2010

National Advanced Driving Simulator Overview

National Advanced Driving Simulator

2401 Oakdale Blvd.

Iowa City, IA 52242-5003

319-335-4673

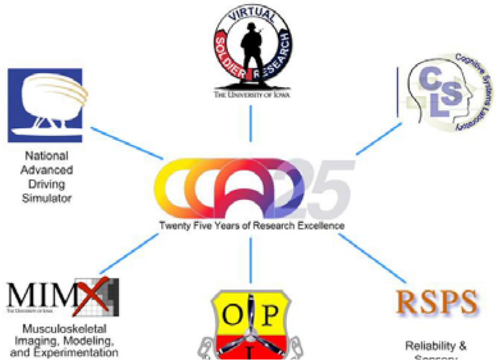
contacts@nads-sc.uiowa.edu

NADS facility at Oakdale Campus

The National Advanced Driving Simulator (NADS) is a center for driving simulation excellence located at the University of Iowa's Oakdale Research Park Campus. The NADS facility is home to a range of simulators that offer varying levels of driving realism. NADS employees are a collection of experts unmatched in their experience in working with all aspects of driving simulation.

Development and research conducted at the NADS – sponsored by government, military, and industry partners – saves lives, improves quality of life for motorists, advances the state of the art in driving simulation, and improves the efficiency and productivity of the vehicle manufacturing sector.

For over 25 years, researchers at The University of Iowa have continuously defined the state-of-the-art in simulation, vehicle dynamics modeling, and cognitive systems engineering. NADS continues this rich tradition by advancing multidisciplinary, collaborative simulation science and technology at the University and beyond.



CCAD family of research centers

NADS Organization

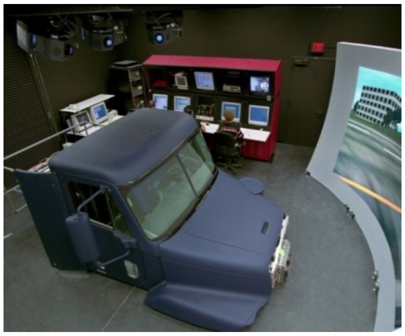
The NADS is an independent, self-funded research unit at The University of Iowa. External contracts and grants fund the approximately 30 full-time staff members, as well as graduate and undergraduate research assistants pursuing degrees at The University of Iowa.

The NADS organization is part of the Center for Computer Aided Design (CCAD), a multidisciplinary research center within the College of Engineering that specializes in conducting applied research in design, optimization, modeling and simulation of materials, structures, vehicles, and mechanical, cognitive, and biomechanical systems at The University of Iowa. NADS shares with CCAD and The University of Iowa a commitment to academic advancement, technological innovation, and the transfer of research results to industrial and governmental communities.

Driving Simulation at NADS

Simulation provides the ideal mechanism for exploring research that is infeasible, too costly, or unsafe in the real world, including assessing cognitive or physical ability, gaining understanding of driver performance and behavior, testing vehicle design in virtual proving grounds, and training drivers. The NADS offers driving simulators with a range of fidelities in order to best address the requirements for each project: NADS-1, the world's highest-fidelity simulator; NADS-2, a fixed-base simulator; and the NADS MiniSim™, a low-cost PC-based portable simulator.

NADS-1



NADS-2

MiniSim™

NADS-1

The NADS simulation center is best known for its high-fidelity ground vehicle driving simulator, NADS-1. This simulator is comprised of a 13 degree-of-freedom motion base with the largest motion envelope of any existing driving simulator. The motion system's unique capabilities set it apart from other simulators, thus enabling NADS-1 to accurately reproduce motion cues for sustained acceleration and braking maneuvers, movement across multiple lanes of traffic, and interaction with varying road surfaces. Realistic reproduction of these combined maneuvers is not possible in fixed-base or limited lateral movement simulators. Motion cues for NADS-1 are correlated with other sensory stimuli, providing the highest-fidelity real-time driving experience in a simulated environment.

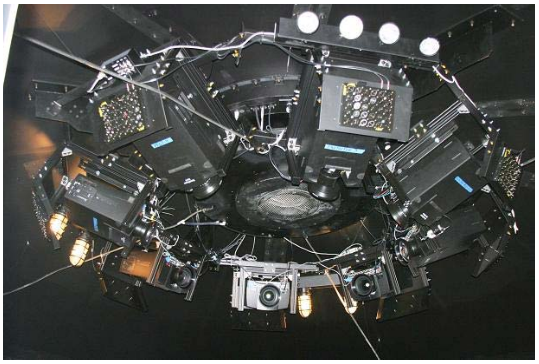
Malibu cab inside NADS-1 dome

Control Feel System

From the driver's standpoint, the simulator consists of an entire car, sport utility vehicle, or truck cab located inside a 24-foot dome. Each vehicle cab is equipped with full instrumentation specific to its make and model. Accelerator and brake pedals utilize software-controlled electrical motors to provide feedback, thus allowing unlimited flexibility in programming specific pedal feedback mechanisms. The steering wheel is similarly designed to allow customized steering response to each vehicle type. All dashboard indicators are operational, and the majority of control switches are instrumented. Multiple in-vehicle cameras provide customized views of the cab environment.

Motion System

Inside the dome, the cab is mounted to the floor through four hydraulic actuators that produce vibrations emulating road feel. The whole dome is mounted on a yaw ring that can rotate the dome about its vertical axis by 330 degrees in each direction. The yaw ring assembly is mounted on top of a traditional hydraulic hexapod, which in turn is mounted on two belt-driven beams that can move independently along the X and Y axes. The X-Y assembly produces lateral and longitudinal accelerations by moving about a 64-foot by 64-foot bay. The motion system is capable of providing high-fidelity acceleration cues by blending the hexapod-induced accelerations with the yaw ring and X-Y assembly accelerations.



Projectors in the NADS-1 dome

Visual System

The visual system consists of eight Liquid Crystal Display (LCD) projectors that project visual imagery inside of the dome. The driver is immersed in a 360-degree photo-realistic virtual environment. Higher resolution is used in the forward field-of-view to accommodate better feature recognition and reduce eye fatigue. All scenery is updated and displayed 60 times per second. NADS staff have developed a rich set of tiles that can be combined to create a wide variety of complex virtual environments, ranging from urban to rural landscapes. When necessary, additional tiles can be developed to meet project-specific requirements.

Audio System

The audio system provides sounds that emulate wind, tire, engine, and other vehicle noise, as well as special effects such as tire blowouts that are correlated with the dynamic behavior of the vehicle. Additional sounds produced by surrounding traffic are blended with the ambient sounds to produce an immersive experience.

NADS-2 with heavy truck cab

NADS-2

The NADS-2 is an ideal complement to the NADS-1 for simulation needs that do not require motion. The NADS-2 features three front visual channels with a field of view of 135 degrees. Two more channels are available to simulate the scenery in the rear and/or side view mirrors. The NADS-2 uses the same vehicle cabs as the NADS-1, has the same control feel and audio systems, and it employs the same underlying software technology to ensure scenario and data compatibility.

NADS MiniSim™

The NADS MiniSim driving simulator is a PC-based simulator system equipped with the same world-class technology used in NADS-1. This portable simulator is easily deployable and can be customized to meet a client's specific needs. The MiniSim can be configured to have single or multiple displays, and runs on only two PCs. The system can be configured to have a high-quality steering wheel and pedals that can be mounted on a desk or built into a sophisticated cab to the user's specifications. The MiniSim is based on the same software technology as the NADS-1 and NADS-2, ensuring compatibility of scenarios and data across simulators.

MiniSim(TM) with single display option

SIREN

The SIREN (Simulator for Interdisciplinary Research in Ergonomics and Neuroscience) is another fixed base simulator located at the University of Iowa Hospitals and Clinics. The simulator's location makes it uniquely positioned to perform clinical research on at-risk subjects. This system has three forward displays providing a field of view of 120 degrees. It uses an instrumented Saturn cab, and provides scenarios specifically designed to collect measures related to driver performance.

Why is Fidelity Important?

As fidelity increases, so too does the transfer of training and the accuracy of assessment, particularly among experienced or expert drivers. Lower fidelity simulation can be used for preparation and development of scenarios or study protocols without incurring the cost of high-fidelity simulation platforms. Lower fidelity simulation is also ideal for new driver training where full immersion is not necessary.

NADS-1

- Scenarios that require the greatest possible motion fidelity for large-scale motion events, such as lane changes, extended braking or acceleration maneuvers, extensive steering or continuous turning events
- Tasks that rely on a full 360-degree field of view, such as intersection navigation, lane changes, and blind-spot research
- Tasks that require the highest level of visual resolution
- Testing of crash avoidance situations where more than the onset of the response is important

NADS-2

- A cost-effective solution for scenarios that are not motion critical, such as headway maintenance, lane keeping, gap acceptance, and hazard detection
- Preliminary research projects that might eventually use NADS-1
- Vision-related studies that require a higher visual resolution or field of view than is available with lower fidelity simulators
- Scenarios which focus on the performance on discrete tasks associated with driving while utilizing a complete vehicle cab

NADS MiniSim

- Tasks that do not require a complete vehicle cab, such as driver training
- Scenarios that are not motion critical such as headway maintenance, lane keeping, gap acceptance and hazard detection
- Projects that require off-site data collection, such as clinical trials or training that will occur at multiple sites around the world
- Preliminary research projects that might eventually utilize the NADS-1 or NADS-2 simulators

SIREN at UIHC

- Studies that require easy access to hospital patient populations
- Assessment of physical and cognitive abilities, with a particular emphasis on neuroergonomics

- Scenarios that are not motion critical such as headway maintenance, lane keeping, gap acceptance, memory tasks, such as route following, and hazard detection

Simulation Core Software

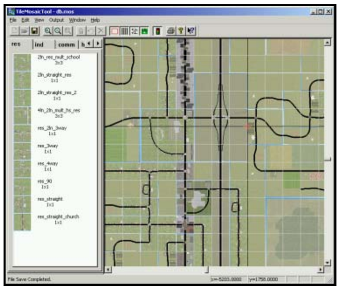
An extensive infrastructure of software, developed at The University of Iowa and the NADS, facilitates the development of virtual environments for all NADS simulation platforms. This includes tools such as the Tile Mosaic Tool (TMT) and the Interactive Scenario Authoring Tool (ISAT), as well as data reduction workstations, which are used for developing new or modifying existing visual databases, experimental scenarios, and data reduction procedures. These tools provide researchers the ability to plan and control vehicle interactions between the subject vehicle, traffic, and the driving landscape. Because NADS simulators share the same software architecture, scenarios and data have seamless compatibility across simulators.

