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Responses and Recommendations

The U.S. transportation sector faces important challenges. Foremost among these challenges is the need to enhance the safety and capacity of the nation's highway system. In 1993, then Federal Highway Administrator Rodney E. Slater noted, "Our current highway transportation, as effective and elegant as it is, is at a critical crossroads in its evolution and has started to plateau in its ability to provide significant new operating performance in its present form."[1] Safety gains are becoming increasingly difficult to achieve, and the capacity of the system is being strained by growing demands for passenger and freight transportation. There is a pressing need for innovative approaches to meeting these challenges.

Intelligent transportation systems (ITS) represent one such approach—offering, as Slater remarked, the potential for "substantial performance improvements in this and in coming decades." Recognizing the possibilities of ITS and seeking to accelerate development and deployment, Congress authorized more than $650 million over 6 years for ITS research and demonstration projects in the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). Congress appears to have seen far-reaching potential in ITS, foreseeing a highway transportation system that is not only more efficient and convenient—thanks to emerging technologies for traffic management, traveler information, and route guidance—but safer because of advanced products that enhance driver awareness and intervene with emergency controls to help motorists avoid crashes. The ultimate application of ITS would be the advent of fully automated vehicles and highways that would turn routine driving tasks over to computer, communications, and information systems; bring about highly orchestrated and more-efficient traffic flows; and lead to substantial gains in system safety, capacity, efficiency, and comfort.

[1] Appendix A contains the full text of Administrator Slater's October 1993 speech announcing the U.S. Department of Transportation's (DOT) intention to establish the National Automated Highway System Consortium.

The notion of fully automated driving is not new; it stems from visions of hands-off, feet-off driving that extend back more than 50 years. As demands for safety and mobility have grown and technological possibilities have multiplied, however, interest in automation has been rekindled. Seeking to accelerate the development and introduction of fully automated vehicles and highways, Congress legislated in ISTEA that

> The Secretary [of Transportation] shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed. Such development shall include research in human factors to ensure the success of the man-machine relationship. The goal of this program is to have the first fully automated roadway or an automated test track in operation by 1997. This system shall accommodate installation of equipment in new and existing motor vehicles. [ISTEA 1991, Part B, Section 6054(b)]

In mandating the development of an automated vehicle-highway prototype and the first fully automated roadway by 1997—interpreted as requiring the demonstration of a fully automated highway system—ISTEA prompted the transportation and research communities to consider how a fully automated system might one day emerge. Traditionally, new highway transportation technologies are developed and introduced through incremental changes in the system, as new products are added, refined, and merged.[2] Following this traditional course, increasingly automated vehicles and highways might emerge over time as a result of the gradual introduction and integration of ITS products. ISTEA's requirement for prototyping a fully automated vehicle and highway, however, prompted consideration of an accelerated path to implementation of fully automated systems.

ISTEA inspired a vision of fully automated driving made possible relatively quickly as a result of concerted efforts to evaluate, test, and publicize alternative system concepts. The preferred system selected through this process would shape the future development and deployment of automated driving technologies. With this vision in mind, DOT established the National Automated Highway System Research Program. The stated mission of the program was to "specify, develop, and demonstrate a prototype automated highway system" that would "provide for progressive development that can be tailored to meet regional and local transportation needs" (DOT 1993). To focus and drive this effort, DOT called for a public-private partnership.

The National Automated Highway System Consortium (NAHSC) was created in late 1994. DOT viewed the consortium—which comprised nine leading organizations from academia and the motor vehicle, highway, electron-

[2] Even the advent of the Interstate Highway program in 1956, often described as revolutionary, was preceded by years of experience in designing, building, and operating divided and limited-access toll roads, turnpikes, and parkways. This experience enabled the federal government and states to develop and agree upon specifications for modern Interstate freeways.

ics, and communications fields—as critical to enriching the program's expertise and resources. In the diverse and decentralized transportation sector, such cooperation and leadership also were deemed essential to garnering the extensive industry and government support and enthusiasm needed to reach early agreement on the kind of system that would influence the design, development, and deployment of automation capabilities for many decades.

