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Report to the Chairman, Subcommittee on Transportation and Related Agencies, Committee on Appropriations, House of Representatives

August 1992

MOTOR VEHICLE SAFETY

Key Issues Confronting the National Advanced Driving Simulator

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Resources, Community, and
Economic Development Division

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August 18, 1992

The Honorable William Lehman
Chairman, Subcommittee on
Transportation and Related Agencies
Committee on Appropriations
House of Representatives

Dear Mr. Chairman:

The Department of Transportation (DOT) plans to develop a state-of-the-art motor vehicle driving simulator at the University of Iowa. As currently planned, the National Advanced Driving Simulator (NADS) is expected to be operational in 1996 and to cost about $32 million. DOT expects that it will provide about $21 million and that the remainder will be provided by non-DOT governmental and private sources.

This report responds to your October 30, 1991, letter asking us to evaluate certain NADS issues. As agreed with your office, we examined (1) the benefits that NADS will provide to the National Highway Traffic Safety Administration's (NHTSA) and the Federal Highway Administration's (FHWA) existing or planned activities, (2) NADS' projected capabilities compared with existing simulator capabilities, (3) NHTSA's efforts to overcome technical risks associated with building NADS, (4) information on the estimated cost to develop NADS and the amount of non-DOT financial commitments, and (5) the allocation of NADS' operating hours to potential users.

Results in Brief

While DOT believes that NADS' research will benefit the Department's programs, it cannot quantify the benefits in such terms as lives or dollars saved. NADS will allow researchers to safely conduct certain automobile/traffic safety and highway design research that cannot be performed now because the methods available for conducting such research present unacceptable risks to the driver. For example, NADS will allow DOT and others to investigate the influence of prescription drugs at various dosage levels on the critical aspects of a driver's performance.

Compared with the world's most advanced existing driving simulator, NADS is expected to more closely simulate real driving experiences. NADS will have a more advanced visual system, a larger and more advanced motion system, and a faster-operating computer system. Thus, simulation experts believe that NADS will enable researchers to conduct considerably more research than can be performed with existing driving simulators.

Simulation experts believe that the state-of-the-art in simulation is such that there should be no technical risk associated with achieving the physical specifications (equipment and computer hardware and software) for NADS. These experts and NHTSA officials believe that the primary technical issue is specifying the outer boundary for the motion system (amount of motion needed to do all desired maneuvers). Also, NHTSA believes that minimizing simulator-induced driver sickness (nausea, dizziness, and cold sweating) is another technical issue. NHTSA is conducting studies and taking other steps to address these technical issues. We believe that NHTSA, after the design phase, will be in a better position to judge whether there are technical risks and whether those risks can be overcome.

Whether the $32 million estimate to develop NADS is accurate is uncertain at this time because the estimate (1) was made in early 1990 and has not been adjusted to reflect any future cost changes and (2) was based on a conceptual design. While NHTSA and University of Iowa officials believe that the $32 million estimate continues to be a good estimate, we believe that NHTSA should be in a position to have a more reliable estimate after the design phase (fourth quarter of fiscal year 1993).

The willingness of non-DOT sources to finance one-third of NADS was also uncertain. NHTSA has received a commitment for $5.25 million (from the University of Iowa) of the $11 million expected from non-DOT sources. To obtain other commitments, on July 8, 1992, NHTSA sent letters to vehicle manufacturers, automotive parts suppliers, insurance companies, and others asking for NADS' financing. The extent to which domestic vehicle manufacturers will respond to NHTSA's request for financing is not clear because they have indicated little need for NADS. According to NHTSA, foreign vehicle manufacturers are more receptive to providing financial assistance than domestic manufacturers.

NHTSA and the University of Iowa have not agreed on a plan for allocating NADS' operating hours. However, NHTSA believes that DOT should be given priority for two-thirds of the total available hours.

Background

NHTSA and FHWA administer vehicle/highway safety programs that entail research, development, testing, and evaluation. The programs are intended to reduce the number of deaths, injuries, and economic losses resulting from traffic accidents on the nation's highways. In November 1989, the Secretary of Transportation assigned NHTSA lead responsibility for NADS development. As conceptualized, NADS will be housed in a 50-foot-high experimental bay with multiple adjacent experiment-staging areas. It will have a large excursion motion platform with a high-resolution graphics display dome and high-frequency vibrators. (See app. I for a conceptual drawing of NADS.)

Under DOT Order 4200.14C, NADS is considered a major acquisition because it is estimated to cost over $20 million. Guidance for major acquisitions is provided under Office of Management and Budget (OMB) Circular A-109. (See app. II for a discussion of Circular A-109 requirements.) On March 14, 1991, DOT's Transportation Systems Acquisition Review Council approved NADS' mission needs statement, subject to NHTSA's (1) providing sufficient information to allow for an assessment of financial commitments from non-DOT sources and (2) explaining why other existing or planned simulators could not meet DOT's research need.

In fiscal years 1990 and 1991, the Congress provided $2.951 million and $1.8 million, respectively, for NADS, which is sufficient to finance NADS development through the design phase. The design phase is intended to develop alternative system designs and related cost estimates, capability objectives, and operating constraints. For fiscal year 1993, NHTSA is requesting an additional $9.45 million for continuing NADS' development after design phase completion.

NADS Could Benefit Safety Programs, but Benefits Are Not Quantifiable

According to NHTSA and FHWA, NADS will allow researchers to more fully examine vehicle/highway safety and highway engineering issues under a wide variety of conditions. NADS will allow researchers to conduct research that cannot now be done in a vehicle because of unacceptable risks to vehicle drivers. The Administrator of NHTSA stated, however, that NADS' benefits cannot be defined in quantifiable terms such as lives saved, dollars saved, and accidents avoided. Such benefits will accrue from new safety devices and designs that will need to be developed and implemented as indicated by NADS.

NHTSA's Administrator said that NADS will be used to assess the safety implications of new vehicle systems and to develop and evaluate vehicle-based crash avoidance countermeasures such as night/fog vision systems, intersection hazard warning systems, driver vigilance warning systems, and near-object warning systems. NADS will also help researchers to better understand the relationship between driving performance and (1) vehicle design characteristics, (2) the age of drivers, (3) medication-related diseases, (4) hazardous drug and alcohol dosage levels, and (5) driver fatigue.

FHWA's Administrator said that NADS will be used in both research and engineering test and evaluation programs. NADS will permit safe investigations of driving situations that involve unacceptably high safety risks to drivers. NADS also offers a very high degree of experimental control that is unachievable in field tests. FHWA plans to use NADS for (1) research that otherwise cannot be safely conducted, (2) research that would significantly accelerate certain national FHWA programs, and (3) engineering evaluations.

According to FHWA, NADS will (1) provide a safe tool for identifying the capabilities, limitations, and problems of older drivers and for evaluating remedial countermeasures; (2) allow much of the intelligent vehicle/highway safety (IVHS) human factors research to be done in shorter time frames and with greater safety than comparable field testing; and (3) permit the identification and elimination of highway design errors before construction. FHWA believes that this latter use will yield a high benefit-to-cost ratio because design errors are expensive to correct after construction is completed. (Written summaries from NHTSA and FHWA regarding the benefits of NADS are presented in full in app. III.)

NADS Would Be the World's Most Advanced Simulator

NADS will have a more advanced visual system and a larger and more advanced motion system and will be supported with faster computers than two other simulators: (1) the Daimler-Benz Driving Simulator (DBDS)—the most advanced driving simulator in the world—and (2) the University of Iowa Driving Simulator (IDS)—the most advanced driving simulator in the United States. As a result, NADS will be able to carry out more research than existing driving simulators can.

For its visual system, NADS will be able, at a minimum, to use 1992 technology, which allows for (1) the representation of color or darkness gradations (shading), (2) photographic-based texturing, and (3) a very high number of geometric shapes (polygons) for generating driving scenes. Applying criteria developed by the Transportation Research Board (TRB) for determining simulator requirements needed to accomplish identified research, a group of simulation experts rated the fidelity (realism) of NADS "high." In contrast, DBDS' visual system uses 1985 image-generation technology, which allows shading and a fairly high number of polygons for generating driving scenes. Simulation experts rated the fidelity of DBDS' visual system "medium." IDS uses 1989 technology, which allows for (1) shading, (2) photographic-based texturing, and (3) a very high number of polygons for generating scene content. Simulation experts rated the fidelity of IDS' visual system "medium plus."

In comparing responses from IDS, DBDS, and NHTSA officials to our simulator capabilities checklists, we found that NADS' other visual improvements include a larger frontal field-of-view, a greater number of operational rear-view mirrors, a much greater number of moving objects that can be displayed simultaneously, and a reduction in the time between a driver's action, such as turning the steering wheel, and the corresponding change in the driving scene (transport delay). (See app. IV for a detailed comparison of IDS', DBDS', and NADS' visual capabilities.)

