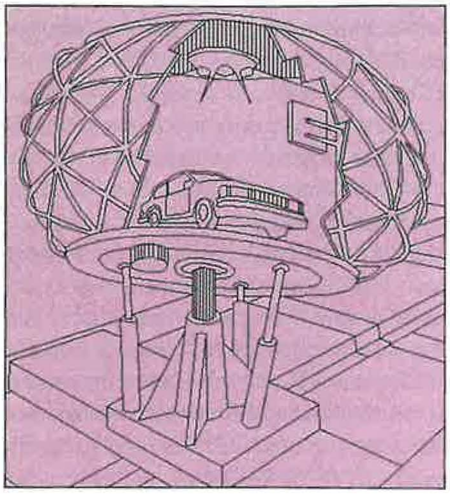

New Developments in Advanced Driving Simulators

WALTER DIEWALD

Early in 1995 at the request of Congress, the Transportation Research Board convened a study committee to examine the potential demand for the proposed National Advanced Driving Simulator (NADS). The committee recently produced a report on its findings entitled *Estimating Demand for the National Advanced Driving Simulator.* As part of the committee's information gathering, a subgroup of the committee traveled to Europe to examine operating advanced driving simulators in Germany and Sweden and to meet with the French development team to review plans for a new simulator similar to NADS. In Germany and Sweden the study team examined and operated the simulators, gathered technical information about them, and learned more about who currently uses them and for what purposes. The team also discovered more about the unique public/private collaboration to develop the French simulator and the underlying reasons for the project.

Driving simulators have been used for many years for a variety of purposes (see accompanying article for a brief history of driving simulator developments). The Federal Highway Administration has operated a highway driving simulator (HYSIM) at the Turner-Fairbank Highway Research Center since the early 1980s to conduct a variety of studies on driver performance (*1*). Several factors have spurred improvements in driving simulators in recent years (*2*). First, improved simulator and computer technologies available at lower costs have significantly expanded driving simulator capabilities compared with previous designs. Second, the emergence of advanced automotive technologies and the potential proliferation of in-vehicle communications and navigation systems associated with intelligent transportation systems underscore the need for safe and inexpensive ways to test these systems to ensure they meet safety and regulatory requirements. Finally, the decline in military spending and coinciding rise in defense conversion activities have caused defense contractors to aggressively pursue automotive applications, further stimulating interest.

Driving simulators range in complexity. Low-end, part-task simulators use a personal computer or graphics workstation, a monitor, and a simple cab and controls. A highly sophisticated driving simulator includes a vehicle or portions of a vehicle with a motion base capable of 6 degrees of freedom. Advanced driving simulators, in addition to requiring the mechanical equipment that forms the motion base and enables the movement, also require computer-generated image systems that react to the subject's control commands. These advanced simulators are operated by numerous specialized computer programs.

Several recent articles describe the expanding role of driving simulators for research and training and provide detailed descriptions of low-cost and mid-level driving simulators that address part of the driving task (*3,4*). Rapid developments in microcomputer technology have provided the base for more applications and experimentation. In 1992 a subcommittee of the TRB Committee on Simulation and Measurement of Vehicle and Operator Performance reported that vehicle simulator technology could "be applied to motor vehicle travel in such a way that will reduce the accident rate, dramatically improve quality, and/or reduce cost" (*5*) and described potential uses for all levels of driving simulators. Specific uses include human factors research; development and evaluation of training, screening, certification, and licensing systems; and highway and automobile design and design evaluation.

NADS is planned to be the most sophisticated driving simulator in the world. Its motion base is designed to accommodate large movements in both the x and y axes, a feat no other simulator has yet accomplished. It will also have a high-frequency motion system capable of simulating certain aspects of road roughness. NADS will have a visual system with a 360-degree field of view.

Walter Diewald is Senior Program Officer, Transportation Research Board.

Advanced Driving Simulator Technologies

Advanced driving simulators have the highest-fidelity visual and motion systems. The visual systems have at least a 180-degree front field of view and some rear field of view, high resolution, texturing, and highly detailed scenery. An advanced driving simulator has a motion base capable of large longitudinal and lateral motion (or distance greater than 2 meters), with a high-frequency motion system for simulating road bumps, vibrations, and variations in road surfaces. It includes a complete vehicle dynamics model consisting of components for longitudinal and lateral directional handling, drive train (engine and transmission), and suspension characteristics appropriate for assessing vehicle ride and handling quality. Alternative cab configurations should be available along with control loading (steering wheel, brake pedal, accelerator, and switch feel), an audio system (noises associated with the engine, roadway, warnings, wind, and traffic), ventilation, nonintrusive monitoring instruments, and a complete suite of research instrumentation.