To achieve its Congressional mandate, DOT directed NAHSC to examine alternative system concepts—ranging from those that would provide full automation through sensors, computers, and other instrumentation installed primarily in vehicles to those that would require integrated instrumentation of vehicles, highways, and other infrastructure. In doing so, DOT asked the consortium to assess the technical feasibility and the economic, institutional, and social implications of alternative system concepts. These matters were to be examined with high regard for the views of public- and private-sector transportation users and providers, termed "stakeholders." To elicit this input and to build interest in fully automated vehicles and highways, the consortium also was directed to undertake outreach, promotional, and public relations efforts. NAHSC also was asked to make all of its key decisions on the basis of consensus opinion of its stakeholder members (DOT 1993, 14). The congressionally mandated demonstration scheduled for 1997 was to be the centerpiece of the program's efforts to showcase and build support for a fully automated highway system.

In late 1996, however—less than 3 years after calling for the creation of the consortium and while the technology demonstration was still being planned—DOT began rethinking the program's emphasis on and ability to achieve the early specification of a fully automated system. DOT was shaping a new program, the Intelligent Vehicle Initiative (IVI), that would emphasize the evaluation and introduction of advanced vehicle control and driver assistance features that could be deployed in the next decade. Initial plans called for government and academic researchers, collaborating in various ways with industry, to evaluate, test, and encourage the introduction and integration of the features offering the largest safety gains and other benefits to the public. Under IVI, the earlier target of fully automated driving would be de-emphasized.

In view of these developments, DOT's ITS Joint Program Office requested the establishment of a study committee by the National Research Council to address specific questions concerning the appropriateness of the original vision and mission of the National Automated Highway System Research Program, the achievements and effectiveness of NAHSC in carrying out its mission, and the prospective role of the consortium in DOT's new intelligent vehicle program. In December 1997—during the course of this study—DOT indicated its intention to withdraw financial support from NAHSC and concentrate its resources on IVI. The committee nevertheless believes a retro-

spective critique of the National Automated Highway System Research Program and NAHSC will prove valuable. Public and private partnerships will continue to command national attention, and they have vital roles in ongoing ITS development and deployment.

COMMITTEE RESPONSES

Given what has been learned to date about the technical, societal, institutional, and economic feasibility of an automated highway system, is the National Automated Highway System Research Program vision and mission still appropriate and worthy of major research investment?

The legislative mandate for a prototype automated vehicle-highway system prompted DOT to envision the early introduction of a fully automated highway system. NAHSC, which was created to fulfill this vision, was directed to demonstrate full-automation technologies and scenarios in less than 3 years and to identify, demonstrate, and select a preferred fully automated highway system within 7 years. Selection of the preferred system would involve active outreach to transportation users and providers to reach agreement on the most suitable system configuration. Once a preferred system configuration had been identified, more concerted efforts to develop, test, and deploy it were envisioned.

This vision was ambitious from the outset. The study committee believes that the concerted efforts of the past 3 years have revealed limited prospects for a fully automated system to be selected in such an accelerated manner. NAHSC vigorously pursued its mission to identify, assess, and promote a preferred fully automated highway system. In the study committee's view, however, this mission was overly optimistic and has proved unachievable.

The condensed time frame for the consortium's work was especially optimistic—and proved problematic. The 1997 demonstration, which was largely ancillary to the end mission of the program, detracted from the consortium's ability to evaluate many of the technical, societal, and institutional issues associated with fully automated highway systems. Budgetary cutbacks caused by reduced government funding exacerbated these difficulties. Even under better circumstances, however, the study committee doubts whether many of the complex issues associated with fully automated driving could have been addressed adequately to support early identification and specification of a preferred system.

Individual members of the study committee differ about whether fully automated vehicles and highways eventually might emerge to significantly improve highway safety and capacity, but they agree that such outcomes

could happen only over time because of the technological changes that would ensue and the many societal, institutional, and economic issues that would have to be recognized, debated, and decided through public policy and political processes. The highway transportation system has become integral to the daily lives of Americans and the national economy. A fully automated highway system with the potential for important safety, social, and environmental effects, as well as changes in public- and private-sector responsibilities, would require careful consideration and debate before a preferred system could be identified for widespread acceptance and adoption. Failure to fully recognize these issues and the processes needed to vet them publicly was a major shortcoming of the National Automated Highway Research Program.