ISAT(TM) -- interactive scenario authoring tool

Scenario Authoring & Control

NADS staff has extensive experience developing highly detailed, complex synthetic environments designed for ground vehicle simulation for military, civilian, and educational markets. NADS uses OpenFlight™, an image generator format for real-time three-dimensional visualization and the visual simulation industry standard, to create on-road and off-road visual databases. On-road visual databases can be rapidly generated using the TMT™ (Tile Mosaic Tool), a graphical interface used to connect pre-existing database modules (tiles) to create large-scale ground vehicle simulation environments. The visual database library has nearly 80 tiles available for use, including suburban, rural, urban, and highway driving environments. For projects requiring scenes not presently available within the tile library, existing tiles are modified or new tiles are created to support the necessary requirements. Off-road driving simulations also can be constructed using GIS data from satellite imagery, ARC coverages, GPS data, digital imagery and digital elevation data, as well as terrain elevation and soil property data from terrain models.

The TMT creates a visual database, which is used by the image generator computers for visualization. It also generates a correlated logical version of the visual database, which is used by ISAT to place dynamic scenario elements and configure objects for simulation. A sophisticated scenario control system is used to simulate traffic within the virtual environment. It utilizes a microscopic traffic simulation engine augmented with high-level coordinators that can orchestrate specific events authored by the experimenter. Individual driver models control scenario vehicles; their behavior has been calibrated to match empirically obtained traffic data. A rich set of coordinators allows for the arrangement of predefined events that can reliably occur during the simulation. Almost every aspect of the virtual environment can be controlled, including weather conditions, vehicle interactions, and mechanical failures. In addition, events in the virtual environment can affect the simulation; for example, the simulation can be programmed to trigger a lead vehicle braking event based on the driver's glance off the road to the instrument cluster. Interactive authoring tools allow graphic definition of these scenarios and storage in libraries for further use.

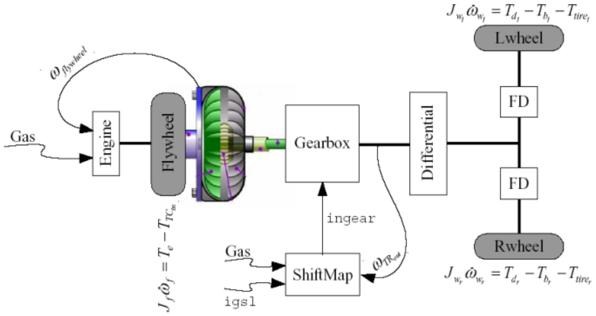


TMT -- Tile Mosaic Tool

Vehicle dynamics, NADSDyna™

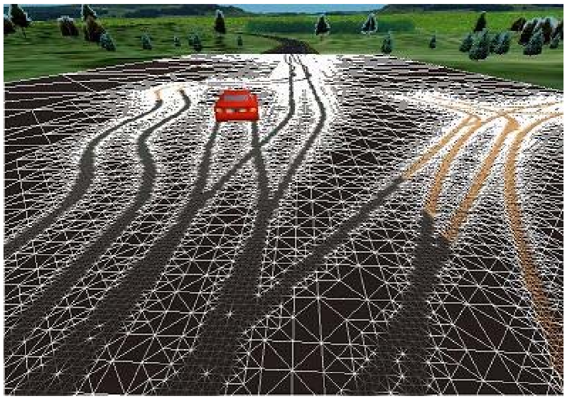
Software that accurately represents vehicle motion and control feel conditions, including driver control actions, tire-surface interaction, aerodynamics; vehicle responses computed in real time; validated models of Intrigue, Expedition, BMW, wheel loader, combine, and HMMWV

All NADS simulation platforms use the dynamics software NADSdyna™ in order to accurately model the dynamics for different types of vehicles. NADSdyna encompasses a general purpose multi-body vehicle code which can be parameterized to simulate specific vehicles. The NADS has validated vehicle dynamics models for passenger cars, heavy trucks, SUVs, tractors, industrial equipment, and tracked and wheeled military vehicles.



These models typically contain bodies and joints to correctly model the dynamics of the suspension. Other vehicle subsystems such as the power-train, steering, aerodynamics, brakes, and tires are modeled as force elements that act on the multi-body model by applying forces to the appropriate bodies. Component flexibility can be included in the vehicle models to improve model fidelity and/or to generate loading history on components for component and/or system durability and reliability analysis. Structural and multi-body dynamics co-simulation using linked commercial software may also be performed.

All newly developed vehicle dynamics models and new modeling capabilities (modules) are implemented and tested in NADSdyna workstation environment and then released for human-in-the-loop NADS simulation. NADSdyna has proven to be robust and capable of accurately simulating vehicle dynamics even with the most extreme maneuvers where all types of nonlinearity, in-vehicle suspension, and tires are present. Many of the models developed and implemented using NADSdyna have also been validated using field test data.



Dynamic terrain and tire-soil modeling

Tire modeling is a critical component of vehicle models as the control forces on the vehicle come from the tires. NADS has made significant contributions to the modeling of tire and tire-terrain interaction, resulting in a suite of models and related capabilities that can be applied to different types of simulations.

The real-time tire model for on-road vehicle simulation is highly sophisticated and requires comprehensive tire test data. It has been successfully used in simulation involving very aggressive maneuvers, such as those that cause the activation of Electronic Stability Control (ESC) systems. Off-road vehicle simulation is accomplished using the real-time dynamic tire model, a terrain model capable of describing arbitrarily uneven, rigid, or deformable terrains, and a tire-soil interaction model. Unlike the on-road tire model, which is essentially quasi-static with first-order relaxation, the dynamic tire model has internal vibration modes and performs 3D enveloping on rough terrain. Plastic soil deformation is recorded in the dynamic terrain database to correctly account for the effects of multiple passages on one soil patch by multiple wheels. The high-fidelity finite element models can be used for detailed analysis, as well as for

generating parameters for real-time models. A virtual test methodology for tire, soil, and tire-soil interaction is used to support the development of a real-time tire-soil interaction model.

Data Collection & Analysis

NADS researchers have developed unique measures and data processing approaches to advance researchers' ability to understand driver responses in our simulation environments. These efforts have been instrumental in interpreting driver response and behavior in normal driving and crash situations.

Engineering Data

Engineering data is collected from sensors in the simulators that capture operator inputs and vehicle motion. A 20-minute drive in NADS-1 can generate over 500 MB of raw data, so NADS staff reduces the data in order to identify meaningful performance measures that can be interpreted and used by the experimenter. Data reduction performed at the NADS is customized to meet the specific needs of each client by building upon preexisting data reduction components. Some data is available immediately after a participant's drive ends, while the remaining reduced data is available within days of the end of data collection.

Eye-tracking Data

Engineering data is augmented with head- and eye-tracking data. The eye-tracking systems run on the faceLAB™ Seeing Machines software which uses a set of dash-mounted cameras as a passive measuring device, allowing seamless integration into the driver's environment and resulting in more naturalistic driving maneuvers. The data output of the system has been integrated into the data acquisition stream, allowing for concurrent uncomplicated analysis of driving and eye-tracking parameters.

On-site expertise in software development has allowed the integration of the eye-tracking data into the virtual environments. We have the ability to superimpose data from the eye-tracking system onto the virtual environment so the researcher can visually track scan patterns during and after an experiment. We also have the ability to trigger scenario events within the virtual environment based on eye-scan locations.

Video Data

Video data provides context to the engineering and eye-tracking data. A digital video recording system allows the simultaneous recording of up to four streams of video. Approximately 15 independent video signals, including in-vehicle cameras, image generator outputs, motion bay cameras, and in-dome overview cameras, can be independently fed to any of the four recording streams. A quad multiplexer can also be fed into one of the recording streams.

A text overlay processor allows text and simulator variables to be superimposed on one of the video streams. Each of the four recording streams can be recorded digitally on tape or stored on hard disks.

Each of the four recording streams can be recorded using a digital VCR in DVCAM or miniDV format. In addition, each of the four recording streams can be stored on hard disks using real-time MPEG2 encoding. This video can be fed real-time to researchers outside the building via secure video conferencing.

Survey, Questionnaire & Interview Data

NADS staff also employ a variety of qualitative, quantitative, and mixed-method approaches to data collection, administering surveys, questionnaires, and/or conducting individual and focus group interviews to assess driver behavior, perception, and understanding.

Data Storage

The data acquisition system can record any of the internal simulator variables at a rate of 240 times per second, or any whole subdivision (i.e., 120, 60, 30, etc.) thereof. Two file servers with approximately 10 TB of storage are used for intermediate and long-term storage of binary and video data. An automated CD/DVD burner duplicator with disc-printing capabilities is also available for the rapid duplication and production of CD/DVD-ROMs. An automated tape backup system utilizing a 500 GB tape carousel is also available. The tape system can automatically back up as much as 5 TB of data in one set of tapes, which can be used for long-term storage of video and binary data. Paper and digital copies of participant study materials, including surveys, questionnaires, and interview transcripts, are stored in a secure archive.

Facilities

The NADS facility supports studies of varying lengths and complexities. The facility features separate and secure areas for study development, testing, and data collection. As participants arrive at our facility, they are greeted by a member of our staff and escorted to a private area for training and preparation. The participant preparation area is equipped for an array of evaluation and training procedures, including a secure medical room for research studies that require physical examinations, drug administration, or monitoring of participants' biophysical systems. Simulator operations for NADS-1 and NADS-2 are overseen by operators and research staff from secure control centers.

The NADS facility can host large groups in our conference room, which is outfitted with full telephone and video conferencing capabilities. Clients may also visit our facility during data collection and monitor the progress of their study through camera links between the simulator and the conference room.

Our convenient location, near Interstates 80 and 380, provides easy access for participants not only from the Cedar Rapids and Iowa City areas, but also from as far away as Des Moines, Davenport, and Chicago. For studies that require participants to be recruited and transported to the facility from around the country, NADS is a short 15-minute drive from the Eastern Iowa Airport and is located within minutes of several hotels.