For simulating motion, DBDS has a hexapod base system and can simulate acceleration/deceleration in the following dimensions—forward/reverse, left/right, vertical, roll, pitch, and spin. As conceptualized, NADS will also be capable of simulating these six movements. The forward/reverse and left/right movements will be enhanced by a large, 30-foot carriage operating on a 90-foot track. Additionally, NADS will have a secondary, high-frequency motion system to realistically simulate running over rough roads, railroad tracks, etc. Simulation experts rated the fidelity of DBDS' motion system "medium" and NADS' motion system "high." IDS does not have a motion system.

Responses to our capabilities checklist showed that DBDS is capable of realistically simulating many of the driving maneuvers that NADS will be capable of simulating: changing lanes, braking in emergencies, sustaining acceleration, avoiding collisions, negotiating hills, and skidding. However, DBDS is not capable of realistically simulating the turning of corners, spinning types of accidents, and jack-knifing. (See app. IV for a detailed comparison of IDS', DBDS', and NADS' motion capabilities.)

TRB's Committee on Simulation and Measurement of Vehicle and Operator Performance identified 54 research areas, each including hundreds of experiments, in which simulators (ranging in fidelity from low to high) could be used to (1) reduce the vehicle accident rate; (2) increase the quality of driver licensing and/or certification without increasing cost; and

(3) provide lower-cost, higher-quality vehicle-highway systems.[1] Using TRB's report as a baseline, we asked knowledgeable simulation experts to estimate the portion of the experiments that could be accomplished with IDS, DBDS, and NADS.

For most of the 54 research areas, the experts responded that IDS and DBDS have the capability to address from few to all of the related experiments. But a very high-level simulator is needed to address all experiments in all 54 areas. NADS would have the capability to address all the experiments in 47 of the research areas and almost all in the remaining 7. Table 1 shows the extent to which IDS, DBDS, and NADS could address the identified research, and appendix V provides more detailed information on the capabilities of the three simulators.

Table 1: Extent to Which IDS, DBDS, and NADS Could Address the 54 Research Areas Compared

Portion of each research area addressed	Number of research areas		
	IDS	DBDS	NADS
All	0	8	47
Almost all	4	8	7
Some	22	25	0
Few	12	4	0
None	16	9	0
Total	**54**	**54**	**54**

Source: Transportation Research Circular No. 388, TRB (Feb. 1992), and simulation experts.

The experts cautioned that the portion of the experiments that could be conducted in a specific research area may either overstate or understate a simulator's usefulness for that area and is not a good measurement of a simulator's effectiveness. For example, the ability to conduct 50 percent of the experiments in one area may result in a tremendous benefit, while in another area, the ability to conduct 50 percent of the experiments may be of very little benefit.

NADS Technical Issues

Simulation experts believe that the state of the art in simulation is such that there should be no technical risk associated with achieving the physical specifications (equipment, computer hardware, and computer software) of NADS. However, they believe that specifying the outer boundary of the motion system does present a technical risk. According to the experts, (1) the motion envelope for any simulator will impose

[1]Transportation Research Circular No. 388, TRB (Feb. 1992).

inherent limitations on some applications because there is no analytical, scientific, or engineering way to define the required motion envelope for any given application and (2) the size of the motion envelope will still rely on simulation experts' best guess, even after washout algorithms[2] have been used.

NHTSA officials generally agree with the experts. They also see the minimization of simulator-induced driver sickness as another technical issue. NHTSA believes that the motion envelope and capabilities of the motion platform are critical to successfully simulating realistic motion signals (cues) to minimize simulator sickness. Driving simulators, which have restricted movement capabilities, must rely on abnormally high amounts of false cues (for example, using the visual system to simulate motion), which can result in cue conflict—the discrepancy between perception and reality experienced by the driver. Cue conflict is believed to be the primary potential cause of simulator-induced sickness.

To address these technical issues, NHTSA (1) conducted a demonstration of motion base design alternatives to compare the capabilities of a large- and limited-excursion motion base, (2) contracted for a study to develop the specifications for sizing NADS' motion envelope, (3) plans to award two competing design contracts to help ensure that NADS can simulate desired maneuvers, and (4) will make the minimization of simulator-induced sickness a design constraint. While NHTSA appears to be taking the necessary action to address the technical issues, it cannot experimentally demonstrate that a large-excursion motion system will minimize the chances for simulator-induced sickness. We believe that, after the design phase, NHTSA will be in a better position to judge whether there are technical risks and whether those risks can be overcome.

First, the alternatives study for motion base design, conducted in December 1990, was undertaken to compare the abilities of a large-excursion motion base (NADS-like) and a limited-excursion motion base (hexapod-like) to (1) produce realistic acceleration/deceleration, cornering, and braking maneuvers and (2) minimize the potential simulator-induced sickness effects of false cues. NHTSA and simulation experts from the National Aeronautics and Space Administration (NASA) and the private sector converted NASA's vertical motion flight simulator (VMS) to a driving simulator and ran 10 people through braking and slalom maneuvers on NADS- and hexapod-like motion systems. The study concluded that (1) the drivers tended to prefer the NADS-like to the

[2]Mathematical equations used to convert real vehicle motion to simulator vehicle motion.

hexapod-like motion system and (2) cases of simulator-induced sickness were rare under both systems. However, because of the demonstration's small sample of drivers (10) and consecutive sequencing of the two maneuvers, several of the simulation experts involved in directing the study told us that the study did not confirm that NADS would perform better or cause a lower rate of simulator-induced sickness than a hexapod motion system.

Second, NHTSA contracted for a motion envelope and drive algorithm study with its Vehicle Research and Test Center (VRTC). Dr. Lloyd Reid (a washout algorithm expert) will conduct a portion of the study. To determine the size of NADS' motion envelope, Dr. Reid is developing a set of washout algorithms for converting real motion to simulator motion and will simulate 12 maneuvers with 9 different vehicles by using vehicle dynamics simulations developed by VRTC. The study is scheduled to be completed in the summer of 1992.

Third, NHTSA plans to award two competing design contracts to further ensure that NADS will be capable of simulating desired maneuvers in real-time. The contracts are scheduled to be awarded in the fourth quarter of fiscal year 1992 and are estimated to cost $3 million. A team of technical experts from the government and private sectors will review these competing designs. The contractor with the best design will become the prime contractor for continued NADS' development.

Cost Estimate Is Uncertain

Whether the $32 million estimate to develop NADS is accurate is uncertain at this time because it (1) was made in early 1990 and has not been adjusted to reflect any future costs changes and (2) was based on a conceptual design that does not identify the specific equipment, computer hardware and software, and building size needed for NADS.

While NHTSA and University of Iowa officials believe that the $32 million estimate is a good "ballpark" figure, NHTSA will have a more specific cost estimate after the planned design phase is completed in the fourth quarter of fiscal year 1993. NHTSA officials told us that, as part of the two competing design contracts, each contractor will be required to develop separate reports on the technical design and the estimated cost for developing NADS, supported by the identification of subcontractors to be used and their related cost estimates.

Non-DOT Financial Commitments Are Uncertain

As of July 1, 1992, it was uncertain whether NHTSA would be successful in obtaining financial commitments from non-DOT sources for one-third of NADS' cost (about $11 million) before its planned design contract date in the fourth quarter of fiscal year 1992. Only the University of Iowa had made a financial commitment toward NADS' development. The University agreed to construct the building to house NADS and to donate vehicle dynamics software—a total commitment of $5.25 million. While private-sector companies have identified many potential uses for NADS, their expressed willingness to pay for such uses is from two to four times lower than the estimated cost to operate NADS. The government sector is willing to pay a higher fee for using NADS that is more compatible with the estimated operating costs.

Development Cost Commitments

Both the Congress and OMB believe that NHTSA should obtain financial commitments for NADS' development from nonfederal sources. In the report on DOT's fiscal year 1991 appropriations, the Senate Committee on Appropriations directed NHTSA to take the steps necessary to maximize nonfederal contributions to NADS. Similarly, OMB, in commenting on NHTSA's 1991 budget, said that DOT should have private-sector financial commitments before awarding contracts for the design, fabrication, and installation of major simulator subsystems. Neither the Congress nor OMB established a threshold for nonfederal commitments.

On March 24, 1992, NHTSA sent letters to the Defense Advanced Research Projects Agency and the Department of the Army's Office of Research, Development, and Acquisition requesting that they consider contributing to NADS' development. On July 8, 1992, NHTSA sent similar letters to over 100 potential private users, including domestic and foreign vehicle manufacturers, automotive parts manufacturers, insurance companies, and tire manufacturers.

The extent to which the private sector will respond to NHTSA's request for financial support is not clear. For example, a Chrysler representative told us that Chrysler does not have any need for NADS and has made a decision not to contribute to NADS' development. General Motors and Ford representatives said that they would have very few applications for a simulator with NADS' capabilities. Although they do not have driving simulators with NADS' capabilities, both General Motors and Ford are concerned about using an off-site simulator to conduct tests or experiments of a proprietary nature. They believe that their proprietary information could not be properly safeguarded. Both General Motors and

Ford told us that a decision had not been made on whether to contribute financially toward NADS' development. NHTSA officials said that the security of users' data is of crucial importance and, consequently, NADS will have a computer data security system commensurate with the Department of Defense's security system.