The difficulty of building an early consensus on a fully automated system was underscored by the consortium's own experience and work. Its preliminary results, for instance, suggested the importance of operating fully automated vehicles on dedicated lanes to manage safety and maximize traffic throughput. Many state and local transportation officials consulted by the consortium were skeptical, however, about the prospects of adopting such a system. These officials expressed concern about the expense and political difficulties of investing in facilities devoted exclusively to fully automated vehicles and making large-scale changes to the well-established transportation infrastructure. Environmentalists, planners, and land use experts consulted by the consortium raised concerns about the overall effects on vehicle emissions, energy use, and urban development patterns that could result from deploying fully automated highway systems that increase travel and traffic volumes. Motor vehicle manufacturers, their suppliers, and insurers questioned whether tort liability issues raised by such systems have been adequately explored to warrant optimism about the prospects for accelerated system development and deployment.

As these and other challenges presented by full automation have become more evident, the kind of broad and deep support needed to reach agreement on a fully automated highway system has failed to build within the transportation community—further revealing the limited prospects for NAHSC to achieve its mission. At a minimum, the early identification of a preferred fully automated highway system promising to have large and lasting effects on the transportation system would require a broad-based commitment from leaders in the public and private sectors of the transportation community. Indeed, DOT recognized the need for such a consensus at the inception of the program. Outreach, promotional, and public relations activities were emphasized as part of the consortium's role and were considered central to the 1997 demonstration. The lack of broad-based support as the program proceeded, despite active promotional and outreach efforts, was indicative of the limited prospects for gaining consensus.

In light of not only the analytical work undertaken by the consortium but the complex challenge it encountered in trying to assess and build support for fully automated highways in the far-reaching transportation sector, the original vision of fully automated systems emerging in a preplanned, accelerated manner seems less plausible than it did 3 years ago. In the study committee's view, it would be unwise to continue efforts aimed at early specification of a preferred fully automated highway system. Nevertheless, the committee recognizes that many transportation needs can be addressed only through persistent and systematic research. DOT must continue to explore and examine transportation needs and solutions over longer time horizons and from system-level perspectives that encompass the vehicle, the highway environment, and the driver.

Are there elements of the National Automated Highway System Research Program that should be continued in the Intelligent Vehicle Initiative, which focuses on a nearer-term horizon?

DOT is placing increased emphasis on safety, as its most recent strategic plan indicates (DOT 1997). The early development and deployment of transportation technologies that promise near-term safety benefits therefore have taken on greater priority within DOT's ITS program in general. The study committee does not question this change in emphasis but believes that it should be accompanied by—and not preclude—research and development aimed at addressing longer-range highway capacity, safety, and efficiency needs that face the nation.

It is premature to comment definitively on the mission and methods of IVI, which is still being shaped. Nevertheless, any major research initiative aimed at furthering intelligent vehicle and highway systems should have certain characteristics. Most importantly, the need for the program and its mission must be defined and well conceived at inception to ensure that time and resources are well spent. Effective strategies for influencing developments in a diverse, global, multibillion-dollar motor vehicle manufacturing industry, and the need for exerting such influence, require careful and critical consideration. This report urges DOT to seek external and independent reviews of its major research initiatives to foster such reflection. The experience of the National Automated Highway System Research Program has demonstrated the importance of such an approach, not only in defining a program's mission and structure but in shaping process and content. As an example, the study committee believes that major research initiatives must employ a systems approach to be valid and effective. For instance, human factors assessments must be integrated into the design, engineering, and testing stages of technology development to ensure safe and effective interactions among drivers, vehicles, and infrastructure. Institutional, liability, and societal bar-

riers to implementation and the safety, reliability, and cost of the technologies must be actively investigated to inform public policy. In subsequent research programs, such issues should not be neglected or repeatedly deferred because of their complexity and controversy—nor should they be underestimated as quickly resolvable.

The National Automated Highway System Research Program would have benefited from earlier outside guidance and criticism; independent, retrospective evaluations of its technical work are still needed, however. The consortium's experience and work has enhanced the transportation community's understanding and recognition of the numerous technical and practical issues associated with fully automated vehicles and highways. To provide a foundation for follow-on research, this work—including the San Diego demonstration—should be objectively and thoughtfully examined. The ISTEA requirements were intepreted as requiring a technology demonstration that would stimulate the public's imagination. Thus, the 1997 San Diego demonstration was designed more to display, rather than assess, automated highway system capabilities. Nevertheless, the staging of the demonstration entailed extensive and creative engineering, planning, and field evaluations, involving thousands of miles of automated vehicle travel during vehicle and system testing, certification, and operations. These efforts should be examined in light of the rare opportunity they presented to gauge the capabilities and compatibilities of different automation technologies in a controlled yet complex setting of vehicles, roadways, and passengers. Technical and practical insights gained from this unprecedented experience should be captured for the benefit of future research.