Because driving simulators share visual system technologies with simulators for aircraft, ships, and space vehicles, they have benefitted from technological advances resulting from demands for improvements to all of these devices. However, developments in large-excursion motion bases have been slow because they are needed only for driving simulators and the demand for them is lacking. This type of motion base is considered essential for several reasons. Vigorous braking, acceleration, or cornering maneuvers produce significant translational accelerations or forces that are applied to the vehicle and driver for one to five seconds or more. A hexapod motion base simulates this type of maneuver by providing a momentary onset cue followed immediately by a rotation or tilt that approximates the desired direction of acceleration. The hexapod uses washout acceleration (acceleration designed to be below perceptible levels and in an opposite direction) to return the simulator cab to a neutral position. When vehicle maneuvers are too vigorous, however, even a hexapod motion base cannot provide appropriate cues to the driver and some drivers will experience simulator sickness that invalidates portions of the research activity.

Although the range of research activity is constrained by the physical limitations of the motion base and most research can be performed satisfactorily on simulators without the range of motion that NADS will provide, researchers have yet to reach consensus on whether motion capability is needed and the types of driving behavior and vehicle maneuvers that would benefit. Simulator developers believe that a motion base capable of large accelerations in two horizontal axes, for example +/- 15 meters lateral and +/- 5 meters longitudinal, will expand the limits of the driving simulators and their research capability and greatly reduce simulator sickness; this is yet to be proven in practice.

European Advanced Driving Simulators

Two of the best-known advanced driving simulators in the world are in Europe. The Swedish Road and Transport Research Institute (VTI) built a simulator with a lateral motion base with 4 degrees of freedom in 1984. In 1985 Daimler-Benz introduced its driving simulator with a large hexapod motion base featuring 6 degrees of freedom. Toyota and Mazda in Japan have each developed advanced driving simulators; although reports indicate that there might be others under development, detailed information about Japanese driving simulators is scarce (4). Table 1 summarizes what the study group learned about the European advanced driving simulators.

In the mid-1980s a French consortium consisting of INRETS (the French national transport and safety research institute), Renault, and Peugeot began developing an advanced driving simulator with the goal of having an operational facility by 1997. The simulator, known as SARA (Simulateur Avance d'Etudes et de Recherche Automobile) is planned to be a large-excursion motion base driving simulator nearly equivalent to NADS.

The Daimler-Benz driving simulator was completed in 1985. Its hexapod motion base supports a full-size automobile and consists of several pistons that enable roll, pitch, and yaw movement; the hexapod is similar to those used for aircraft simulators. Daimler-Benz recently upgraded its simulator with the addition of improved visual and computer systems and a rail assembly that enables lateral motion of +/- 5.6 meters. The visual system has a 180-degree field of view. The simulator does not have high-frequency motion to simulate road bumps, vibrations, and variations in road surfaces, and the audio system is of low quality.

Daimler-Benz engineers use the simulator primarily for vehicle dynamics studies and for research on the driver-vehicle interface. In a recent study Daimler-Benz engineers were concerned with how the vehicle and the driver would react when sensors in the antilock braking system failed independently or in combination. The results gave them insights into how to develop redundant sensor systems and what failure warning systems are needed. They then tested several alternative designs in vehicles on a test track before making manufacturing changes.

The Daimler-Benz simulator is located in Berlin, partly because of a formerly West German economic development program aimed at stimulating private investment in West Berlin. The main Daimler-Benz design and manufacturing facilities are several hundred miles away in Stuttgart. Total development cost for the simulator to date is about $30 million.

The VTI simulator was completed in 1984, having been designed and developed by a group of VTI engineers and researchers. The motion base provides roll, pitch, heave, and lateral motion of +/- 3 meters, and rests on a vibration table. The motion base is partially reminiscent of a design used for a Volkswagen driving simulator built in the early 1970s. The simulator cab consists of a car body cut off behind the driver's seat. The visual system provides a 120-degree lateral view and a 30-degree vertical view.