NHTSA officials also said that foreign vehicle manufacturers with plants in the United States have been more receptive than U.S. manufacturers toward providing financial assistance for NADS' development. In response to a NHTSA briefing concerning NADS, a Honda official indicated that his company might be willing to contribute up to $500,000 if NHTSA would send a letter requesting assistance. Representatives of other foreign manufacturers have encouraged NHTSA to make formal requests for assistance, although they did not quote any dollar amounts that their companies might be willing to contribute.

Private Sector's Willingness to Pay Operating Cost

According to the two needs studies contracted by NHTSA, the private sector identified many research opportunities for NADS but would be willing to pay only two to four times less than NADS' estimated operating cost for much of the research. The private consulting firm used to assist in NADS' feasibility study estimated that NADS would cost about $2,000 per hour to operate. The estimate was based on the cost to operate one public and one private research flight simulator. The University of Iowa's Center for Computer Aided Design estimated that NADS would cost about $1,100 per hour to operate. University officials told us that the estimate was based on actual cost and operating experience with IDS. Both estimates assumed that NADS would operate for 3,500 hours per year.

Private-sector representatives responding to the two needs studies indicated a willingness to pay $500 or less per hour for most of the research areas identified. Only one user group indicated a willingness to pay an average of $1,100 per hour for only one of many research areas. None of the private-sector user groups were willing to pay an average of $2,000 per hour for any of the research identified.

Allocating NADS' Operating Hours

As of July 1, 1992, NHTSA and the University of Iowa had not agreed on a plan for allocating NADS' operating time among potential users. NHTSA officials told us that DOT's rights to use NADS would be covered in a cooperative agreement between NHTSA and the University. While the portion of NADS' operating hours allocated to DOT must be negotiated, NHTSA officials believe that DOT should have priority for two-thirds of the total operating hours.

Conclusions

NADS has the potential to be the world's most advanced driving simulator and will allow both government and private researchers to greatly expand their research capabilities. While its benefits cannot now be quantified in terms such as lives or dollars saved, DOT believes that NADS would improve the effectiveness of its vehicle safety, IVHS, and highway construction programs. According to DOT and simulation experts, NADS' capabilities will allow researchers to conduct a great amount of research that cannot be safely conducted today. For example, with NADS, researchers could measure the influence of prescription drugs at various dosage levels on critical aspects of a driver's performance. Simulation experts believe that the expanded research capabilities will result in reduced vehicle accident rates and lower-cost, higher-quality vehicle highway systems.

At the present time, the estimated cost to develop NADS and the willingness of non-DOT sources to help finance NADS are uncertain. The $32 million estimate made in early 1990 has not been adjusted and was based on a conceptual design. A better picture of the cost of NADS and its ability to perform as a simulator will be clearer once the two design contracts are completed in the latter part of fiscal year 1993. Although DOT approved NADS' development contingent upon NHTSA's obtaining the one-third financial commitment from non-DOT sources, NHTSA has yet to obtain this level of commitment. However, NHTSA has officially asked the private sector to make a financial contribution.

Matters for Congressional Consideration

In view of the uncertainties concerning (1) the estimated cost to develop NADS, (2) NADS' capability to perform as conceptualized, and (3) NHTSA's success in obtaining the one-third financial commitment from non-DOT sources, the Congress may wish to either defer further funding for NADS until after the design phase, when these uncertainties should be answered, or approve the $9.45 million requested for fiscal year 1993 but restrict its expenditure until NHTSA reports on the resolution of the uncertainties.

Recommendations

We recommend that the Secretary of Transportation report to the Congress, after the design phase, on the three uncertainties listed above. In addition, the Secretary should require NHTSA to follow through with its plans for meeting the goal of obtaining the one-third financial commitment from non-DOT sources. If NHTSA should fail to attain the one-third goal, we recommend that the Secretary discuss alternative funding approaches with the Congress and OMB.

Agency Comments

NHTSA's Associate Administrator for Research and Development provided oral comments on a draft of this report on July 1, 1992. Also, DOT's Assistant Secretary for Administration provided written comments on July 9, 1992. (See app. VI.) Both the Associate Administrator and the Assistant Secretary agreed with our findings and conclusions but expressed concerns over and consequences of a congressional decision not to approve NADS funding for fiscal year 1993.

The Associate Administrator stated that deferring NHTSA's request for further NADS funding would have an adverse effect on the NADS program. He said that such action would invalidate NHTSA's plan for awarding two competing design contracts and selecting the contractor with the best design to become the prime contractor for continued NADS development. He also said that deferring the commitment for federal funding could (1) discourage investment by the design contractors during the design phase, (2) cause the development schedule to slip as much as 18 months, (3) increase NADS' cost because a follow-on contract could not be immediately awarded and the design team could be dispersed, (4) force NHTSA to separately contract for the fabrication (assembly) phase, and (5) impede efforts to secure non-DOT cost sharing. Furthermore, he said that such action could prompt the State of Iowa and the University of Iowa to withdraw from the project because Iowa's cost-sharing commitments will expire in June 1994. The Associate Administrator said that NHTSA would prefer that the Congress appropriate the $9.45 million for fiscal year 1993 even with a requirement that NHTSA report to the Congress on how the uncertainties we identified have been resolved before the money could be spent.

We recognize that deferring further funding until after the design phase could adversely affect NADS as NHTSA contends. However, without knowing how potential design contractors and potential non-DOT contributors would react to such a decision, the full impact of delayed funding cannot be evaluated. We continue to believe that the deferment option is a valid option for the Congress to consider. We agree with NHTSA, however, that the Congress could approve the fiscal year 1993 request for funding and require NHTSA to report on how the uncertainties were resolved before any money could be spent. Therefore, we revised this report to include the option of approving the fiscal year 1993 funds with restrictions in our matters for congressional consideration.

Scope and Methodology

Our review work was conducted primarily at NHTSA headquarters in Washington, D.C. We interviewed NHTSA officials to determine what NHTSA has done, is doing, and plans to do to develop NADS. We reviewed reports on (1) the feasibility and conceptual design of NADS, (2) a demonstration of motion base alternatives for NADS, and (3) two studies to identify the potential uses and users of NADS. We requested that the Administrators of NHTSA and FHWA summarize the ways that NADS will benefit their research and other programs. Also, we asked NHTSA, Daimler-Benz, and University of Iowa officials to complete identical checklists defining capabilities of their respective driving simulators. NHTSA officials helped us to design the checklist.

We reviewed a February 1992 Transportation Research Circular issued by TRB's Committee on Simulation and Measurement of Vehicle and Operator Performance on the applicability of simulator technology to motor vehicle travel. We asked a group of simulation experts to determine the portion of the research that TRB identified for simulator application that could be accomplished with (1) DBDS, (2) IDS, and (3) NADS.

We interviewed University of Iowa officials and test drove IDS. We interviewed several simulation experts, some of whom were involved in the various NHTSA studies, to help us identify any technical risks involved in developing and operating NADS. We interviewed representatives of Chrysler, Ford, and General Motors to determine how and to what extent they would use NADS and whether they had made a formal decision to help finance NADS' development. We conducted our review from November 1991 to May 1992 in accordance with generally accepted government auditing standards.

We are providing copies of the report to the Senate Committee on Appropriations; other interested congressional committees; the Director, Office of Management and Budget; the Secretary of Transportation; and the Administrators of NHTSA and FHWA. Copies will be provided to other interested parties upon request. This work was conducted under the direction of Kenneth M. Mead, Director, Transportation Issues, who may be reached at (202) 275-1000 if you or your staff have any questions. Major contributors are listed in appendix VII.