Apart from the demonstrations, NAHSC devoted a great deal of effort to assessing automation concepts and enabling technologies from a broad perspective, developing evaluation frameworks that could prove useful for examining long-range and systemwide implications and requirements of automated vehicle and highway technologies. For instance, the consortium examined safety, throughput, and public infrastructure effects for several automated highway system concepts that allocate sensing, computing, and communications responsibilities differently among vehicles and infrastructure. These kinds of generic, system-level assessments can be helpful in identifying important issues that will warrant early consideration as automation capabilities are developed.

Although a thorough examination of the specific projects undertaken by NAHSC was outside the scope of this study, the study committee agrees that certain general areas of research explored by the consortium—such as opportunities for vehicle-to-vehicle and vehicle-to-infrastructure interaction—warrant continued investigation in follow-on programs. An independent review and documentation of the consortium's experience, methods, and findings undoubtedly will point to significant contributions in these areas.

In representing a new approach for conducting research and development, has NAHSC been effective and efficient?

DOT's decision to establish NAHSC was bold and innovative, as was the decision of the nine public, private, and academic organizations to participate. Subsequent unreliability in federal funding reduced the program's luster and proved disruptive and financially troublesome. The study committee believes, however, that several conflicts built into the consortium's role and structure would have hindered its effectiveness even in the absence of these funding shortfalls.

Most significant was the conflict presented by the consortium's dual responsibilities for evaluating and promoting fully automated highway systems. NAHSC's ability to fully and critically evaluate automated systems was susceptible to criticism in light of its promotional role. Moreover, the latter role entailed a highly inclusive, consensus-building structure that limited program flexibility and complicated management. This structure proved especially burdensome when modifications to the program appeared warranted in response to reductions in budgets, changes in government priorities, and early feedback and findings about the difficulties involved in assessing, building support for, and selecting a fully automated highway system specification. Moreover, it is doubtful that DOT, acting as both a member of the consortium and its overseer, could offer objective and consistent policy guidance.

The conflicts built into this collaborative process hindered the consortium's effectiveness and efficiency. The mixing of evaluation and promotional roles affected the quality of the consortium's analyses and the conclusions it drew based on the tentative results from this work. Blended together, neither role could be performed effectively and efficiently. The consortium's fixed membership, pre-allocated budgets, and consensus decision-making process slowed its responsiveness and proved burdensome for program management. Arguably, no amount of restructuring or reconstituting of the consortium to improve its efficiency would have made its mission any more achievable. Nevertheless, important insights can be gained from the way this program was planned, structured, and directed.

Collaborative arrangements that combine the perspectives and resources of the public and private sectors will continue to be essential to ITS research, development, and deployment. These arrangements facilitate shared commitment and risks while providing access to a diversity of technologies, ideas, expertise, and financial resources. They also can forge links between organizations and industries that can have a lasting impact on how transportation technologies are developed and introduced. Other, more flexible, kinds of partnerships and cooperative arrangements, however, may be better suited for evaluation, development, and promotional functions. Best practices can be identified by studying past and ongoing collaborations between the public and private sectors. NAHSC's approach—including its responsibilities, its

organizational structure, its internal and external funding arrangements, and its relationship with DOT—should be examined in light of the experiences of other collaborative efforts. Such an evaluation was not possible within the time frame and scope of this review. Nevertheless, the lessons learned from undertaking such an assessment undoubtedly would prove valuable in shaping the public- and private-sector partnerships that will be essential to ITS.

Although the focus of this review has been the National Automated Highway System Research Program, broader implications can be drawn from the responses given to the four questions posed by DOT. The study committee believes that the conclusions drawn from this review should form the basis for continuing deliberations on best practices for future government-industry consortia.

Is there an appropriate role for the consortium in the Intelligent Vehicle Initiative?

DOT originally established NAHSC with a mission, composition, and set of procedures aimed at evaluating and building consensus for the early specification of a fully automated highway system. DOT now is focusing its efforts on the development and testing of intelligent vehicle technologies that have the potential for nearer-term application. Although some of NAHSC's individual members may be well suited for this new emphasis, the consortium as a whole—as it has been constituted and organized—is not.

