tor 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.*

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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.

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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 drivers' reaction time. This effort was interrupted by World War II when attention shifted to the study of fighter pilots. Driving simulation at Berkeley resumed after the war with a device in which the subject sat behind the wheel and viewed filmed road scenes projected on a screen in front of an actual car body (*2,6*).

One type of simulator used in the 1950s was known as a "point light source" or "shadow-casting" simulator, which used a clear plexiglass disk approximately 4 feet in diameter. Road markings and scale models of roadside buildings, vehicles, and other objects and hazards could be placed on the surface of this disk. The test subject sat in a vehicle cabin mockup. The subject's actions on the accelerator and brake pedals controlled the disk's rotation speed; steering wheel inputs controlled the angular motion of the rotating disk. A "point light source" shone down through the clear disk projecting a real-time moving image on a rear projection screen in front of the driver. All objects, including vehicles, buildings, and road markings, appeared as dark silhouettes against the bright roadway surface. Although considerable research was conducted on these simulators over the years, reliability problems and a high incidence of simulator sickness limited the system's widespread application.

In the 1950s technology began to coalesce around the filmed approach to driving simulation. In addition to the system used at the University of California, Berkeley (and operated under a contract with the California Department of Motor Vehicles), facilities that used filmed images were operated at Ford, General Motors, the American Automobile Association, and the Aetna Insurance Company. These devices projected a filmed driver's-view image on a screen, accompanied by a sound track of road sounds. The subject sat in a car mockup or an actual vehicle cab; however, the subject's actions on the controls caused no change to the stimulus.

Continued development of this technology, which is still manufactured and used, took advantage of different approaches to give the systems a degree of interactivity so that the driver's actions on the simulator controls could have some influence on the road scene being observed. Developments have included the following:

- Controlling film playback speed based on the subject's actions on the simulator's accelerator and brake pedals.
- Making multiple runs through the driving route with the camera car (or using multiple camera cars simultaneously) so that multiple lanes of a highway can be filmed and the images projected over one another on the screen; the film is moved in the projection gate in response to the driver's input to the steering wheel to simulate lane change maneuvers.
- Filming multiple routes, including every turning possibility at every intersection, and transferring the film footage onto computer-driven laser videodisk instead of film or videotape. This technology, first available in the mid-1970s, enables the subject to make a route choice at each simulated intersection that had been previously recorded. A computer interface between the simulator and the videodisc player ensures that the subject sees the appropriate visual image in response to his or her control inputs.

Despite these developments, simulators using photographic imagery are inherently limited because the original film footage has recorded and fixed the behavior of other traffic. Thus the test subject cannot effect any change in the prerecorded scene, including traffic signals and other traffic, and cannot interact with that scene in any meaningful way. For a high degree of interactivity, a synthetic model of the roadway environment and its traffic is needed.

Two types of synthetic visual models have been developed: terrain models and computer-generated images. Terrain model technology, which reached its peak in the 1970s, uses miniature reproductions of the roadway, its environment, and other roadway users with an optical system and a mechanism for moving the optics through the model.

An elaborate system of tracks or a gantry is typically mounted near the ceiling of the room housing the model. Suspended from the gantry is an optical tube with a high-quality lens positioned just above the model's road surface. The entire optical system can be moved along the model's roadways under computer control on command of the experimenter and the resulting driver's-eye view filmed or videotaped for later playback. Sophisticated vehicle and operator actions can be simulated by pivoting the lens itself in any of three axes, and other objects in the scene can be moved with hidden wires or magnets. Varying the height of the lens above the board's terrain changes the apparent driver's eye height.

In the most sophisticated applications of this technology, subjects can drive through the model in real time by operating the controls (configured as a vehicle's steering wheel, brake, and accelerator) that maneuver the gantry-mounted camera over the terrain board. The technology has been limited by the space required for the model itself (which effectively limits the amount of terrain that can be simulated), by the costly process of creating objects appearing in the scene, and by the operational costs associated with the computer-controlled gantry system and the complexity of the lighting system necessary to create a realistic appearance. Nonetheless, this technology has been and continues to be successful in supporting a wide variety of research, training, and legal applications.

The second technology that creates a synthetic roadway environment is computer-generated imagery (CGI). In less than two decades CGI has become the method of choice for driving simulation. The accessibility of high-speed, low-cost computers and graphics processors, coupled with powerful image-rendering software, has opened the door to true, interactive driving simulation to anyone or any organization with a personal computer. Brewer (*7*) has reported on the progress made in the development of CGI-based simulation, from angular images lacking shading and detail, to shading and texture-mapped graphics creating more realistic images and smoother road markings, to photo-driven texturing providing excellent detail. Recent driving simulators have been demonstrated with convincing depictions of complex scenes such as the cityscapes of Melbourne, Australia, and San Francisco, California.

Although the previous discussion concentrated primarily on visual image

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