Sincerely yours,

J. Dexter Peach
Assistant Comptroller General

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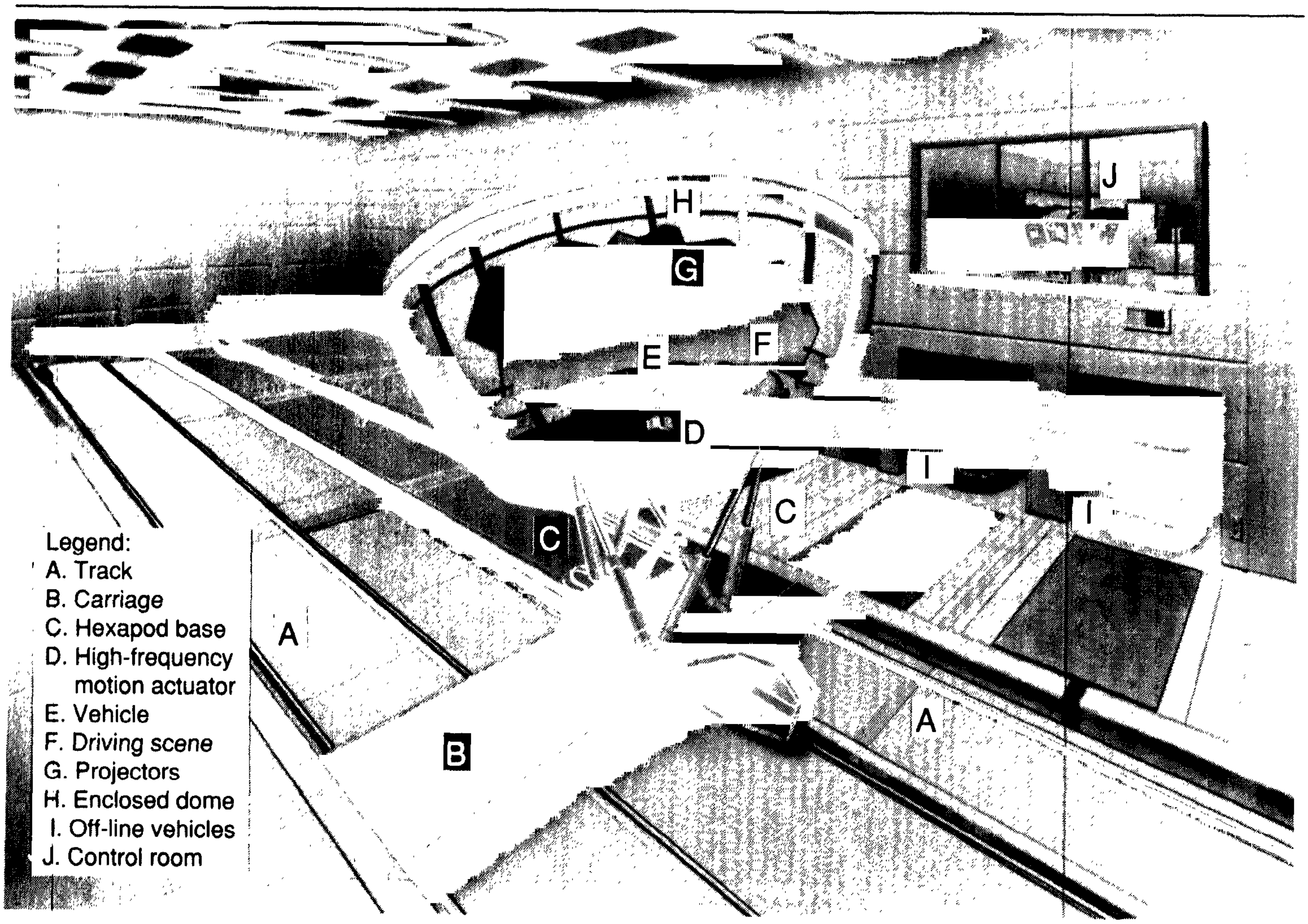
Abbreviations

CIG	Computer Image Generator System
DBDS	Daimler-Benz Driving Simulator
DOT	Department of Transportation
FHWA	Federal Highway Administration
GAO	General Accounting Office
IDS	Iowa Driving Simulator
IVHS	Intelligent Vehicle/Highway Safety
NADS	National Advanced Driving Simulator
NASA	National Aeronautics and Space Administration
NHTSA	National Highway Traffic Safety Administration
OMB	Office of Management and Budget
TRB	Transportation Research Board
VRTC	Vehicle Research and Test Center

Conceptual Drawing of NADS



Source: NHTSA.

Requirements of OMB Circular A-109

Office of Management and Budget (OMB) Circular A-109 is the federal government's principal guidance for acquiring major systems and has two primary objectives: (1) to avoid cost overruns and schedule delays and (2) to ensure top-level approval. To achieve the first objective, Circular A-109 divides the acquisition process into five phases: (1) determination of mission needs, (2) identification and exploration of alternative design concepts, (3) demonstration of alternative design concepts, (4) full-scale development and limited production, and (5) full production. For the second objective, Circular A-109 requires that top management approve each of the five phases before proceeding to the next phase—this process comprises four key decision points.

The National Advanced Driving Simulator's (NADS) updated mission needs statement and acquisition plan—the second decision point for this acquisition—were submitted to the Department of Transportation's Transportation Systems Acquisition Review Council for approval on April 29, 1992. The National Highway Traffic Safety Administration plans to award two contracts in the fourth quarter of fiscal year 1992 to explore and demonstrate alternative design concepts (phase three of this acquisition). Approval for full- scale development is expected to be made in the fourth quarter of fiscal year 1993 (phase four). Because only one NADS will be built, this acquisition will be completed after phase four.

NHTSA and FHWA Administrators' Responses to GAO'S Request to Document the Benefits of NADS

U.S. Department of Transportation
National Highway Traffic Safety Administration

The Administrator

400 Seventh St., S.W.
Washington, D.C. 20590

MAR 26 1992

Mr. Ron E. Wood
Assistant Director
U.S. General Accounting Office
Washington, DC 20548

Dear Mr. Wood:

Thank you for your letter requesting a summary of the ways the National Advanced Driving Simulator (NADS) will benefit the National Highway Traffic Safety Administration's (NHTSA) research programs. You requested that these benefits be related directly to individual programs and that the benefits be defined in quantifiable terms such as lives saved, injuries reduced, money saved, safer vehicles, safer roads, etc. Unfortunately, information of the type that you have requested cannot be provided. Benefits to traffic safety accrue not from the research tool used but rather from technology countermeasures that the tools allow us to develop. Thus, meaningful data on benefits is only obtainable after research leads to feasible countermeasures that can be practicably implemented in the vehicle fleet.

An example is the development of the Center High Mounted Stop Light (CHMSL). The goal of the original research effort was to identify and develop countermeasures that could reduce rear end collisions by providing a more commanding warning to drivers following vehicles that were stopping. The initial research involved determining if a high mounted stop light had the potential for crash reduction. Once this was established, it was then necessary to define its optimal size, location, brightness, color, etc. Following this basic research, large scale fleet test evaluations were conducted. Only after this fleet test program was completed was NHTSA then able to quantify the possible reductions in rear end crashes using this countermeasure. It was on this basis that the Agency took a regulatory action to require the CHMSL on all new vehicles manufactured after 1985. Subsequent studies were also conducted after the requirement for CHMSL to establish that there was a positive benefit actually being achieved.

While the quantified data that you have requested is not currently available, we are providing you, as an enclosure, an overview of the general areas in our crash avoidance research program where the NADS would be utilized, together with example research project statements summarizing the research that might be conducted. We would also like to call your attention to the two recently completed NADS Needs/Requirements Studies conducted by NHTSA, and the Transportation Research Board Circular on Simulator Technology. The Transportation Research Board study was publicly issued in

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January 1992. My staff has provided you with copies of these documents previously. All three of these reports contain numerous example research applications for the NADS in the areas in which you are interested.

We hope that the enclosed information will help you in your review of the NADS project, and if we can be of further assistance, please feel free to contact me.

Sincerely,

Jerry Ralph Curry

Enclosure

RELATIONSHIP OF THE NATIONAL ADVANCED DRIVING SIMULATOR (NADS) TO THE NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION (NHTSA) RESEARCH & DEVELOPMENT PROGRAMS

BACKGROUND

Motor vehicle crashes are a leading cause of death and injury in the United States. Of the 193 million motor vehicles in use, approximately 11 million are involved in police-reported crashes each year. Another 14 million vehicles are involved in non-police-reported crashes. In 1990, motor vehicle crashes resulted in 44,529 deaths and more than three million injuries. Motor vehicle travel and traffic density are increasing dramatically, particularly in urban areas. Both the general population and the population of registered drivers are increasing steadily. The driving population is aging, and vehicles of vastly different sizes and weights are sharing the same ever-more-crowded roadways. Traffic crashes represent an ever-present threat to personal safety and property; the congestion they cause harms economic productivity, personal convenience, and the overall quality of American life. The relative contributions of driver, vehicle, and highway/environmental causal factors in traffic crash causation have been compared in a number of studies. Consistently, human errors have been shown to be leading causes and contributing factors. The Indiana Tri-Level Study (Tri-Level)[1] cited human factors as definite or probable causes or as severity-increasing factors 93 percent of the time. In contrast, environmental factors were cited as certain or probable for 34 percent of the in-depth cases; vehicle factors were cited in 13 percent. These percentages add to more than 100 percent since more than one causal or severity-increasing factor could be cited.

The NADS will benefit a number of program areas within NHTSA as follows:

CRASH AVOIDANCE RESEARCH

Crash avoidance research develops and utilizes the tools necessary to support all phases of crash avoidance research and development. This includes such diverse research methods as advanced simulation, instrumented vehicles, accident data analysis, crash scenario modeling, and countermeasure effectiveness evaluation protocols. The NADS will be a major development effort in the area of simulation. Simulation will be used to examine the driver-vehicle interaction characteristics relevant to crash involvement and identify specific vehicle designs, components, or parameters associated with driver performance errors. The NADS will be used to assess the safety implications of new vehicle systems and to develop and evaluate vehicle-based crash avoidance countermeasure concepts and devices. Crash avoidance research by means of NADS simulation will provide the tools for developing countermeasures, e.g., radar collision warning systems, that affect both crash occurrence and severity. By providing drivers with additional warning time of an impending crash, the collision may be avoided or at least a reduction in impact speed and severity can be achieved. The NADS will be used to develop and evaluate advanced crash avoidance countermeasures reliably and in the safety of the laboratory, as opposed to full-scale vehicle testing that would involve unacceptable risk to the test subjects.