How to work with us

Work at the NADS can be done in a variety of ways, including (but not limited to):

- using our suite of driving simulators and in-house expertise to conduct research and/or clinical studies
- utilizing our experience to design and build a driving simulator specifically for your needs
- collaborating with our staff and faculty to enhance the functionality of your existing simulation platform
- utilizing our expertise in writing in-house simulation software to develop applications suited for your needs

Some examples of previous collaborations are as follows:

- NHTSA used the NADS-1 to conduct research on the effects of advanced vehicle systems such as Electronic Stability Control (ESC). Research has provided critical data about participant reaction to loss-of-control situations that can only be performed safely and realistically in a high-fidelity driving simulator such as the NADS-1.
- The FDA used the NADS-2 to validate a vision test that would provide sponsors with an alternative for evaluating a new ophthalmic device while providing the FDA with valuable information regarding the impact of such products on public health and safety.
- U.S. Army TACOM used our expertise in designing a real-time off-road terrain virtual environment.
- A defense contractor in Europe had NADS design and implement the core simulator software for their military truck driver training simulation product.

Contact us at contacts@nads-sc.uiowa.edu for more information about the benefits of conducting research at our facility.

Clinical Trials to Measure Driver Impairment

Driving simulation provides a powerful tool for analyzing the effects of medications on driving performance. Drug manufacturer Hoechst Marion Roussel, Inc. (HMRI) commissioned a drug safety study from the Center for Computer-Aided Design (CCAD) using the National Advanced Driving Simulator's predecessor, the Iowa Driving Simulator, to compare incidences of impairment and drowsiness between two FDA-approved antihistamines.

First generation antihistamines sedate users by crossing the blood-brain barrier, causing drowsiness and performance impairment. The study's objective was to compare the effect of a first generation antihistamine, HMRI's second generation antihistamine, alcohol, and placebo on driving performance, which included analyzing car following, drowsiness, lane keeping, and response to lane incursion, as well as on self-reported drowsiness of participants with seasonal allergic rhinitis during their season.

The study design consisted of a randomized, double-design, double-dummy, four-treatment, four-period trail. Forty licensed drivers between the ages of 25 and 44 who suffered from seasonal allergic rhinitis participated in the study. Participants drove in the simulator one time each week for four consecutive weeks. They received each of the following experimental drug treatments, one per week: Fexofenadine (60 mg), alcohol given in doses to approximate a 0.10% blood alcohol concentration (BAC), diphenhydramine (50 mg), and a placebo. After receiving and absorbing each of the study treatments, participants completed a driving scenario that included a car-following segment; a long, uneventful drive in a rural highway setting; and a "critical event" in which a vehicle pulled out suddenly from a side street. Each of these three segments was designed to examine a specific aspect of driving performance, as described above.

Results of this study revealed that Allegra did not impair driving performance or cause subjective drowsiness.

Weiler, J.M., Bloomfield, J.R., Woodworth, G.G., Grant, A.R., Layton, T.A., Brown, T.L., McKenzie, D.R., Baker, T.W., and Watson, G.S. (2000). Effects of fexofenadine, diphenhydramine, and alcohol on driving performance: A randomized, placebo-controlled trial in the Iowa Driving Simulator. Annals of Internal Medicine *132(5): 337-344.*

Using simulation to evaluate advanced vehicle technologies

Driving research conducted at the National Advanced Driving Simulator (NADS) has been instrumental in the Department of Transportation’s proposal to require the installation of electronic stability control (ESC) on new passenger vehicles under 10,000 pounds starting with the 2009 model year. ESC is an active safety system that helps drivers maintain control of their vehicles and avoid collisions in dangerous—often fatal—driving situations. The ESC system detects when the vehicle is moving in a direction different than that indicated by the steering wheel position and automatically triggers computer-controlled braking of the appropriate wheels to stabilize the vehicle and help the driver stay on course.

NADS has completed two studies funded by the National Highway Traffic Safety Administration (NHTSA) that examine drivers’ responses to dangerous driving situations and the effects of ESC on drivers’ performance across a range of age groups (from 16 to 74 years of age). The first study examined the potential safety benefits of ESC while driving on wet pavement. The second examined the potential benefits of ESC while driving on dry pavement, as well as comparing drivers’ performance using ESC while driving different vehicle models. More than 600 volunteers participated in the two studies which were conducted over a 16 month period.

Every year over 40,000 lives are lost due to motor vehicle crashes. According to NHTSA, the ESC system has the potential to save more than 10,000 lives annually by automatically stabilizing vehicles that begin to skid or plow out of control, thereby decreasing the number of single-vehicle crashes that result from the vehicle departing the roadway or rolling over. Currently, collisions of this type account for 57% of all fatal crashes in the United States.

Department of Transportation, National Highway Traffic Safety Administration (2006). *Federal Motor Vehicle Safety Standards; Electronic Stability Control Systems*, 49 CRF Parts 571 and 585, [Docket No. NHTSA-2006-25801], RIN: 2127-AJ77. Available: http://www.safercar.gov/esc/Rule.pdf.

The NADS at a glance

In 1992 The University of Iowa won a national competition conducted by the National Science Foundation (NSF) on behalf of the National Highway Transportation Safety Administration (NHTSA) to host the world's most sophisticated driving simulator. NHTSA oversaw the construction of its device, and NADS staff, building on the engineering, computer science, graphics, and hardware expertise of the NADS' predecessor, the Iowa Driving Simulator, assisted in the simulator's completion. NADS-1 became operational in 2001. Since then, we've conducted over 20 studies, and collected data from over 1,300 participants.

Our expertise and commitment to an open architecture have resulted the NADS-1 being adapted to simulate driving environments for passenger vehicles, heavy trucks, military vehicles, and farm and earth moving implements. NADS-1 is not only the world's most advanced driving simulator, but also the most rapidly reconfigurable, quickly adapting both software and hardware to accommodate each client's specific research requirements.

- Unparalleled realism with respect to visual, motion, and auditory sensation
- 13 degree of freedom motion platform capable of providing motion cues for sustained maneuvers
- High-resolution, high contrast, 360 degree field of view image generation system
- Human factors expertise in design and analysis of driving simulator studies
- Real-time multi-body vehicle dynamics capable of simulating any vehicle; validated vehicle models for a variety of cars, SUVs, heavy trucks, military and industrial vehicles
- Reconfigurable to accept a variety of vehicle cabs and controls
- Comprehensive support for scenario authoring and development
- A suite of compatible simulation platforms at different levels of fidelity to suit client needs

Our center-wide commitment to academic advancement, technological innovation, and the transfer of research results to industrial and governmental communities provides a winning combination for clients, both in terms of access to world-renowned faculty and research staff and to the multidisciplinary networks supporting simulation research at The University of Iowa.

THE UNIVERSITY OF IOWA
The National Advanced Driving Simulator
2401 Oakdale Blvd. / Iowa City, IA 52242-5003

Human Factors and Operator Performance

NADS research staff has a broad range of expertise in cognitive systems engineering, transportation safety, and simulation. As a research unit at The University of Iowa, NADS has full-time research staff with ample experience in every aspect of study design, implementation, analysis, and reporting. Staff works to ensure the consistency, quality, and timely completion of data collection and of reports and papers documenting research conducted on the client's behalf. NADS also works closely with faculty and students in support of the university's research, education, and service missions, providing clients with access to faculty and graduate researchers in a number of colleges at The University of Iowa. NADS staff and affiliated faculty represent some of the top researchers in the field, conducting cutting-edge research on a variety of topics, including driver behavior, drugs and driver impairment, driver distraction, and driver performance while interacting with advanced vehicle systems.

NADS has a unique infrastructure for conducting large-scale research projects:

- Experience running over 1300 participants in under 5 years
- Largest study ran 350+ participants
- Recruitment coordinator with over 10 years experience
- Recruitment database of over 3,000 potential participants
- Collaboration with medical researchers facilitates recruitment of patient populations for clinical trials

NADS researchers have developed unique measures and data processing approaches to advance researchers' ability to understand driver responses in the simulator. These efforts have been instrumental in interpreting driver response and behavior in normal driving and crash situations. NADS staff has particular expertise in the analysis and interpretation of eye-tracking data and crash events.

To help extend the findings of research efforts, NADS designs studies to facilitate the development of human performance models related to driving. This research utilizes current research findings to further develop and validate existing models of driving behavior, as well as develop new models in a variety of driving situations. Driver modeling efforts have been highly effective at enhancing research findings in the area of longitudinal vehicle control and advanced safety warning systems.

The primary goal of the NADS is to improve driving safety by conducting independent research that examines research questions related to driver performance and systems safety. Although research can be supported on many topics, the NADS provides particular expertise in the following areas:

Advanced Safety Technology. Working with industry and government partners, NADS has a rich research program examining a wide range of driver warning and crash avoidance telematics systems.

- Forward collision warning systems
- Lane departure warning systems
- Road departure warning systems
- Blind spot warning systems
- Anti-lock braking systems (ABS)
- Electronic stability control (ESC)
- Adaptive cruise control (ACC).

In-Vehicle Information Systems. Projects in this focus area include research on operator performance while using a range of driver information and distraction mitigation systems.

- Wireless phone use
- Route navigation
- In-vehicle email
- In-vehicle text messaging
- Cab geometry/placement of displays and controls

Visibility. As the ability to obtain visual information from the environment is critical to safe driving, NADS has collaborated with sponsors from various agencies, including the Federal Highway Administration and the Food and Drug Administration. NADS studies in this focus area examine the ability of drivers to identify objects in the driving environment and to understand their surroundings.

- Retro-reflective pavement markings
- Signage and object identification in low-vision situations

Clinical Trials Support. In conjunction with numerous medical researchers, NADS has collaborated on the clinical evaluation of effects of a variety of medications and devices on driver performance.

- Prescription and OTC medications, alcohol, and other drugs
- Medical devices such as intra-ocular lenses

Older drivers. Due to the criticality of understanding the impacts of aging on driving performance, NADS has worked with a variety of clients to examine the potential changes in driver behavior associated with aging and technology-based mitigation strategies that might benefit or impact older drivers.

- Simulator and on-road studies of age-related effects on various measures of performance
- Blind spot warning systems
- Electronic stability control

Novice Drivers. Projects in this focus area include research on novice driver behavior and attitudes, as well as on technology-based interventions to mitigate young driver crash risk.