VTI is a government organization that performs road safety research for the government and under contract. The users of the simulator are primarily VTI staff, although several projects have been conducted by others with VTI staff operating the simulator. The VTI simulator has been used to study driver behavior related to items such as mobile telephones and an intelligent gas pedal, evaluate vision enhancement devices, test hand controls for disabled drivers, and examine the behavioral effects of fatigue, task demands, alcohol and other drugs, sleep apnea, and visual field defects in drivers. VTI researchers are currently assisting the designers of an extensive tunnel beltway project in Stockholm by simulating alternative road designs to assess the effects of tunnel and roadway design features on driving. Although the design project is not yet completed, the road designers have found the simulator helpful in examining and testing a large number of alternative designs in a short time.

Much less is known about the technical characteristics of the French SARA simulator because it is still under development. Having recently completed feasibility and preliminary design studies, the consortium members are now validating their technical choices. The potential users are directly involved with all stages of planning and development, which ensures that the simulator will be designed for maximum use by the partners. Plans include a 180-degree by 30- to 40-degree visual system, a vehicle dynamics system with interchangeable modules, fully interchangeable cabs, and a large-excursion motion base. The system development contractor for SARA is currently testing a hydraulic system for the motion base; the prototype has an excursion of 15 meters.

The SARA engineers are developing the simulator as a research tool for improving road safety and as an engineering tool for vehicle design and development. The needs analysis for SARA identified several types of investigations that the simulator is being designed to address vehicle and component design, specification, and functional prototyping; ergonomic studies related to vehicle design; failure consequence analysis for vehicle subsystems and combinations of subsystems; performance and comfort of alternative design configurations; and studies of driver performance regarding information needs, decision making, and driver judgment. Francois Hordonneau, head of the Vehicle and Product Department of Renault's Research Division, told the study group that development of the SARA simulator is needed to meet the French automobile industry's future needs but that it is difficult at this time to measure the return on simulator investment. He considers his company's current interest in simulator development analogous to past commitments to develop Renault's computer-aided design and manufacturing capabilities. Such developments involve considerable organizational and cultural changes and the benefits are difficult to quantify at this time but he believes that the greater risk is to fail to make the investment.

TABLE 1 Summary Information About European Advanced Driving Simulators

	FRANCE	SWEDEN	GERMANY
Organization	A government-industry partnership composed of INRETS, Renault, and Peugeot; development team has 10 people assigned full time	Developed by a team of 5 engineers at VTI, a government agency that performs road safety research	A division of Daimler-Benz, the simulator team consists of about 20 people
Development and operation costs	Development cost is projected to be at least $20 million, could reach $30 million; operating cost goal is about $2000 per hour, not including project preparation time and costs	Development cost was about $5 million (in hardware) and operating cost is about $3000 per day for the first week and $1500 per day for the second week of experiments, not including preparation time	Total development cost to date is about $30 million; operating cost is about $2800 per hour, not including preparation time
Users and uses	The three partners expect to use the available facility time for vehicle design and behavioral research; others could contract to use it if all three partners agree	Principally used by VTI researchers for behavioral research, studies of vehicle controls, and evaluation of highway design alternatives	Daimler-Benz is currently the sole user but it has had partners for cooperative projects in the past; research focuses on vehicle design and driver-vehicle interface
Limitations	(unknown - simulator is under development)	No longitudinal motion; primitive visual system	No high frequency motion; no longitudinal motion; poor sound system
Comments	Peugeot engineers have conducted tests on the Daimler-Benz facility; team believes that SARA is an investment in the future and return on investment cannot be measured yet	A second simulator was completed in 1991 and is used by an insurance company for research and training for truck drivers	Commitment to the simulator was exhibited by the recent $20 million upgrade; additional motion capability cannot be added without major change to the visual system

Advanced Driving Simulator Developments in the United States

Soon after the European tour the entire TRB study committee examined and operated the Iowa Driving Simulator (IDS) at the University of Iowa. Development of IDS began in 1990 as an outgrowth of research in real-time dynamic simulation. Located at the Center for Computer Aided Design (CCAD), IDS is an academic research device that has been modified and upgraded over time and is largely a hybrid. It started as a fixed-base simulator with a limited field of view. It now has a hexapod motion base that formerly served a B-52 aircraft simulator and is capable of 6 degrees of freedom. Its visual system has a 270-degree field of view and fully textured graphics.