Example Project:

Evaluate the changes in directional stability and control in vehicles equipped with prototype active suspension systems. The purpose of the study would be to assess the effect of changing vehicle properties such as weight, inertia, tires, brakes, etc., on the response and performance of the resulting vehicle system over a range of tasks and operating conditions. These changes could alter the vehicle response in such a way that its lateral-directional stability could be seriously degraded, resulting in a reduced safety margin for the driver. The active suspension system would be mathematically modeled on the NADS in the conceptual design phase and later replaced with actual hardware for final evaluation.

INTELLIGENT VEHICLE-HIGHWAY SYSTEMS (IVHS)

Driving is a dynamic information processing activity that encompasses mental and behavioral processes such as sensation, interpretation, working memory, decision-making, response execution, and attention. Each of these driver functions and processes has limitations in terms of speed, capacity, and reliability. In addition, there are limits to the total mental capability available for continuous information event processing. Because of these human limitations, drivers make mistakes, and crashes result.

Although the causes of crashes are largely human, important solutions may be found in technology. Successful collision avoidance systems generally act by enhancing some element of human information processing. For example, analytical modeling has shown that 50 percent of all intersection and rear-end crashes could be avoided if drivers were made aware of crash threats one-half second sooner and then reacted correctly. Examples of high-technology systems that would provide such driver performance enhancement include night/fog vision systems, intersection hazard warning systems, driver vigilance warning systems, and near-object warning systems. Other potential countermeasures supplement driver responses (automatic braking) or enhance the vehicle's response to driver control inputs (variable-assist steering).

Advancing technology in electronics, artificial intelligence, and communications provide the basis for designing the smart sensors, processing units, and control systems needed to facilitate and augment driver performance. The IVHS initiative is a multi-sector and multi-disciplinary national effort to apply these technologies to improving motor vehicle transportation. IVHS technology is being applied to increase the safety of the driver-vehicle system, initially by means of collision warning and control systems that are vehicle-based; i.e., totally self-contained within the vehicle. Vehicle-based IVHS crash avoidance countermeasures hold great promise for crash reduction and the NADS will be used to assess these countermeasures.

An appraisal of the IVHS opportunity reveals that significant safety risks may be imposed by systems that are ill-suited to the human operator. In particular, care must be taken to match in-vehicle displays and control systems to human capabilities so that drivers are not distracted, overloaded, or confused. While large safety and productivity benefits are possible from IVHS, any national IVHS initiative must guard against the introduction of new technology which presents a safety hazard.

NADS research will examine the level of improved crash avoidance performance that can be achieved through the application of IVHS technology and support the successful development of promising IVHS crash avoidance countermeasures. The use of the NADS in this program will ensure that there is no net loss of safety from the implementation of IVHS systems intended to increase the efficiency of motor vehicle transportation. Full scale vehicle testing could present potential dangers of a collision to a driver.

Example Project:

Evaluate the safety and effectiveness of in-vehicle, remote sensing, (infrared, microwave, laser, etc.) collision warning systems. The NADS will be used to conduct studies (in the safety of the laboratory) to systematically evaluate driver response in crash avoidance and/or crash imminent situations in vehicles equipped with these advanced collision detection and warning systems. These studies will involve assessing the relationship between the driver-vehicle interface, e.g., display, warning, and operating systems, and the capabilities of the human driver. The research will be directed at determining the optimal means of communicating collision warning information to the driver without creating excessive demands on his physical and mental capabilities, e.g., workload, vigilance, and vehicle control. Actual prototype hardware will be evaluated on the NADS using "hardware in the loop" simulation techniques. Using this approach, candidate collision warning systems will be connected directly to the simulator (hard-wired), and will function as they would in the real vehicle. This will allow design refinements and "fine tuning" to be made as well as an assessment of the effects of various system failure modes, all with complete safety and repeatability.

HUMAN FACTORS/DRIVER-VEHICLE INTERACTIONS

Driver errors have been found to be a definite or probable cause, or a severity-increasing factor in 93 percent of the crashes investigated in the Tri-Level Study. The specific objectives of the human factors research program are to gather fundamental data that will result in a better understanding of the source of driver errors and how the driver-vehicle interface can be improved to reduce their frequency. The driver errors and deficiencies which cause crashes include recognition, decision and performance errors. Recognition errors include situations where a conscious driver does not properly perceive, comprehend, and/or react to a situation requiring a driver response. It includes inattention, distraction, and "improper lookout," i.e., the driver "looked but did not see." Recognition errors were a definite or probable causal factor in 56 percent of the in-depth Tri-Level crashes. Decision errors are those in which a driver selects an improper course of action or takes no action when one is required to avoid a crash. This includes misjudgment, false assumption, improper maneuver or driving technique, inadequate defensive driving, excessive speed, tailgating, and inadequate use of lighting or signaling. Decision errors were a definite or probable causal factor in 52 percent of the Tri-Level crashes. Performance errors are those in which drivers properly comprehend crash threats and select appropriate actions, but simply err in executing these actions. They include overcompensation such as over-steering or braking, panic or freezing, and inadequate directional control. Performance errors are less common than recognition or decision errors; they were apparent in 11 percent of the Tri-Level crashes.

NADS research will be used to better understand the effects of vehicle design characteristics on human driving performance. Crashes and other driving errors are the major human performance measures of interest. Research relating vehicle designs to driving performance takes into account both intrinsic driver characteristics and extrinsic factors that influence driving behavior. The intrinsic factors (driver characteristics) include age (as an inferential indicator of risk-taking tendencies and experience); skill/training (amount, type, quality and currency); physical attributes (visual capabilities, hearing, etc.); physical condition (sick, fatigued, drunk, etc.); psychological condition (personality/attitude, life situation/stability, financial solvency, job satisfaction/security, etc.); and perceptual and information processing capabilities. The extrinsic factors include driver licensing; traffic law enforcement; driver supervision and qualifications (applicable primarily to commercial fleets); vehicle design; and roadway/environment. Deficiencies and/or limitations associated with any of these underlying factors could be a significant contributing factor in any given crash. The use of the NADS in this program will ensure that there is no imminent threat of danger to the driver while performing the human factors studies. Full scale vehicle testing could present potential dangers of a collision to a subject driver.

Example Project:

Intersection accidents are the result of the driver misunderstanding what is required at a complex intersection. This can result in inappropriate turning maneuvers by the driver by not allowing adequate time for approaching vehicles to clear the intersection. Inattention by the driver can result in vehicles striking pedestrians at intersections. The research with the NADS would study the variables associated with turning movements which result in multi-vehicle and pedestrian collisions. The two major variables to be studied would be determining how the intersection complexity relates to the problem and how the driver's situational awareness affects his ability to safely complete turning movements. The NADS would be used to study driver behavior when exposed to various levels of intersection complexity, including uncontrolled residential, stop sign controlled residential and business, signal controlled business and complex intersections. This research would provide information about developing driver countermeasures for these accidents and about the intersection design weaknesses. This category has the potential for large reductions if countermeasures can be identified.

ELDERLY DRIVERS

The safety of older drivers is expected to become an even greater public concern in the coming years as older adults become a larger portion of the U.S. driving population. Currently, about 12 percent of the U.S. population is 65 years or older. By the year 2020, this percentage will increase to 17 percent. Moreover, a greater percentage of the older adults will be drivers, and mobility will be one of their principal concerns. Maximizing the driving safety of this group will likely be viewed by the public as a priority goal of traffic safety research. Older adult drivers have crash rates that begin to increase at about age 60 and rise very sharply and progressively beyond age 75. In particular, older drivers show increased rates of involvement in intersection crashes. They may fail to see oncoming vehicles and/or to correctly process information and make decisions regarding oncoming vehicles and the time/distance available for intersection-crossing. Age-related decrements in visual accommodation and in night vision are also of concern, but are potentially addressable through vehicle design enhancements such as head-up displays and infrared vision systems.

The NADS research program will develop data about the functional limitations of older drivers and how these limitations affect the driving ability of these drivers. It is well known that older drivers have diminished visual capabilities in daylight, dark and dusk conditions and decreased sight distance and closing speed estimation abilities. These limitations affect the driving performance of the older driver. Although research data exists which shows where and when the older driver operates an automobile, no detailed information exists that show how they operate an automobile. Some drivers who have age-related diseases (e.g., dementia, stroke, medication dependent, and arthritis) appear to experience significant declines in functional ability which impact directly upon their ability to safely and efficiently operate an automobile. Little is known about the relationship between functional limitations associated with common age-related and medication related diseases and driving performance.