- Longitudinal questionnaire studies regarding driving and risk-taking
- Simulator and on-road studies of age-related effects on various measures of performance
- Blind spot warning systems
- Electronic stability control

Crash biomechanics. Collaborating with researchers in the Colleges of Engineering, Medicine, and Public Health, the UI has a unique capability for providing research expertise in physics-based electronic figure modeling. UI researchers have developed a new generation of digital humans comprising realistic human models. The model is called Santos™, and it includes anatomy, biomechanics, physiology, and intelligence that generates behavior in real time. When combined with the sophisticated driving simulation environment at the NADS, this model becomes one of the most highly sophisticated biomechanics tools available to aid in vehicle design.

Driver State Monitoring and Prediction. Projects in this focus area include a number of research efforts examining the most reliable and accurate methods of assessing and determining the current state of the driver.

- Eye behavior
- Vehicle control
- Electroencephalogram (EEG) measurements
- Development and testing of real-time driver models to predict driver state

Although human factors support is generally focused on research conducted on one of the NADS simulators, NADS also can provide a variety of human factors support services for research conducted off-site.

Selected references:

1. Bloomfield , J.R., Weiler, J.M., Grant, A.R., Brown, T.L., Layton, T.A., Grant, P.R., Woodworth, G.G., McKenzie, D.R., Baker, T.W., and Young, M.A. (1999). The influence of first- and second generation anti-histamines and alcohol on driving performance. In M. A. Hanson, E. J. Lovesey, & S. A. Robertson (Eds.) *Contemporary Ergonomics* (pp. 63-67). London: Taylor and Francis.
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Real-time Geo-typical and Geo-specific Visual Databases

Real-time geo-typical and geo-specific databases are two different ways to describe the simulation environments at NADS. These environments contain detailed information and create a sense of place within the simulator. This place can be a generic, typical place or it can be intended to accurately represent a particular place. NADS databases support both off-road and on-road simulation environments.

Roadways are constructed based on AASHTO standards or to project-related specification. Road related attributes that are defined include: surface material, lane width, roadway markings, shoulder width, and shoulder material.

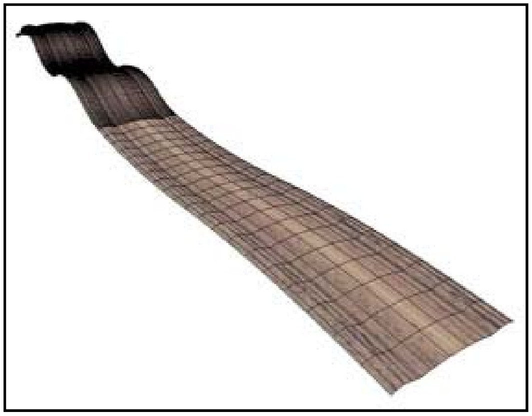
The foundation of creating variable geo-typical databases is the use of small, reconfigurable database components called tiles. Tiles are re-useable templates that connect to each other to build a larger simulation environment. This approach provides flexibility over static defined environments, as tiles are designed to function in relation to a larger whole even if the overall terrain design is not well defined.

Variability
Tiles are constructed to permit control of various elements such as street signs, speed limit signs, traffic lights and select features. These elements provide a mechanism to make small alterations to the basic tile, extending the power of variation even when the same tile is re-used.

Reliability
Once tested and integrated a tile may be re-used. Because each tile is essentially a library element, functionality is ensured for all instances of any tile.

Extensibility
For any project requirement not presently available within the tile library, either existing tiles are modified or new tiles are created to supply the necessary requirements.

Geo-specific visual database of a dirt racetrack



Geo-specific databases are intended to re-create a specific real-world location. There are more demanding requirements placed upon this type of simulation environment because there is a clear ground-truth metric; does the simulated environment truly represent the real world location? Validation may take the form of expert drivers familiar with the real-world locale driving the simulated environment, comparison of instrumented vehicles with simulator data and comparing video or site imagery with the constructed environment.

NADS utilizes multiple source data types to ensure accurate geo-specific database construction. GIS data are provided in the form of satellite imagery, ARC coverages, GPS data, digital imagery and digital elevation data.

Geo-specific databases typically require higher feature density, higher resolution geometry and significantly more texture memory than geo-typical databases.

Weather effects include wet roads

Night-time driving environments with functioning headlights

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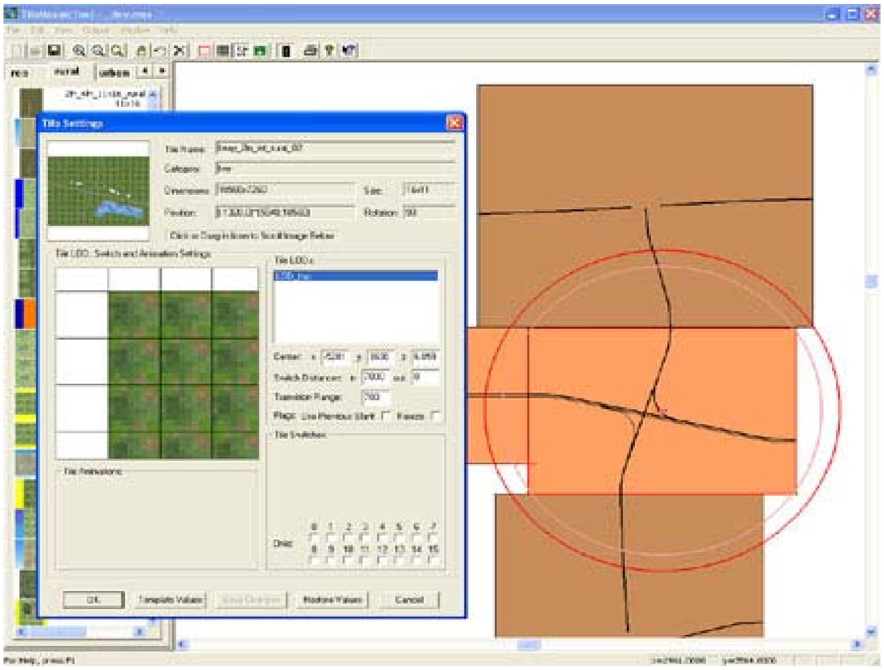
Scenario Authoring

A sophisticated scenario control system is used to simulate traffic within the virtual environment. The system uses a microscopic traffic simulation engine augmented with high-level coordinators that can orchestrate specific events authored by the experimenter, including weather conditions, vehicle interactions, and mechanical failures. Individual driver behavior models control scenario vehicles; their behavior has been calibrated to match empirically obtained traffic data.

A rich set of coordinators allows the management of predefined events that can reliably occur during the simulation. Coordinators can trigger events based on geometric and relative locations of specific vehicles with respect to each other or the participant, mathematical expressions involving data from the simulation, and time. Coordinators also trigger several types of actions within the virtual world, including the creation or deletion of scenario elements, commands to control vehicle behavior, triggering of specific audio cues, and controlling the state of traffic lights, as well as inserting markers into the data being collected, performing embedded data reduction, and pre-positioning the motion base.



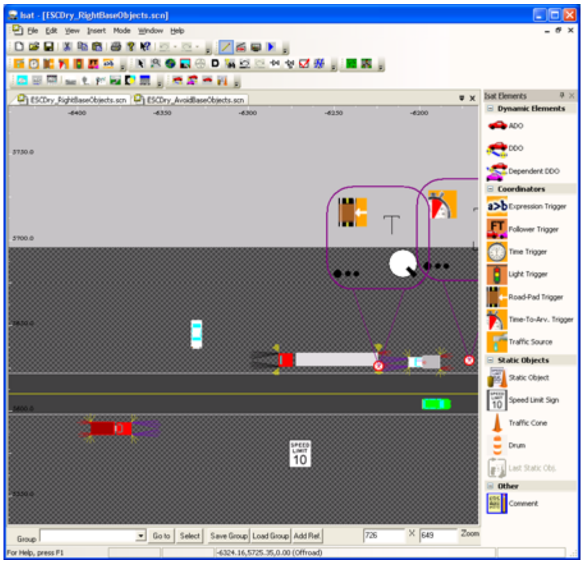
TMT -- Tile Mosaic Tool

The Interactive Scenario Authoring Tool (ISAT™) allows users to graphically author complex scenarios. The ISAT runs on typical desktop and laptop computers. Scenarios built using the ISAT can then be executed on NADS simulators or any other simulator that supports the NADS scenario (SCN) specification format.

Areas of research under this effort include:

- Building a library of road networks, with associated traffic lights and signs, following AASHTO guidelines and engineering standards.
- Development of the **Logical Road Information (LRI)** format for specifying road networks, including complex road networks that mimic American and European locations.
- Development of the **Correlated Virtual Environment Database (CVED),** featuring a rich set of real-time queries that provide information about the road network and any object in it.

- Development of behavior modeling software that enables autonomous or externally modifiable and controllable behaviors, including lane changes and intersection navigation.
- Utilization of a set of coordinators allowing experi menters fine control over the events in the scenario.
- Development of a mature version of a graphical scenario au thoring tool called the **Interactive Scenario Authoring Tool (ISAT)**.



ISAT(TM) -- Interactive Scenario Authoring Tool

Selected references:

1. Ahmad, O. (2005). Design of simulator scenarios to study the effectiveness of electronic stability control systems. In *Proceedings of the 85 th Annual Meeting of the Transportation Research Board*, Washington, DC: Transportation Research Board.
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Modeling

Real-time vehicle modeling at NADS is performed with NADSdyna, a program that uses general-purpose multibody dynamics code to model the overall motion of the vehicle. This model typically contains bodies and joints to correctly model the dynamics of the suspension. Other vehicle subsystems such as the powertrain, steering, aerodynamics, brakes, and tires are modeled as force elements that act on the multibody model by applying forces to the appropriate bodies. A brief description of each of these systems and the data required to create a model are described in the following sections. For a more detailed description of the NADSdyna models, see the citations at the end of this document. The software is highly configurable and those changes that can't be accommodated in a parameter file can be written into the dynamics code.

Multi-body Model

The multibody model typically contains a chassis body, a rack body (for rack and pinion steering), and the bodies of the suspension. The bodies for the suspension depend on the suspension type. The multibody model for an SLA suspension, for example, would contain bodies for the upper control arm, lower control arm, knuckle, connecting rod, and wheel. Other suspension types may require different bodies.

In order for the multi-body model to run in real-time, many bodies are simplified or not modeled. These elements are modeled as pure force elements between the chassis and lower control arms, and the mass and inertia of these bodies are added to other bodies to approximate the actual vehicle as closely as possible. Another way of achieving real-time is to use ideal rigid joints in the place of bushings. This eliminates much of the high-frequency content that would reduce the integration step size.