IDS has been used to investigate human performance related to the vehicle and the roadway, study vehicle design, examine automated highway system human factors issues, and carry out vehicle prototyping. Specific studies have addressed human factors issues related to automated highway systems and rear-end collision avoidance systems; examined the effects of multifocal intraocular implants in cataract patients, particularly in low-visibility conditions; and developed a human-in-the-loop virtual prototyping system for an off-road vehicle that allowed engineers to test a wide range of design options in the driving simulator before they developed a vehicle prototype. IDS has also been used to study the effects of raised pavement markings on driver performance and perception.

NADS will also be located at the University of Iowa. In 1990 it was estimated to cost approximately $32 million. The National Highway Traffic Safety Administration expects to provide about $21 million toward its development; the state of Iowa will provide the remaining $11 million. NHTSA chose to site NADS at a university to create a production facility that could be used by public and private researchers and could be partially funded by other organizations. NHTSA will contract for the construction of NADS; user charges will cover the operating costs.

As the TRB committee completed its deliberations, federal funding for NADS was still in question. If funding is approved NHTSA plans to select a contractor for the system development phase in 1995. Development will be completed in 1998 and testing is planned for mid-1998. After NHTSA accepts the system, it will turn NADS over to the University of Iowa as federally owned property and the university will then be responsible for its operation, maintenance, and upgrades.

The TRB Study committee report, Estimating Demand for the National Advanced Driving Simulator, *is now available. Please see page 48 for ordering information.*

References

1. Alicandri, E. HYSIM: The Next Best Thing to Being on the Road. *Public Roads,* Winter 1994.
2. Hein, C.M. Driving Simulators: Six Years of Hands-on Experience at Hughes Aircraft Company. *Proc., Human Factors and Ergonomics Society 37th Annual Meeting,* 1994.
3. Allen, R.W., A.C. Stein, B.L. Aponso, T.J. Rosenthal, and J.R. Hogue. Low-Cost Part Task Driving Simulator Using Microcomputer Technology. In *Transportation Research Record 1270.* TRB, National Research Council, Washington, D.C., 1990.
4. Weir, D., and A. Clark. *A Survey of Mid-Level Driving Simulators.* Society of Automotive Engineers, Warrendale, Pa., 1995.
5. *Transportation Research Circular 388—Simulator Technology, Analysis of Applicability to Motor Vehicle Travel.* TRB, National Research Council, Washington, D.C., Feb. 1992.

Brief History of Driving Simulators

JERRY WACHTEL

The origins of driving simulation go back at least 85 years, when the first mechanical and electrical tests were developed to evaluate the skills and competence of public transit operators. The common thread uniting these early tests with today's sophisticated driving simulators is that they place the subject in an artificial environment believed to be a valid substitute for one or more aspects of the actual driving experience. The reasons for these systems have remained the same: to provide a safe environment for testing in which controlled, repeated measurements can be undertaken cost-effectively. Researchers and examiners hope that the measurements obtained through this substitute testing can help them predict equivalent measurements in the real world.

The earliest known studies of driving ability appeared in the second decade of this century. Munsterberg (*1,2*) placed various stimuli on a moving conveyor belt to test a subject's responses to them as they moved through his field of view. Stern (*2,3*) used a similar approach, placing letters on the conveyor belt. The subject pressed a key when certain letters appeared. Further refinements in the experimental procedure by Sachs (*2,4*) used patterns punched in the belt to represent pedestrians or other vehicles. Other stimuli were presented at the periphery of the visual field and the procedure was continued for an extended period in an attempt to induce fatigue. Driving ability was measured by the number of correct responses under these varying conditions.

In the late 1920s Weiss and Lauer (*5*) further modified the moving belt protocol, creating the forerunner to a type of driving simulator that continued in use through the 1970s, when it reached its zenith at the University of California, Los Angeles. The Weiss and Lauer apparatus used a conveyor belt on which were mounted scale model vehicles on a painted image of a roadway. The subject sat in front of a frame with a steering wheel and standard vehicle pedals. These studies concluded that the major causes of actions leading to accidents were nervousness, eye strain resulting from visual defects, inattention, and inexperience. The researchers also concluded that any one personal defect could be offset by other adjustments.

In the 1930s the engineering staff at the University of California at Berkeley developed a "reactometer" to measure

Jerry Wachtel is President of the Veridian Group.