Example Project:

NADS research would involve conducting simulator experiments with elderly drivers operating vehicles under various levels of demand or stress, i.e., heavy traffic, poor visibility, unfamiliar road network, etc. The objective of this research will be to determine and classify the limitations of older drivers in the physical and mental performance of the driving task. If feasible, this information will be used to improve vehicle and highway design to enhance the mobility of older drivers. This research will also form the basis for developing performance based assessment techniques and guidelines for use by medical advisory boards, and motor vehicle administrators in driver licensing renewal decisions.

ALCOHOL/DRUGS RESEARCH

Although there has been significant improvement in the alcohol-related crash problem in recent years, a great deal remains to be done since well over 20,000 people still die in alcohol-related crashes each year. There is also little known about the contribution of prescription drugs such as tranquilizers, sedatives, stimulants, etc., to the highway safety problem. This is due to the difficulty in safely conducting research in this area. However, a sizable percentage of fatally and seriously injured drivers have been found to have prescription drugs, or combinations of prescription drugs and alcohol in their systems. The presence of a drug does not necessarily mean it is a causal factor. Fundamental research is required to determine the precise nature and extent of drug dosage levels that are hazardous. The range of blood alcohol and prescription drug concentration levels will be examined to determine their effect on driver competence in various driving scenarios. The use of the NADS in this program will ensure that there is no imminent threat of danger to the driver while performing under the influence of alcohol or prescription drugs. Full scale vehicle testing would present an unacceptable risk of physical harm to subject drivers.

Example Project:

The NADS will be used to conduct research to investigate the influence of prescription drugs and dosage levels on the critical aspects of driver performance. The subject test drivers will be dosed with specific prescription drugs that may adversely impact their capability to perform the driving task. They will then be exposed on the NADS to situations that place various levels of demand on their driving skills. The road course will involve a number of standardized driving scenarios which either require a normal response or an emergency response. A similar number of undosed drivers will drive the same simulated road course to serve as a control group. The studies will assess what driving skills become degraded with specific prescription drugs and dosage levels and identify the skills that become sufficiently degraded.

HEAVY VEHICLE RESEARCH

Commercial truck drivers have a work-related accident fatality rate that is more than twice the national average for all occupations. Driver fatigue is an important human factors issue relevant to this group, as is the concern over driver information overload associated with multiple in-vehicle displays such as navigation systems, trip recorders, and collision-avoidance warning systems.

NADS research will be used to better understand the effects of heavy vehicle design characteristics on human driving performance. Crashes and other driving errors are the major human performance measures of interest. Research relating vehicle designs to driving performance must take into account both intrinsic driver characteristics and extrinsic factors that influence driving behavior. The intrinsic factors (driver characteristics) include age (as an inferential indicator of risk-taking tendencies and experience); skill/training (amount, type, quality and currency); physical attributes (visual capabilities, hearing, etc.); physical condition (sick, fatigued, drunk, etc.); psychological condition (personality/attitude, life situation/stability, financial solvency, job satisfaction/security, etc.); and perceptual and information processing capabilities. The extrinsic factors include driver licensing; traffic law enforcement; driver supervision and qualifications (applicable primarily to commercial fleets); vehicle design; and roadway/environment. Deficiencies and/or limitations associated with any of these underlying factors could be a significant contributing factor in any given crash.

Example Project:

Driver fatigue has been identified as a major factor in commercial truck accidents. The NADS research would identify the major physiological and mental areas of driver impairment associated with a sustained driving schedule as opposed to an intermittent or on and off schedule. The relationship between driving schedules and heavy truck accident modes will also be studied in the simulator. The purpose of the research will be to compare the regulation hours service with the other driving group for a measure of fatigue. The results are expected to provide data on the effects of maintaining a normal driving schedule.

1. Tri-Level Study of the Causes of Traffic Accidents, Institute for Research in Public Safety, Indiana University, Bloomington, IN

US Department of Transportation
Federal Highway Administration

Office of the Administrator

400 Seventh St. S W
Washington D C 20590

March 12, 1992
Refer to: HSR-30

Mr. Ronald E. Wood
Assistant Director, Resources, Community,
  and Economic Development Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Wood:

Your letter of January 6 requested a summary of the ways the planned National Advanced Driving Simulator (NADS) will benefit Federal Highway Administration research and other programs.

The Federal Highway Administration foresees a number of NADS applications that would facilitate certain research programs and engineering tests and evaluations. Because of our desire to make cost-effective use of this important resource, the specific work to be undertaken must be chosen with some care. Consequently, we plan to limit NADS utilization to areas where a high cost-benefit exists, where significant acceleration of program objectives would be realized, and/or where the work could not be safely conducted in the field.

An expanded discussion of planned usage is provided in the enclosure.

If you require additional information, please do not hesitate to call Dr. Samuel Tignor at 703-285-2033, or Mr. King Roberts at 703-285-2008.

Sincerely yours,

T. D. Larson
Administrator

Enclosure

BENEFITS OF NADS TO FHWA

The planned National Advanced Driving Simulator (NADS) is a very advanced simulator with capabilities to simulate a broad range of situations at levels of realism never before achieved for transportation research. Its primary benefit is that driving situations that involve unacceptably high risks to drivers can be safely investigated in the NADS. For situations where risks are acceptable, the NADS offers a very high degree of experimental control that cannot be achieved in field tests. Also, in most cases, use of the NADS allows research to be carried to conclusion in a shorter time and generally at lower costs than equivalent field testing. Given these facts, the FHWA foresees potential uses for the NADS both in research and in engineering test-and-evaluation.

The exact cost savings accruing from NADS utilization are difficult to quantify on a study-by-study basis. The FHWA has operated a much less sophisticated simulator, the DOT/FHWA Highway Driving Simulator (HYSIM), since 1983. It has been our experience that, on average, HYSIM studies can be conducted for approximately one-twentieth of the cost of equivalent field tests. The HYSIM, excluding capital procurement, costs approximately $100 per hour to operate. The projected NADS operating cost is $1,000 per hour. This indicates that the costs to conduct studies on the NADS may be about half as much as doing the research in the field. However, NADS studies, relative to field studies, can be set up and conducted quickly; study schedules can be significantly accelerated and additional cost savings may result. Further, the NADS will have a very high level of realism; the performance of drivers in the NADS should adequately represent the performance of real-world drivers in similar driving situations. Consequently, the data from the NADS should be very similar to data from actual field testing and should require very minimal, if any, verification under real-world driving conditions.

Because of its operating costs, the FHWA plans to utilize the NADS for (1) research that cannot be safely conducted by other means, (2) work that would significantly accelerate certain national FHWA programs, or (3) engineering evaluations with very favorable cost-benefit ratios. The following planned uses of the NADS are delineated within these constraints.

- **Conduct of research involving unacceptably high levels of risk to participants**

The FHWA has a long-range program to identify the capabilities, limitations, and problems of older drivers and to identify and evaluate countermeasures for identified safety concerns. The NADS will provide a safe test bed for problem identification and evaluation of remedial countermeasures.

As a part of Congressionally-directed Intelligent Vehicle Highway Systems (IVHS) design and development, the FHWA is investigating certain human factors issues associated with fully automated highway systems. Of primary concern, for example, are (1) issues of how drivers should safely make the transition to and from manual and fully automated vehicle control; (2) early identification of those functions that cannot be fully automated, but rather must remain under human oversight; and (3) development and evaluation of effective procedures to be utilized in emergency situations occurring under automated control. NADS simulations will be used to simulate the automated highway environment and to study human performance in that environment.

The FHWA also has the responsibility to regulate certain aspects of motor carriers. Among these is the responsibility to regulate the number of continuous hours commercial drivers may work. The content of these regulations is primarily based on results from the study of commercial driver fatigue, attention, and other associated factors affecting the safety of commercial drivers' performance. The NADS can be utilized to study unique motor carrier regulatory issues in a safe, realistic, and highly controlled environment.

- **Acceleration of certain national programs**

The FHWA is responsible for IVHS human factors research that will provide guidance to those responsible for IVHS engineering design. Human factors responsibilities include identification, optimization, and integration of equipment functions, user tasks and workload evaluations, information integration, and other human centered aspects of human/machine interactions within IVHS Advanced Traffic Information Systems and Commercial Vehicle Operations that are necessary to optimize system performance. A great deal of the work can be effectively accomplished on the NADS in a shorter time frame, and with greater safety, than comparable field testing.

- **Engineering evaluations with high cost-benefit**

The FHWA foresees application of the NADS to test and evaluate, *a priori*, the geometric and signing aspects of highway designs. Because design errors are so expensive to correct after construction is completed, it is anticipated that this NADS application would have a very high cost-benefit ratio.

To utilize the NADS in this manner, a faithful simulation of highway design geometry would first be developed and a representative sample of the driving population would then repeatedly "drive" the simulated highway. Any safety problems attributable to highway geometry would be identified and corrected. Thus, through iterative testing, the highway geometry would be optimized. Subsequently, the number, location, type, and placement of traffic control devices (signs, signals, and markings) would be simulated. Through further iterative testing, traffic control devices would be optimized. Culmination of this work would provide fully optimized designs, in terms of safe geometry and effective traffic control device applications, prior to the start of construction, or as a remedial measure for problem roadway sections.