Data required: Mass, inertia, and location of the center of mass of the chassis and each body in the suspension. Also needed are the locations of all the joints in the suspension.

Springs/Shocks/Antiroll Bar

The springs, shocks, and antiroll bars are all modeled as nonlinear force elements between the chassis and lower control arms. No effects from frequency response are modeled.

Data required: Curves defining spring force vs. displacement, shock force vs. velocity, and antiroll bar torque vs. angle.

Aerodynamics

The aerodynamics model used by NADSdyna is based on the SAE J1594 standard [4] in which model curves are used to define the coefficients for lift force, drag force, side force, roll moment, pitch moment, and yaw moment as a function of wind direction.

Data required: Curves defining the coefficients for lift force, drag force, side force, roll moment, pitch moment, and yaw moment versus wind angle. Also needed are the frontal areas of the vehicle and the wheel base.

Steering

NADSdyna supports steering systems that are kinematically driven or force driven. The steering geometry is determined by the hard point locations in the multibody model, with components such as tie rods modeled as distance constraints. Both rack and pinion and pitman arm configurations are supported, and power-assisted steering is modeled. A typical NADSdyna model uses rack-and-pinion steering, with the rack kinematically driven based on the input from the steering wheel.

Data required: The gear ratio between the rack position and the steering wheel angle is needed. Camber angle, toe-in, and other steering geometry information is set in the multibody model described above.

Powertrain

The powertrain is modeled with a combination of several systems—engine, torque converter, transmission, differential, and final drive. For computational efficiency, the powertrain components are modeled as differential equations, or quasi-static assumptions are used to reduce the model to algebraic equations. Supported powertrain configurations are front wheel drive, rear wheel drive, four wheel drive, and dual axle drive.

Engine

The engine is modeled using a quasi-static engine map that gives the engine torque based on the current throttle position and engine speed. External torques that act on the engine are the accessory torque and the load torque. Accessory torque is losses due to friction and pumps and is a linear function of the engine speed. Load torque is the torque absorbed by the torque converter. The engine speed is modeled by a differential equation that uses the effective engine inertia and is limited by the maximum speed.

Data required: Surface defining the engine torque as a function of the engine speed and throttle position. Also need effective engine inertia and maximum engine speed.

Torque converter

The torque converter uses a quasi-steady-state model to handle the power transfer between the engine and the transmission. The absorbed input torque and the torque passed to the transmission depend on capacity factor and torque ratio curves that are functions of the input/output speed ratio.

Data required: Curve defining the ratio between the engine load torque and transmission torque versus the speed ratio. Curve defining the inverse capacity factor squared versus the speed ratio.

Transmission

The transmission is assumed to be an inertialess connection between the torque converter and the differential. Gear shifting is determined based on the current gear, throttle input, output shaft speed, and shift logic map. Because gear shifting occurs in a finite time, blending functions are used.

Data required: All gear ratios and gear efficiency are needed. The shift logic maps that define the upshift and downshift points as a function of the output speed.

Differential

The differential allows for a variable torque distribution between the right and left wheels, with the torque distribution defined by the speed difference and the bias.

Data required: The gear ratio, gear efficiency, and torque bias ratio, minimum and maximum angle difference between axle shafts.

Final drive

The final drive is a gear ratio between the drive axle and the wheels.

Data required: Final drive gear ratio.

Tire

The tire is modeled using a semi-empirical STI model, which relies heavily on test data for accurate simulations. For previous projects, the data required for the STI model were obtained from Smithers Scientific Services, Inc., using their MTS Flat-Track II measurement machine.

Data required: The following tests were performed by Smithers Scientific Services, Inc.:

- Discrete sinusoidal steering - The slip angle frequency is varied as follows: 0.13, 0.63, 1.25, 1.88, 2.5, 3.13, 3.38, 3.75, 4.38, and 5.0 Hz. For each frequency, five cycles are run with the slip angle amplitude peak-to-peak value set at 1.6 degrees. Test speed is 30 mph.
- Quasi-static discrete cambering - The inclination angle is varied as follows: -10, -8, -6, -4, -2, 0, 2, 4, 6, 8, and 10 degrees. For each angle, the normal load is varied as follows: 40%, 80%, 120%, 160%, and 200% of the reference load. Test speed is 30 mph.
- Low slip angle quasi-static steering - The normal load is varied as follows: 40%, 80%, 120%, 160%, and 200% of reference load. For each load, the slip angle is varied from -2 to 2 degrees at 1 deg/sec and then at 2 deg/sec. Test speed is 30 mph.
- Quasi-static steering - The normal load is varied as follows: 40%, 80%, 120%, 160%, and 200% of reference load. For each load, the slip angle is varied from -28 to 28 degrees at 3 deg/sec. Test speed is 30 mph.
- Quasi-static braking/diving #1 - The normal load is varied as follows: 20%, 40%, 60%, 80%, and 100% of the maximum allowable (determined to be about 1250 lbf). For each load, the slip ratio is varied from -80% to 80% with a ramp time (0 to 80%) of 1.5 sec. Test speed is 30 mph.
- Quasi-static braking #2 - The normal load is varied as follows: 20%, 40%, 60%, 80%, and 100% of the maximum allowable. For each load the slip ratio is varied from 0% to -80% to 0% with a ramp time (0 to 80%) of 1.5 sec. Test speed is 60 mph.
- Quasi-static combined steering/braking/driving #1 - The normal load is kept at the reference load. The slip angle is varied as follows: -6, -4, -2, 0, 2, 4, and 6 degrees. For each slip angle, the longitudinal slip is varied from -80% to 80% with ramp time (0 to 80%) of 1.5 seconds. Test speed is 30 mph.
- Quasi-static combined steering/braking #2 - The normal load is kept at the reference load. The slip angle is varied as follows: -6, -4, -2, 0, 2, 4, and 6 degrees. For each slip angle, the longitudinal slip is varied from 0% to -80% to 0% with ramp time (0 to 80%) of 1.5 seconds. Test speed is 60 mph.

Brakes/ABS

The brake system models the simulated vehicle’s braking force from the brake pedal pressure or master cylinder pressure to the wheel brake torques. Options for the brake model configuration include: manual hydraulic brakes, power-assisted hydraulic brakes, and phuematic brakes. An idealized anti-lock braking system (ABS) controller is also included as part of the brake system model. This controller attempts to achieve maximum traction during sever braking maneuvers by controller wheel slip using brake pressure modulation.

Data required: inboard/outboard, number of calipers, brake proportioning, knee-point pressure, pressure curves for normal and damaged brakes (ex: worn, heated). Brake pressure to torque curves.

ESC/TCS

NADS does not have its own model for the electronic stability control or traction control systems; for prior projects, these models were provided by the manufacturers of these systems. Therefore, for any future model that includes ESC, the cooperation of the manufacturer is required to provide this software. Because the brakes are so closely integrated into the ESC system, it is also likely that the brake model will be included as part of the ESC model.

Data required: A library from the manufacturer that can be linked to our NADSdyna software that models brakes, ESC and TCS.

Validation

In order for the model to be deemed acceptable, the results must be validated against real vehicle. This can be done in several ways. Face validity is sought through having experts familiar with the performance of the vehicle drive the model in the simulator and give detailed feedback. More quantitative forms of validation can be done by simulating test track maneuvers in the virtual environment and recording variables matching traditional sensor data, along with variables that cannot normally be accessed on the test track. This suite of maneuvers must adequately test each of the subsystems described in the previous section. A suite of maneuvers that we have used in the past is listed below, and the data that are generally required for each maneuver is also given.

Maneuvers

The following is a list of maneuvers that have been used to validate the vehicle model:

- Straight line acceleration
- Straight line braking
- Brake in turn
- Coast down
- Shifting progression
- Pulse steer
- J-turn/Step steer
- Lane change and Double lane change
- On center steer
- Ramp steer
- Frequency response steer
- Understeer gradient test (any method in SAE J266)

The selection of maneuvers will depend on what real world data is available and whether there is a focus on any particular vehicle subsystem.

Data Required

The following is a list of test data needed for the maneuvers described above. In some cases, not all data is required for each test. For instance, brake pedal force is not needed for the straight line acceleration maneuvers. If channels are not available for all the variables in the data acquisition equipment, a more detailed list for each specific maneuver could be created.

- Time from beginning of maneuver
- Chassis
    - Lateral and longitudinal acceleration
    - Roll, pitch, and yaw
    - Roll, pitch, and yaw rates

    - Vehicle position from GPS
    - Vehicle speed
    - Sensor locations
- Powertrain
    - Engine speed
    - Transmission input shaft speed
    - Transmission output shaft speed
    - Transmission gear
    - Speed of each wheel
    - Accelerator pedal position
    - Transfer case, if applicable
- Brakes
    - Brake pedal force
    - Brake line pressure for each wheel
- Steering
    - Steering wheel angle
    - Steering wheel rate
    - Rack position

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2. M. Kamel Salaani, Gary J. Heydinger and Paul A. Grygier, “Parameter Determination and Vehicle Dynamics Modeling for the NADS of the 1998 Chevrolet Malibu,” SAE 2001-01-0140, 2001.
3. M. Kamel Salaani, Dennis A. Guenther and Gary J. Heydinger, “Vehicle Dynamics Modeling for the National Advanced Driving Simulator of a 1997 Jeep Cherokee,” SAE 1999-10-0121, 1999.
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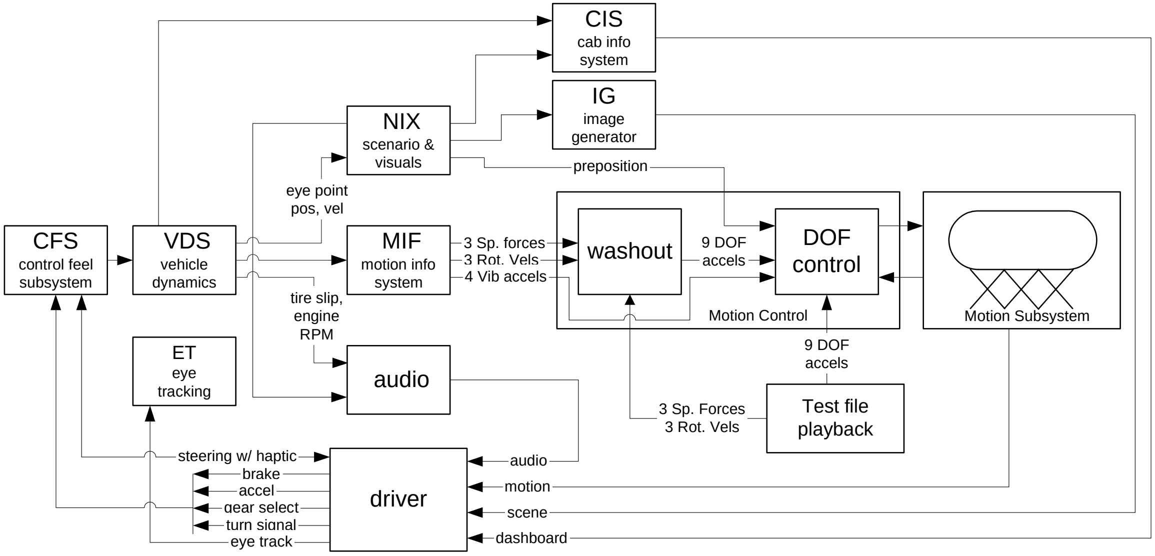
Motion Base Wash-out and Tuning

The NADS-1 motion system provides motion cues to the driver using a 9 degree-of-freedom (DOF) motion system that responds in real-time to the driver's inputs, with significant complexity in its control, operation, and maintenance. The system diagram below illustrates the major subsystems that work together in real-time to present the simulated environment to the driver. The motion system is physically comprised of the motion control system (washout and DOF control) and the motion subsystem (the machine elements).



