Bus Docking
Automation could position a bus precisely along a curb, assisting with wheelchair access and preventing tire damage. The driver would first maneuver the bus into the general loading area, then turn control over to automation. Sensors would determine the lateral distance to the curb, front and rear, and the longitudinal distance to the end of the bus loading area. Automation would steer the bus toward the curb and straighten it out to position both front and rear of the bus within the prescribed distance of the curb, with the wheels straight. When properly docked, the bus would stop, open its doors, and revert to manual control. This system could provide experience with technologies envisioned for lane-change collision avoidance systems.

Automated Container Movement (within terminal)
Resembling an "automated" forklift, this specialized application would use vehicle automation technologies to move containers to the next state or to storage within rail-, truck-, or shipyards or to other centralized facilities. Benefits would include labor savings and high accuracy. The origins and destinations of containers could be dynamically reconfigured with high precision. The automated forklifts would move containers to the proper destinations safely (requiring some combination of protected area and obstacle detection) and with high lateral and longitudinal accuracy (requiring preview detection schemes).

BOX 4-6 (*continued*)

Interterminal Passenger Shuttle
Several airports have driverless (rubber-tire) shuttles that move on fixed guideways between terminals. A similar system of automatically driven shuttles could be employed on "dedicated" ways with more flexibility. The drivers of these shuttles would be able to resume manual control at a few designated exits but use automation for longer segments. This early form of full automation would operate in a controlled environment, yet offer experience and insights about potential problems.

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ABBREVIATIONS

DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration
NAHSC	National Automated Highway System Consortium

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