IDS', DBDS', and NADS' Capabilities Compared

Attribute	IDS	DBDS	NADS
Capabilities of the Motion System			
Provides realistic motion cues to simulate turning a corner	No	No	Yes
Provides realistic motion cues to simulate changing lanes	No	Yes	Yes
Provides realistic motion cues to simulate braking to slow down or stop	No	No	Yes
Provides realistic motion cues to simulate operating on laterally sloped roads	No	Yes	Yes
Provides realistic motion cues to simulate sustained acceleration	No	Yes	Yes
Provides realistic motion cues to simulate emergency braking from speeds exceeding 30 miles per hour (sustained deceleration)	No	Yes	Yes
Provides realistic motion cues to simulate changing lanes at speeds exceeding 30 miles per hour	No	Yes	Yes
Provides realistic motion cues to simulate severe and sustained cornering (e.g., entrance and exit ramps on freeways) at speeds exceeding 15 miles per hour	No	[a]	Yes
Provides realistic motion cues to simulate negotiating hills and undulations in the roadway at speeds exceeding 30 miles per hour	No	Yes	Yes
Provides realistic motion cues to simulate accidents involving the following spins			
0 to 90 degrees	No	No	Yes
91 to 180 degrees	No	No	Yes
181 to 270 degrees	No	No	Yes
271 to 360 degrees	No	No	Yes
Greater than 360 degrees	No	No	Yes
Provides realistic motion cues to simulate accidents involving jack- knifing	No	No	Yes
Provides realistic motion cues to simulate collision avoidance maneuvers at speeds exceeding 30 miles per hour	No	Yes	Yes
Provides realistic motion cues to simulate skidding maneuvers	No	Yes	Yes
Provides realistic motion cues to simulate wind gusts	No	Yes	Yes
Provides realistic motion cues to simulate icy and wet road surfaces	No	Yes	Yes
Provides realistic motion cues to simulate the effects of air pressure changes resulting from a large truck passing other vehicles (large truck bow wave buffeting)	No	Yes	Yes
Provides high-frequency motion cues to simulate			
Wheel-hop	No	No	Yes
Rough road surfaces	No	No	Yes
Running over potholes	No	No	Yes
Running over railroad crossings	No	No	Yes

(continued)

Attribute	IDS	DBDS	NADS
Running over road joints	No	No	Yes
Running over curbs	No	No	Yes
Running over road edges	No	No	Yes
Sense of vehicle speed	No	No	Yes
Running over different road surfaces (concrete, asphalt, gravel, dirt, etc.)	No	No	Yes
Other—soft, off-road surfaces (loose dirt, sand, etc.)	[a]	[a]	Yes
Capabilities of the Computer Image Generator (CIG) System			
Frontal visual driving scene			
Field of view			
Horizontal	150 degrees	180 degrees	180-220 degrees
Vertical	30 degrees	30 degrees	40 degrees
Number of CIG channels used to generate the frontal visual driving scene	3	6	5-6
Number of polygons that each frontal visual CIG channel can process per second	60,000	37,500	600,000
Operational left-side rear-view mirror	No	Yes[b]	Yes
Field of view			
Horizontal		[a]	20 degrees
Vertical		[a]	15 degrees
Number of polygons that can be processed per second		37,500	600,000
Operational right-side rear-view mirror	No	Yes[b]	Yes
Field of view			
Horizontal		[a]	20 degrees
Vertical		[a]	15 degrees
Number of polygons that can be processed per second		37,500	600,000
Operational center rear-view mirror	Yes	No	Yes
Field of view			
Horizontal	20 degrees		35 degrees
Vertical	20 degrees		15 degrees
Number of polygons that can be processed per second	60,000		600,000
Provides full-color driving scenes	Yes	Yes	Yes
Provides three-dimensional driving scenes	Yes	Yes	Yes
Provides true-perspective driving scenes	Yes	Yes	Yes
Provides realistically shaded driving scenes	Yes	No	Yes
Provides photo-based textured driving scenes	Yes	No	Yes
Provides smooth motion for simulating moving objects in the visual scene (i.e., there are no abrupt changes in the relative positioning of scene content)	Yes	Yes	Yes

(continued)

Attribute	IDS	DBDS	NADS
The transport delay between a driver's action (steering, accelerating, decelerating, etc.) and the visual system response	100 milliseconds	80-100 milliseconds	Less than 50 milliseconds
The number of moving objects (cars, trucks, motorcycles, pedestrians, etc.) can be simulated (displayed) at the same time	14	6	About 4,000
The number of moving objects (vehicles, pedestrians, etc.) that can be tracked to detect collisions with other objects at a 60-Hz update rate	14	[a]	About 4,000
Has the capability to simulate			
Sequential turn signals	Yes	Yes	Yes
Traffic lights	Yes	Yes	Yes
Windshield wipers	No	Yes	Yes
Oil spots on the pavement	Yes	Yes	Yes
Fixed-geometry shadows	Yes	Yes	Yes
Chain-link fences	Yes		Yes
Transparent windows allowing the viewing of other vehicles' interiors	Yes	Yes	Yes
Lighted windows	Yes	Yes	Yes
Pools of light on the ground	Yes	Yes	Yes
Tail lights	Yes	Yes	Yes
Other—head-light beam patters	[a]	[a]	Yes
Moving objects completely occult background objects that they pass	Yes	Yes	Yes
Has the capability to simulate special environmental effects			
Variable illumination from day to dusk to night	Yes	Yes	Yes
Ground fog	Yes	Yes	Yes
Haze	Yes	Yes	Yes
Patchy fog	No	Yes	Yes
Wet roadways	No	No	Yes
Snow and ice covered roadways	Yes	Yes	Yes
Glare	No	No	[c]
Lightning	Yes	Yes	Yes
Self-luminous surfaces (roadway reflectors)	Yes	Yes	Yes
Flashing and strobing point light sources (traffic signals, emergency vehicles, etc.)	Yes	Yes	Yes
Smoke	Yes	No	Yes
Horizon glow	Yes	No	Yes
Clouds	Yes	Yes	Yes
Other—various road surfaces	[a]	[a]	Yes
Provides a range of ambient visibility			
From	0 meters	0 meters	0 meters
To	Infinite meters	Infinite meters	Infinite meters

(continued)

Attribute	IDS	DBDS	NADS
Capabilities of the Vehicle Cab and Driving Environment			
Utilizes an actual production vehicle cab(s) with all interior controls, instruments, seats, windows, etc., exactly as they are on an actual production vehicle	Yes	Yes	Yes
Allows use of interchangeable vehicle cabs	Yes	Yes	Yes
Passenger cars	Yes	Yes	Yes
Light trucks and vans	Yes	Yes	Yes
Heavy trucks	Yes	Yes	Yes
Tractor trailer cabs	Yes	Yes	Yes
Buses	No	Yes	Yes
Wheeled military vehicles	Yes	No	Yes
Provides the following fully functional vehicle instruments and indicators in the cab			
Speedometer	Yes	Yes	Yes
Odometer	No	Yes	Yes
Engine tachometer	Yes	Yes	Yes
Ammeter	No	Yes	Yes
Oil pressure gauge	No	Yes	Yes
Fuel gauge	Yes	Yes	Yes
Engine temperature gauge	Yes	Yes	Yes
Engine warning lights	Yes	Yes	Yes
Brake failure light	Yes	Yes	Yes
Seat belt alarm	Yes	Yes	Yes
Open-door alarms	Yes	Yes	Yes
Key-in-lock alarms	No	Yes	Yes
Provides the following fully functional vehicle lights and electrical controls			
Ignition switch	No	Yes	Yes
Turn signals	Yes	Yes	Yes
Electrical seat adjustment	Yes	Yes	Yes
Mirror adjustment	Yes	Yes	Yes
Courtesy lights	Yes	Yes	Yes
Running lights and headlights	No	Yes	Yes
Windshield wipers	No	Yes	Yes
Power door locks	Yes	Yes	Yes
Entertainment system	Yes	Yes	Yes
Other—IVHS technology			Yes
Has the capability to simulate hot and cold environments	No	No	Yes
Capabilities of the Vehicle Dynamics			
Number of parallel processors in computer system.	26	1	

(continued)

Attribute	IDS	DBDS	NADS
Capable of realistically simulating the dynamics of the following vehicle systems that are unique to the mounted production model			
Suspension	Yes	Yes	Yes
Chassis	Yes	Yes	Yes
Bushings	No	[a]	Yes
Brakes	Yes	Yes	Yes
Tires	Yes	Yes	Yes
Two-wheel steering	Yes	Yes	Yes
Four-wheel steering	Yes	Yes	Yes
Rear-wheel-drive power train	Yes	Yes	Yes
Front-wheel-drive power train	Yes	Yes	Yes
Four-wheel-drive power train	Yes	Yes	Yes
Capable of simulating collectively, in real time, all vehicle dynamics for the systems listed above	Yes	Yes	Yes
Capable of simulating the flexibility of materials used in the components of the systems listed above	No	Yes	Yes
Capabilities of the Control Loading System			
Provides realistic touch cues (tactile feedback) to the driver through the			
Steering wheel	Yes	Yes	Yes
Brake pedal	Yes	Yes	Yes
Clutch pedal	No	Yes	Yes
Accelerator pedal	Yes	Yes	Yes
Manual or automatic transmission shift lever	Yes	Yes	Yes
Capabilities of the Audio System			
Provides auditory cues to simulate			
Continuous/cyclical/repetitive sounds, such as sounds emanating from the engine, drive train, tires, wind, and different types of pavement	Yes	Yes[d]	Yes
Discrete audio events, such as sounds emanating from passing traffic, a tire hitting a pothole, crossing railroad tracks, and crossing expansion joints in the roadway surface	No	No	Yes
Output speakers emulate accurately the location and direction of sounds	Yes	Yes	Yes

(Table notes on next page)

[a]Did not answer.