GENERAL OBSERVATIONS AND SUMMARY OF RECOMMENDATIONS

In a diverse and democratic society, it is difficult to reach consensus about which needs warrant attention by government and how they should be addressed. In retrospect, the mission of the National Automated Highway System Research Program proved unachievable, not only because of the daunting technical, institutional, and societal issues that would need to be addressed but also because the needs justifying this accelerated approach were not made evident. Some of the fundamental difficulties arising in pursuit of this mission might have been foreseen at the inception of the program by posing questions about the program's goals and process. For example, is it plausible to expect fast-track attainment of a technological outcome that would involve many complex societal, institutional, and technical issues? To what extent can evaluation and advocacy be mixed? Can a federal agency serve effectively as a program's sponsor, active participant, and overseer? Such reflective questions were not asked at the outset of the program—for instance, as a central element of the precursor phase—suggesting the need for early and frequent program reviews by third parties that compel such discipline.

The tenor of this review should not be construed as critical of further efforts to undertake research on vehicle and highway automation with a long-range and systems perspective. Information and communications technologies undoubtedly will play an increasingly important role in meeting the nation's transportation safety and mobility needs. Defining, sponsoring, and ensuring continuity of funding for such long-range and system-level research remain critical to the mission of DOT and the federal ITS program. The following general recommendations, distilled from the committee's responses to DOT's four questions, underscore this sentiment.

Exploration of opportunities for vehicle-to-vehicle and vehicle-to-infrastructure interaction to meet long-term transportation safety and capacity needs should continue.

Early specification of a fully automated highway system is an inappropriate research goal. Nevertheless, exploration of advanced vehicle and highway technologies and their possible coordination and interaction to meet long-term transportation safety and capacity needs should continue to have a place in the ITS program. Such long-range research should be guided by a strategic plan that attempts to define the responsibilities of the vehicle and infrastructure in ITS. Doing so will raise many questions—for instance, about the respective roles of the public and private sectors—that an ITS research program should be designed to address.

Human factors should be thoroughly integrated into advanced vehicle and highway research, development, and deployment.

Human factors considerations—that is, the behavior and capabilities of drivers—must have a central role in shaping advanced vehicle and highway technologies and ensuring their safety and use. Driver behavior and performance should not be treated as side issues or addressed in a perfunctory manner; they must be repeatedly and comprehensively incorporated into technology design, development, and evaluation processes.

The work of the National Automated Highway System Research Program should be evaluated and documented.

From its technology demonstrations and concept analyses to its workshops, outreach efforts, and consultations with transportation system users and providers, NAHSC has fostered interest in and debate about vehicle and highway automation. It also has yielded many technical insights. This experience and work should not be ignored. DOT should sponsor an independent review of the consortium's methods, results,

and conclusions, including other findings and conclusions that can be drawn from this effort. The results should be documented and made accessible to the ITS community to help build a foundation for future work in this area.

Public- and private-sector collaborations should continue to be pursued.

NAHSC has demonstrated the potential value and possibilities of cooperation between the public and private sectors of the diverse transportation and technology communities. The conflicts that were inherent in the consortium's approach, however, illuminate the importance of carefully evaluating collaborative options to ensure compatibility with the program's intended purpose. Public- and private-sector cooperation will be essential to ITS development and deployment, ensuring product compatibilities while expanding ideas, resources, and interest. Many collaborative efforts are under way in the transportation sector. DOT should systematically study these activities to identify the best practices and approaches for use in ITS.

External, independent reviews of research programs should be sought.

External review committees often are established to offer independent advice about the mission plans of a research and development program and to critique progress toward goals and objectives as the program proceeds. Such external reviews have proved valuable in many government and industry research programs; they should have been undertaken as part of the National Automated Highway System Research Program. External reviews should accompany future research initiatives on advanced vehicle and highway systems, as well as other ITS programs.

REFERENCES

ABBREVIATION

DOT U.S. Department of Transportation

DOT. 1993. *Request for Applications to Establish a National Automated Highway System Consortium.* Number DTFH61-94-X-00001. December 15.

DOT. 1997. *Department of Transportation Strategic Plan 1997 to 2002* (also available on DOT World Wide Web home page, http://www.dot.gov).