Block diagram of the NADS-1 subsystems

The motion control system uses a washout algorithm to transform the 3 specific force and 3 rotational velocity commands generated by the vehicle dynamics system into acceleration commands for each of the motion system's 9 degrees of freedom. The DOF controller uses a three-variable control topology to provide good control bandwidth fidelity at both low and high frequencies by using acceleration and displacement feedback signals, and constructing a velocity feedback channel from these. Four additional high-frequency vibration actuators under the cab provide road-surface-specific vibration cues depending on the surface type, and custom vibration command files can be used to emulate different road surfaces.

There is a continual effort to characterize, improve, and monitor the performance of the motion subsystem, utilizing qualitative and quantitative daily operational tests. The qualitative tests involve daily 'test-drives' by Simulator Operations staff to ensure that all the subsystems operate together as intended, i.e. motion, visuals, and cab. Quantitative tests involve the use of specific file playback files to drive the DOFs individually and in coordinated motion. The systems response is analyzed, and performance measures such as step response, roughness, and backlash are calculated. These measures are tracked over time to allow identification of possible trends indicating a change in system characteristics. Transfer functions for each DOF are also routinely generated, to ensure the flattest response possible for the bandwidth in question.

The motion system supports several active areas of research:

- Washout and Limiting
    - Washout and motion apportionment algorithms
    - Motion limiting methods to reduce or eliminate false cues
- Motion Characterization and Monitoring
    - Development of motion performance monitoring methods

Selected references:

1. Schwarz, C. (2005). *Two mitigation strategies for motion system limits*. Paper presented at DSC 2005 North America, Orlando, FL.
2. Schwarz, C., Gates, T., and Papelis, Y. (2003). *Motion characteristics of the National Advanced Driving Simulator*. Paper presented at DSC 2003 North America, Dearborn, MI.

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2401 Oakdale Blvd. / Iowa City, IA 52242-5003

Case Study: Heavy Truck Air Disc Brake

In 2003[1], approximately 436,000 crashes involving heavy trucks were reported to police. 4,289 of these crashes resulted in fatalities. Most of the fatalities involving heavy trucks were the occupants of the light vehicles with which they collided.

In an effort to improve traffic safety on US highways, the National Advanced Driving Simulator (NADS) partnered with the National Highway Transportation Safety Administration (NHTSA) in 2006 to test the effectiveness of air disc brakes on heavy trucks – braking systems widely used in Europe but limited to select applications in the North American market. In the study, 108 CDL-A licensed truck drivers drove the NADS to help traffic safety researchers examine the extent to which shorter stopping distances were able to help drivers avoid crashes.. Drives featured:

- 18-speed Freightliner cab with realistic user interface
- 6x4 tractor configuration
- Fully loaded 53' box trailer
- S-CAM or air disc brakes
- Realistic scenery and traffic behavior

Realistic gear shifting in the NADS heavy truck cab

The objective of this research is to study the functional effects of three different brake configurations:

- Standard truck where S-cam brakes are used on all wheels
- Enhanced truck where only the steer axle is equipped with an enhanced version of an S-cam brake
- Disc truck where all the wheels of the tractor are equipped with disc brakes

The brake parameters were set such that severe braking from 60 mph provides a stopping distance of 307 ft for standard brake, 256 ft for enhanced brakes, and 215 ft for disc brake. This corresponds to a reduction in stopping distance of 17% and 30% if the standard S-CAM brake system is exchanged with the enhanced and disc systems respectively. In this study all these systems are mounted on the same tractor-trailer model

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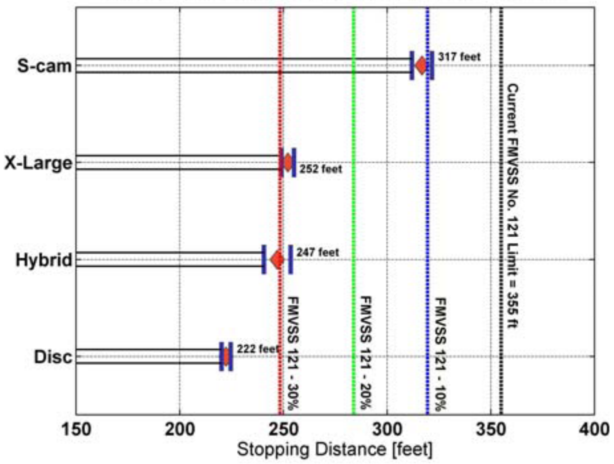
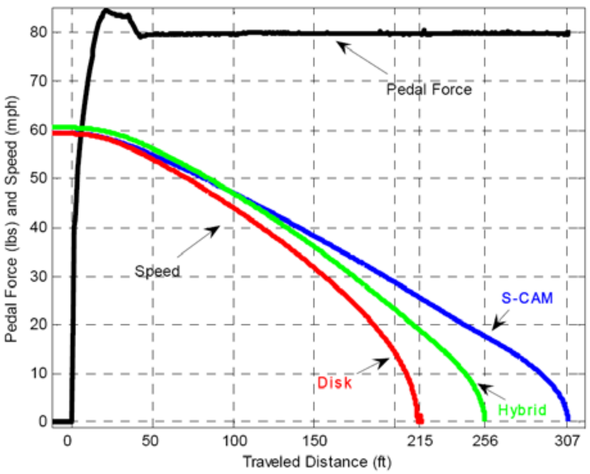
[1] FMCSA's Large Truck Crash Facts 2003



NHTSA Stopping Performance Results



Brake Performance on NADS

The incidence and severity of crashes were analyzed to determine the benefits of disc brakes compared to S-CAM brakes.

The results of this study show that the drivers who used the air disc brakes will have fewer collisions in the emergency scenarios than those drivers using standard Scam brakes or those using the enhanced S-cam brakes. The fundamental hypothesis that this research validates can be phrased in this question: “Does reducing heavy truck stopping distance decrease the number and severity of fatal crashes in situations requiring emergency braking?”

Century-class heavy truck cab at the NADS

References

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Case Study: Heavy Truck Electronic Stability Control Systems

Heavy trucks have long been the dominant mode of freight transport in North America, carrying an estimated 62 percent of the total value of freight in 2006 and accounting for most of the growth in the values of North American freight between 1996 and 2006. While the number of trucks involved in fatal crashes has decreased over the past twenty years and the number of heavy trucks involved in injury crashes has decreased over the past ten years, the numbers are still high, and the unique characteristics of heavy trucks make them particularly susceptible to single-vehicle crashes due to loss of control, such as rollover and jackknife. Research examining electronic stability control systems on passenger vehicles and light trucks and vans suggests a dramatic reduction in the number and severity of certain crashes caused by loss of control, including rollover, but little research has been published on the potential safety benefits of electronic stability systems for heavy trucks.

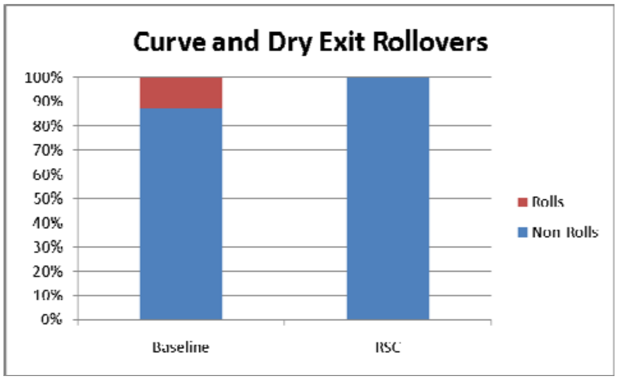
In the study, 60 CDL-A licensed truck drivers drove the NADS to help traffic safety researchers examine the extent to which stability control algorithms were able to help drivers avoid rollovers and jackknifes. Drives featured:

- 9-speed Freightliner cab with realistic user interface
- 6x4 tractor configuration
- Fully loaded 53’ box trailer
- Realistic safety critical driving environment and traffic behavior

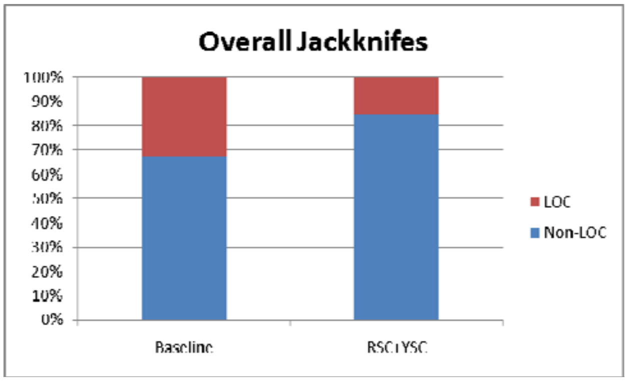
The objective of this research is to study the functional effects of three different stability control configurations:

- Baseline configuration with no stability control
- Roll Stability Control (RSC) configuration for rollover prevention
- Electronic Stability Control (ESC) configuration for rollover and jackknife prevention

The study showed that Roll Stability Control was effective in reducing the frequency of rollovers in situations where drivers encounter changes in roadway direction. The study also showed improvement in yaw rate decay when Electronic Stability Control is present for similar events.