[b]DBDS provides either an operational left-side or right-side rear-view mirror, but not both.

[c]The capability of NADS' CIG to reproduce glare would not be identical to glare experienced in the real world. For instance, the glare produced by NADS' CIG would not be strong enough to fatigue the driver.

[d]Cannot simulate sounds of different pavement types.

Source: Responses to GAO-developed checklist.

Extent to Which TRB's Research Areas Could Be Addressed With IDS, DBDS, and NADS

	Portion of experiments addressed		
Research area	**IDS**	**DBDS**	**NADS**
Driver related			
Braking and steering behavior and motion perception	Few	Few	All
Risk perception and decision-making	Few	Some	All
Work load	Some	Some	All
Hazard perception	Some	Some	All
Effects of stressors	None	None	All
Driving characteristics of classified groups	Few	Few	All
Social interactions	Some	All	All
Multiple driver situations	Few	Some	All
Driver performance measures	None	Some	Almost all
Develop and validate a theory of driving	None	None	Almost all
Prescreen elderly (and other potentially unsafe) drivers	None	Some	All
Prescreen personnel	None	Some	All
Vehicle operator licensing tests	None	None	All
Vehicle operator certification tests	None	None	All
"Fit-to-drive" tests/certification	None	None	All
Portable drug/alcohol intoxication test	Some	Some	All
Emergency vehicle	None	None	All
Law enforcement	None	None	All
Rehabilitation driver training program	None	Almost all	All
Special driver training programs	None	Almost all	All
Skill transfer—vehicle to vehicle	Few	Almost all	All
Vehicle related			
Directional control system design	Few	Some	All
Directional control device development	Few	Some	All
Unexpected changes in vehicle dynamic behavior	Few	Some	All
Powertrain	None	None	All
Automated car following and braking	None	None	All
Heavy truck cab design	None	Some	All
Seat assessment	None	Some	All
Sound quality	Some	Some	All
Augmented vision systems and head-up displays	Some	All	All

(continued)

	Portion of experiments addressed		
Research area	**IDS**	**DBDS**	**NADS**
Navigation or route guidance devices	Some	All	All
Lighting and visibility	Some	Almost all	Almost all
Hazard-alerting devices	Few	Almost all	All
Secondary controls and convenience devices	Some	All	All
Display quantification	Some	All	All
Systems evaluation of interior layouts	Some	All	All
Environment related			
Signs, signals, and markings	Almost all	Almost all	Almost all
Horizontal and vertical curvature	Some	Some	All
Lane and shoulder width	Some	All	All
Median and barrier design	Some	All	All
Illumination	Some	Some	Almost all
Surrounding environment	Almost all	Almost all	All
Traffic interactions	Some	Some	All
Tunnels	Some	Some	Almost all
Preconstruction overall design review	Some	Some	All
Temporary traffic control devices	Almost all	Almost all	All
Conspicuity of impending personnel and vehicle movement	Some	Some	All
Effects of natural and built environments	Some	Some	All
Effects of weather	Some	Some	All
Underground highway systems	Some	Some	All
Other			
Simulator design studies for developing other simulators	Few	Few	Almost all
Skill transfer—simulator to vehicle	Few	Few	All
Simulator sickness	Almost all	Some	All
Accident reconstruction and analysis	Few	Some	All

Source: TRB Circular 388 (Feb. 1992) and knowledgeable simulation experts.

Comments From the Department of Transportation

U.S. Department of Transportation

Assistant Secretary for Administration

400 Seventh St. S.W. Washington, D.C. 20590

July 9, 1992

Mr. Kenneth M. Mead
Director, Transportation Issues
U. S. General Accounting Office
Washington, DC 20548

Dear Mr. Mead:

On June 23, 1992, the General Accounting Office (GAO) submitted a draft report to the Secretary of Transportation, Andrew H. Card, titled Motor Vehicle Safety: Key Issues Confronting the Development of the National Advanced Driving Simulator (GAO/RCED-92-195), for departmental review and comment. The GAO requested that the Department provide oral comments on the report within 10 working days so that GAO could meet the needs of the Congressional requestor. These were provided to GAO during our July 2, 1992, meeting. We are providing this follow-up to our meeting to communicate our concerns over the section of the report titled MATTERS FOR CONGRESSIONAL CONSIDERATION, page 17.

In this section of the report it is stated that, due to the uncertainties associated with the National Advanced Driving Simulator's (NADS) estimated cost, capability, and cost-sharing commitments, "Congress may wish to defer further funding for the NADS until after the design phase when these uncertainties should be answered." The Department of Transportation's (DOT) interpretation of this statement is that the GAO intends to recommend to the Congress that there be a cessation in NADS funding until after the design phase is complete and that, assuming these uncertainties have been resolved, the Department then may initiate a new budget request for funding the NADS fabrication phase. If this interpretation is correct, it will have an adverse effect on the NADS program.

As GAO recognized in its draft report, the NADS program offers extensive benefits for improving highway safety. Research in areas such as human factors, elderly drivers, and Intelligent Vehicle Highway Systems (IVHS) will benefit from NADS. In addition, NADS will permit safe investigations of driving situations that involve unacceptably high safety risks to human subjects. If the Congress decides to adopt GAO's recommendation to place a moratorium on NADS funding until after the design phase is completed, a delay of 12 to 18 months will occur. The consequence of this delay will be that important safety-related research and associated benefits in these critical areas could be delayed. The impact on IVHS technology development could be particularly serious, since the Department would not have the technology available to test these systems as thoroughly as would be possible with NADS, especially with regard to the critical interface between the technology and the driver.

As we have stated previously in response to questions from members of the Congress, the NADS fabrication contract will not be awarded unless $11 million of non-DOT funding can be secured. We maintain that a continuous funding stream is critical to our prospects for obtaining the required cost sharing from non-DOT sources. A funding interruption could be perceived by potential contributors as the Government's lack of commitment to the project. In this case, the Department would find itself in a difficult situation, since we are required to have the cost-sharing commitments in place before granting approval to proceed with the NADS fabrication phase. It also is possible that the existing cost-sharing commitment of $5.25 million from the University of Iowa could be jeopardized, since this commitment has a state-imposed expiration date of June 30, 1994. If the NADS fabrication phase has not commenced by that time, the Iowa State legislature may decide to withdraw its funding commitment to this project.

Another serious consequence of a NADS funding interruption is the chilling effect it could have on the simulator companies that have expressed interest in bidding on the NADS project. The Department's proposed acquisition strategy, currently awaiting Transportation Systems Acquisition Review Council (TSARC) approval, creates a powerful incentive for private investment and the development of an innovative and technically superior design, since each of the two design contractors would stand an equal chance of winning the multi-million dollar fabrication phase of the NADS development. If a discontinuity were created between the design and fabrication phases because of a funding interruption, the industry could likewise view this as a lack of Government commitment to the project. This uncertainty could result in reduced competition and an unwillingness on the part of contractors to devote the resources necessary to fully achieve the NADS objectives.

We wish to make it absolutely clear that our proposed approach to acquiring NADS will not and is not intended to lock the Government into a decision to proceed with the NADS fabrication phase at the conclusion of the design phase. Our

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acquisition plan requires NHTSA to secure final approval from the TSARC before proceeding with the NADS fabrication. This approval, together with the approvals of the Source Evaluation Board and the Source Selection Official constitute sufficient departmental control over the NADS acquisition to preclude going forward with the NADS fabrication until all of the risk elements of cost, performance, and cost-sharing commitments identified in the GAO report have been adequately addressed.

In view of the potentially serious, negative consequences of a disruption in NADS funding, the Department respectfully requests that the language cited on page one, paragraph two of this letter be withdrawn from the report. If you do not agree, then we request that this letter be incorporated into the final version of your report.

Sincerely,

for Jon H. Seymour

Major Contributors to This Report

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