Reduced rollover percentage with RSC



Improved yaw stability with ESC

Century-class heavy truck cab at the NADS

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Case Study: Incontinence Medication

Background

Empirical studies using driving simulators as instruments for examining driver impairment, including the effects of high blood alcohol levels, illicit drug use, or fatigue on driving performance, have a well-established history in human factors research. Driving simulators provide a safe, ethical, and controlled environment in which the effects of impairment on performance can be measured.

Co-investigators at the National Advanced Driving Simulator (NADS) at the University of Iowa and in the Department of Internal Medicine at the University of Iowa Hospitals and Clinics queried whether driving simulators also could be used to evaluate cognitive change and impairment for prescription and/or nonprescription medications. With increased numbers and availability of drugs, as well as demographic shifts leading to an increased demand for drugs (especially those catering to the health and lifestyle issues associated with older generations), devising and refining research methods used to understand the intersections between medications and impairment presented a valuable extension of earlier work in human factors and in Internal Medicine. As mobility is an important quality of life issue, using a driving simulator to evaluate changes to cognitive function due to medication also serves the double function of addressing changes to driving performance that may affect people's ability to drive safely.

Problem Definition

Cognitive impairment is a potential clinical problem in drugs with known anticholinergic actions, especially in the elderly population. This study compared the effects of two anticholinergic agents on cognitive function in comparison to placebo in a healthy elderly population. One drug crosses the blood-brain barrier while the funding agency's drug and its metabolites have shown a lower penetration into the central nervous system. Both drugs are nonselective muscarinic antagonists, with anticholinergic effects.

For the purpose of this study, cognitive function was defined by a participant's memory and thinking skills. Both drugs were approved by the U.S. Food and Drug Administration to treat urinary bladder conditions, including incontinence, and marketed in the United States and other countries. Their use in this study was considered investigational in that they had not been reviewed by the FDA for memory and thinking problems.

The primary objective of the study was to assess the effects the experimental treatments on performances in neuropsychological (memory) and driving simulator (phase angle) tests. Secondary objectives were to assess the effects on other performance measures in neuropsychological and driving simulator tests and evaluate the safety of multiple doses in healthy elderly subjects.

The National Advanced Driving Simulator coordinated an investigator-driven, multidisciplinary clinical trial comparing the effect of two medications and placebo on cognitive function and driving safety. NADS staff collaborated with the Departments of Internal Medicine, Neuropsychology, and Pharmacy at the University of Iowa Hospitals and Clinics (UIHC), and with a major pharmaceutical company to develop and implement the study protocol, which included subjects completing a battery of neuropsychological tests and an hour-long drive in the NADS.

Research Approach

The hypothesis was that the drug that crosses the blood-brain barrier will have effects on some aspects of cognition, while the funding agency's drug has been associated with lower incidence of central nervous system side effects. Assessments of the cognitive effects were made by utilizing a battery of neuropsychological tests and the National Advanced Driving Simulator. Single-dose and steady-state testing were conducted using the neuropsychiatric test battery, and the simulator was used for steady-state testing only.

This was a randomized, placebo-controlled, double-dummy, double-blind, 3-period crossover study of 3 treatments administered in 6 sequences. Twenty four (24) healthy male and female subjects between 55 and 75 years of age, inclusive, were enrolled. Each subject participated in the study for approximately 6 weeks.

There was once-daily dosing for 5 days in each treatment period, separated by minimum 5-day washout between consecutive treatment periods. In each treatment period, Neuropsychological Tests alone were performed after a single dose (Day 1), and both Neuropsychological and Driving Simulator Tests were performed on consecutive days at steady state (one on Day 4 and the other on Day 5, in a randomly assigned fashion).

Subjects were administered a neuropsychological battery of tests that assessed the cognitive domains of procedural learning, psychomotor speed, set shifting, working memory, learning and memory, general intellectual functioning, and visuo-perception/construction. A shorter, repeatable battery of tests was also developed to be administered at follow-up visits to assess the neurocognitive effects of the two drugs compared to placebo. Memory Day 4/5, the primary endpoint for the Neuropsychological Tests, was a composite of Auditory Verbal Learning Test (AVLT) Trial 1 total, Trials 1-5 total, and Long Delay total. Each of these variables was standardized, and memory was the sum of the standardized values. This is a new endpoint created to explore possible overall treatment effects on memory.

Phase angle, the primary endpoint for the driving simulator, was a measure of the lag between the speed signal of the lead vehicle and that of the subject's vehicle. Secondary endpoints include root mean square error, steering instability, number of lane excursions, velocity instability, standard deviation of lateral position, accelerator release reaction time, minimum time to collision with blocking vehicle, subjective drowsiness, subjective performance, saccade rate, and fixation rate.

Due to the complexity of the study protocol, NADS collaborated with the UIHC's General Clinical Research Center (GCRC), a unit located in the General Hospital with facilities and staff specifically dedicated to inpatient and outpatient clinical research trials, in order to successfully execute multiple inpatient sessions consisting of laboratory work, dietary and lifestyle restrictions, and neuropsychological and driving tests.

Results

Final results are pending further analysis of data. Initial analysis suggests that the funding agency's drug did not result in cognitive impairment or a reduction in driving performance. Using a high-fidelity driving simulator to examine changes to cognitive function proved to be highly beneficial, particularly in controlling stimuli while driving as well as providing a safe alternative to naturalistic inquiry.

THE UNIVERSITY OF IOWA
The National Advanced Driving Simulator
2401 Oakdale Blvd. / Iowa City, IA 52242-5003

Case Study: Intraocular Lens (IOL) Visual Performance

Background

The development of cataracts as people age results in a worsening of the quality of that person's vision over time. In order to improve the vision of a person with cataracts, it is necessary to perform surgery to remove the damaged lens and replace it with a fabricated intraocular lens (IOL). Every year, more than 1.5 million people have this type of surgery.

New IOLs are continuously developed to provide better vision to recipients and to improve the ease of implantation. Although clinical trials spend significant amounts of time assessing the change in visual performance, they do so from a clinical rather than an applied perspective. Aging populations often note that the continued ability to drive is a key component to maintaining their quality of life. Because of this, it is often a significant consideration in the decision to have cataract surgery and in the selection of which IOL is most appropriate. Driving research evaluating the impacts of IOLs on visual performance in driving provides an applied assessment of IOLs that would be meaningful to IOL manufactures, eye health practitioners, and recipients of the IOLs. Because of the unique nature of this study and the importance of controlling light and the appearance of objects on in the driving environments, driving simulation provides a safe and controlled environment in which to compare different types of IOLs

Problem definition

Intraocular lenses have the potential to impact visual performance in low-contrast situations. This study assesses the impacts on nighttime driving associated with three different types of intraocular lenses.

The study's objective was to quantify the differences between the funding agency's IOL with two of its competitors' IOLs in subjects implanted in a previous study conducted by the funding agency. The primary aims of this study was to (1) determine the differences between the funding agency's IOL and a second IOL in visual performance measures associated with driving, and (2) determine the differences between the funding agency's IOL and the third IOL in visual performance measures associated with driving.

The secondary aims of this study was to (1) determine differences between the funding agency's IOL and the second IOL in driving performance measures, and (2) determine differences between the funding agency's IOL and the third IOL in driving performance measures.

Research approach

This was a single-site follow-up study of the multi-site study previously conducted by the funding agency. Subject selection was limited to subjects who completed the funding agency's original study, underwent cataract extraction, and received one of three intraocular lens implantations in one eye. Based on previous research, it is estimated that a sample size of 40 subjects per cell is sufficient to detect the difference in visual and driving performance measures between the three lens groups.

This study involved two 2-cell comparisons. Independent comparisons were made between the funding agency's IOL and the second IOL, and the funding agency's IOL and the third IOL. To facilitate these independent comparisons, subjects with the funding agency's IOL underwent two separate data collection visits.

In this study subjects completed two tasks: a reaction time test and object detection and identification tests while driving. The reaction time test was designed to measure the subject's latent reaction time to the presentation of signs on the roadway, so that individuals' driving performance can be corrected for variations in reaction time between subjects. A series of ten signs were presented to the subject at a simulated distance of 20 feet in front of the driver. When the driver could identify the content of the sign, the subject presses a button and repeats the content of the sign aloud. To determine average reaction time for the subject, only correctly identified signs from the last five signs are considered. The median of the reaction time for the correct responses were then determined.

After the reaction time test, subjects were given the opportunity to drive the simulator in order to become familiar with the handling of the vehicle. Following the familiarization drives, subjects drove 8 study drives, which were approximately 10 minutes in length. They consisted of a rural roadway and an urban setting that were presented to the subjects under two visibility conditions: clear weather at night and foggy weather at night. Visual performance measures and driving performance measures included recognition distances for road signs and roadway obstacles, detection distances for road signs and roadway obstacles, number of correctly identified signs and objects, reaction time to lead vehicle

braking, lead vehicle braking correctly identified, lane exceedences, and eye glace behavior.

After completing all study drives, subjects completed visual acuity and contrast sensitivity vision tests. Subjects had the pupil of the eye with the original study lens implant dilated. Once dilated, the subject’s visual acuity and contrast sensitivity under photopic and mesopic conditions (with current spectacle correction) were tested utilizing an Optec® vision tester.

Following collection of the data, the raw data files were reduced to provide distances at which the subject detected or recognized each object or sign and detected each braking event. All distances were adjusted to accurately reflect subject reaction time. Reaction times to the braking lead vehicle and the number of exceedences for each drive were also derived from the raw data.

Participants traveled to the National Advanced Driving Simulator at The University of Iowa in order to participate in the study. NADS conducted all aspects of this clinical trial, including all recruitment, consenting, and coordination of subjects’ travel to and from eastern Iowa. This includes coordinating protocol development, regulatory compliance, recruitment of subjects from test sites, collection of simulator and vision data, analysis of the data, and reporting of the study findings. All staff involved in the direct collection or analysis of the data were masked, including those who collect visual acuity and contrast sensitivity measures and those who execute the in-vehicle protocol. The exceptions were the principal investigators and the NADS clinical coordinator who were unmasked to facilitate recruitment and scheduling of subjects.

NADS partnered with the Carver College of Medicine's Department of Ophthalmology and Visual Sciences to evaluate the IOLs.

THE UNIVERSITY OF IOWA
The National Advanced Driving Simulator
2401 Oakdale Blvd. / Iowa City, IA 52242-5003

Case Study: Lane Change Collision Avoidance Systems (CAS)

Background

Lane change and merge crashes constitute approximately 9 percent of police reported crashes in the General Estimates System data. Previous literature indicates that many crashes occur during lane change maneuvers because the driver is unaware of hazards within the vicinity of the vehicle. Lane change collision avoidance systems (CAS) have been designed to assist drivers in lane change maneuvers by providing alerts when hazards are present in adjacent lanes. Lane change CAS notify drivers of hazards to the side and behind the vehicle through auditory tones or visual icons on the rear- or side-view mirrors. While these systems recently have been introduced in new vehicles, research to support driver performance using various configurations of such systems is limited.

Problem Definition

The objective of this study was to examine driver behavior using lane change CAS to determine what system configuration leads to the safest driver behavior, and to evaluate if proximity warning system-only lane change CAS provides adequate alerts to assist drivers in avoiding lane change and merge related crashes.

Research Approach

The study evaluated and compared five different lane change Collision Avoidance Systems (CAS) types: a representative commercially available proximity warning system, the TRW proximity only CAS system, the TRW comprehensive system, nonplanar mirror on the left side of the vehicle, and a baseline with standard passenger vehicle mirrors. The driver's acceptance of the CAS and decision to use CAS information in making lane change decisions were also evaluated. The age groups involved in this study included subjects 16-17 years of age, 18-21 years of age, and over 65 years of age. 8 males under the age of 18 completed the study.

The scenarios were completed on a four-lane commercial road (2-lanes of traffic in each direction). During each of the scenarios, participant encountered vehicles braking or changing lanes in front of them, forcing them to make a decision to change lanes to the left or to the right or to brake and remain in their current lane. Participants were instructed to complete the drives as quickly as possible without violating traffic laws. The speed limit for all the drives was 50 mph. Each subject drove a familiarization drive to become familiar with the simulator, the driving route, and the lane change collision warning system. After the familiarization drive was completed, participants completed a baseline drive with the collision avoidance system not active, and 4 main drives of approximately 30 minutes in length.

Results showed no significant main effects between the type of system and age. However, there was a significant difference with type of CAS and lane deviation. The greatest deviation came with the non planar mirror and the least deviation with LPWS. The only significant variable affected by age was range. The range was described as the square root of the sum of the longitudinal gap and the lateral distance squared. The range was significantly larger for older driver. The distance was almost double that of 16-21 year olds. These results along with others in this paper indicate that there are both advantages and disadvantages to each of these systems and that not one can be signaled out to be better than the others.

Svenson, A.L., Gawron, V.J., and Brown, T.B. 2007. Performance of Drivers in Two Age Ranges Using Lane Change Collision Avoidance Systems in the National Advanced Driving Simulator. Paper Number 07-0042.

THE UNIVERSITY OF IOWA

The National Advanced Driving Simulator

2401 Oakdale Blvd. / Iowa City, IA 52242-5003

Case Study: PC-Based Driving Simlators

The NADS MiniSim™ driving simulator is a PC-based simulator system equipped with the same world-class technology used in the NADS-1 simulator. It is a low-cost alternative to the more sophisticated NADS-1, and has a more flexible structure. It can be easily customized to specific needs while remaining compatible with the powerful tools developed at NADS for creating realistic virtual environments and complex scenarios.

Advanced Simulator in a Small Package

MiniSim™ driving simulator with 3 plasma display and quarter open cab setup

The MiniSim is a modular system that can be configured for different needs. It uses two or more regular PCs as the simulator computational engine. Off-the-shelf products can be used for local network connection, visual display, audio components, steering wheel and pedals, and instruments. The software consists of nine modules: front end operator GUI, terrain database manager, vehicle dynamics, scenario/behavior controller, visuals, audio, control input/feedback system, motion controller, and run configuration manager. This structure is almost identical to that of the software running on the NADS simulator, and most of the upper-level source codes are shared, including terrain database manager, vehicle dynamics, scenario/behavior controller, and run configuration manager. A particular instance of the MiniSim does not require all eight modules to be present, although some modules are considered necessary for the most basic driving simulator configuration. These include the control input/feedback system, terrain database manager, vehicle dynamics, and visuals. A good example of an optional module is the motion controller. Its necessity depends on whether the MiniSim simulator has a motion base.

Front End Operator GUI

The front end GUI provides a user-friendly interface that allows the operator of the MiniSim simulator to select the content of the simulator run and take full control of each drive and playback.

Visuals

The visuals module of the MiniSim is developed on top of a high-performance graphics library ideally suited for real-time simulation. The latest technologies in computer graphics are constantly incorporated into the library, while its core remains stable. The library can be modified to meet special needs in visualization, some of which are not possible with commercial graphics libraries. In addition, it is a cross-platform library that can run on many general-purpose computers instead of expensive special image generators. Hardware updates can be performed easily, quickly, and at a relatively low cost.

Vehicle Dynamics and Terrain Database Manager

The vehicle dynamics module uses the same world-class physics-based dynamics model that drives NADS-1. It calculates real-time high-fidelity own vehicle movement, taking the same vehicle model data as NADS-1 as input. Therefore, the MiniSim can be used as a validation tool for developing new vehicle dynamics models because the results will be identical to those from NADS-1. The terrain database management module is closely linked to the vehicle dynamics module. It provides elevation and other properties of the terrain surface that the own vehicle is driving on. It can easily be swapped between on-road and off-road databases for respected simulation environments, just like NADS-1.

Behavior/Scenario Controller

The core code of the behavior/scenario controller is also identical to that used on NADS-1. Many years of continuous effort has been put into developing and improving tools for designing realistic virtual environments and complex scenarios for the simulation tasks to be run on NADS-1. The results are some of the most advanced yet user-friendly tools capable of producing highly sophisticated driving environments. The outputs from the tools are fed to NADS-1, and they can be used on the MiniSim without modification as well. One of the most powerful parts of the NADS-1 technology is therefore built into the MiniSim simulator. Again, the MiniSim can be used for validating visual database and scenario designs and improvements in vehicle behaviors.

Corvette-based MiniSim™ installed in trailer installed (photo courtesy of Tom Zwica)

Control Input/Feedback System

There are several options for the control input/feedback system on the MiniSim. For the most realistic driving experience, a cab modified from a real vehicle can be custom built, with force feedback and full instrumentation. In a less expensive configuration, an off-the-shelf steering wheel and pedals set can be installed, with a choice of genuine instrument panel, simplified gauges, or virtual panel shown in the visual display. For a baseline set-up, keyboard and mouse control is sufficient for driving the MiniSim simulator.

Motion Controller

The MiniSim system, although very compact, can also have a motion system. In fact, because of its relatively small dimensions, its motion system can be smaller-scale than that of NADS-1. Specific software will be designed for the particular motion system chosen for the simulator, since there are variations between different motion systems. However, the baseline wash-out algorithm will be similar. Naturally, for many purposes, the motion system is not necessary at all.

Flexible System for Customized Needs

The software architecture and hardware requirements of the MiniSim simulator are flexible enough to accommodate the most specific needs of customers. We have already built several very different driving simulators based on the MiniSim structure.

Corvette Simulator. The Corvette simulator is a three-channel display stationary simulator using a genuine partial Corvette cab, with original steering wheel, pedals, and instrument panel. It was designed to be placed in a trailer and demonstrate driving safety to teenage drivers.

John Deere Simulator. The John Deere simulator is a MiniSim simulator. However, it is in many senses close to the NADS-1 simulator. It has a fully instrumented John Deere tractor cab, with a single-channel semi-sphere shaped display that provides 180 degrees of view, including some visibility of the ground. The cab and the display are mounted on a motion base.

Allegra Simulator. The Allegra simulator is a single-channel display, stationary simulator that uses a custom-made cab from genuine parts of a Ford Focus vehicle, with off-the-shelf steering wheel and pedals, and an original instrument panel. This simulator has extended capability for drive playback and performance analysis to demonstrate the effects of drugs on drivers.

Kiosk Simulator. The Kiosk simulator is a low-cost, single-channel display stationary simulator using off-the-shelf steering wheel and pedals, virtual instruments, and no cab. It was built to be part of a kiosk in a shopping mall to improve public awareness of driving simulators and to recruit drivers for driving simulation studies.

In Switzerland, all young men are required to spend a period of time in military service. A significant portion of their exercises includes driving truck convoys across the Swiss countryside and mountainous regions. The FATRAN simulator is a fixed-base simulator system specifically designed to facilitate the training of novice military truck drivers.

THE UNIVERSITY OF IOWA
The National Advanced Driving Simulator
2401 Oakdale Blvd. / Iowa City, IA 52242-5003

Case Study: Training Military Truck Drivers

In Switzerland, all young men are required to spend a period of time in military service. A significant portion of their exercises includes driving truck convoys across the Swiss countryside and mountainous regions. The FATRAN simulator is a fixed-base simulator system specifically designed to facilitate the training of novice military truck drivers.

The FATRAN simulator was developed by Oerlikon-Contraves AG (OCAG) of Zurich, Switzerland. OCAG collaborated with NADS to develop the real-time virtual environment and scenario control software because of the well-known expertise of NADS staff in integrating driving simulation environments. The collaborative effort between OCAG and NADS illustrates the ability of NADS to facilitate development of world-class driving simulators that are not necessarily focused on research.


Swiss-specific urban driving environment

NADS contributions to the FATRAN simulator include the development of a:

- Real-time virtual environment database that tracks information about the state of the driving environment. This database has an interface that provides instantaneous information about any aspect of the environment to multiple subsystems.
- Library of scenario vehicles (trucks, cars, buses, tanks, bicycles and trams) that possess an advanced behavior model.
- Rich synthetic environment consisting of nine geo-typical regions, each nine square kilometers in size. The environment consists of multiple classes of different roadway and intersection types, representing all significant combinations the trainee is likely to encounter in the real world. The intersection elements include controllable signs, crosswalks, islands, interchanges, rest areas and tunnels.
- Sophisticated graphical user interface tools that allow users (military instructors) to design driving exercises and scenarios and monitor trainee performance during training.

Target simulator bank installed at customer's site

After the completion of FATRAN and its delivery to the client, NADS continued its collaboration with OCAG. NADS staff made upgrades to help OCAG develop new markets for FATRAN as a simulator useful for commercial truck driver training, off-road use (with a motion base), and emergency vehicle use.