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CAPABILITIES OF THE FEDERAL HIGHWAY ADMINISTRATION'S HIGH-FIDELITY DRIVING SIMULATOR (HYSIM)

Christopher A. Monk
Science Applications International Corporation
NHTSA R&D, NRD-52
400 7th St. SW
Washington, DC 20590
(202) 366-6827
(202) 366-7237 fax
Chris.Monk@nhtsa.dot.gov

Peter Goodman
MiTech Corporation
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296
(202) 493-3392
(202) 493-3374 fax
Peter.Goodman@fhwa.dot.gov

M. Joseph Moyer
Federal Highway Administration
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296
(202) 493-3370
(202) 493-3374 fax
Joe.Moyer@fhwa.dot.gov

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Capabilities of the Federal Highway Administration's High-Fidelity Driving Simulator (HYSIM)

ABSTRACT

The Federal Highway Administration's (FHWA) High-Fidelity Simulator, called HYSIM, was recently upgraded to better meet the needs of FHWA's Human Centered Systems research program. The HYSIM is a fully interactive driving simulator used for human factors research in highway safety and highway operations. It provides a platform to study driver performance in a broad spectrum of driving situations. It is also used to evaluate the effectiveness of countermeasures developed as a result of identified driver performance problems. The HYSIM's capabilities are highly responsive to the increasing scope, complexity, and requirements of the FHWA's research programs. This paper describes the different modules of the HYSIM and the research areas where it will be utilized. With the upgraded HYSIM currently operational, the Human Centered Systems Team looks forward to conducting important and relevant research in the areas of speed management, run-off-road, intersections, and visibility that will help to improve driver safety, mobility, and productivity.

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INTRODUCTION

The Federal Highway Administration's (FHWA) High-Fidelity Simulator, called HYSIM, became operational in 1983 and was recently upgraded to better meet the needs of FHWA's Human Centered Systems (HCS) research program. The HYSIM is a fully interactive driving simulator used for human factors research in highway safety and operations. It provides a platform to study driver performance in a broad spectrum of driving situations, specializing in infrastructure problems including roadway signs. It is also used to evaluate the effectiveness of countermeasures developed as a result of identified driver performance problems. The HYSIM's capabilities are highly responsive to the increasing scope, complexity, and requirements of the FHWA's research programs. As part of the upgrade, the HYSIM now is equipped with a motion base that increases its fidelity. This paper describes the eight modules of the HYSIM architecture, the software used to run HYSIM, the scenario development process, and a brief description of the FHWA research program areas that utilize it.

MODULAR DESCRIPTION OF THE HYSIM

For the purposes of this paper, the description of the HYSIM has been broken down into eight subsystems, or modules, that roughly correspond with its system architecture (see figure 1). These modules include:

- Computer control and graphics
- Display system
- Car cab
- Motion base
- Sound generators
- Sign generators
- In-vehicle information sources
- Operator's console.

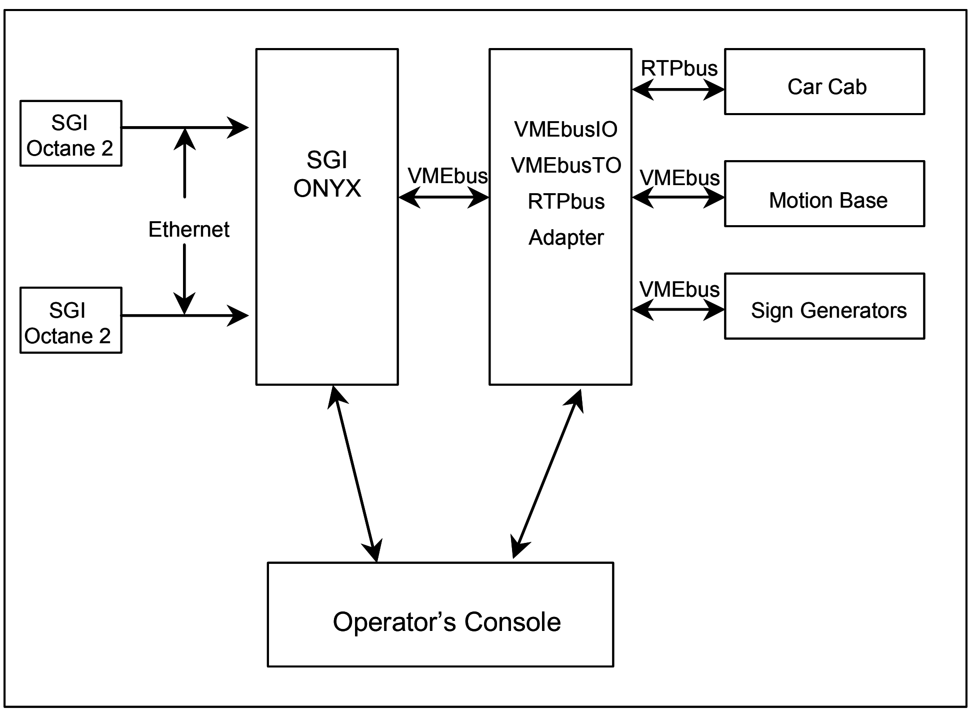

Figure 1. HYSIM configuration.

These HYSIM modules operate in various combinations to meet simulation requirements to study a broad range of Human Factors highway research issues. The simulator was designed on a modular basis to (1) allow maximum

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system flexibility, (2) retain partial operational capability in the event of failure of a subsystem, and (3) facilitate modification and augmentation of the system as the state-of-the-art changes with regard to individual subsystems.

Computer Control and Graphics

The HYSIM is based on an SGI ONYX2/Infinite Reality 2 Computer system, which is rated as being capable of displaying more than 10 million polygons per second. A 60Hz frame rate is obtainable depending on scene complexity. The ONYX2 system provides textured images and full scene anti-aliasing. The system features an architecture allowing for component upgrades to allow faster CPUs, increased polygon rate, increased pixel fill rate, and an increase in number of display channels (or Pipes). The ONYX2 is currently configured as an eight CPU system. The system currently has two Infinite Reality 2 (IR2) Hardware Graphics Pipes.

The SGI ONYX2 provides all control functions of the experimental scenario during real-time HYSIM operations. It performs navigational calculations to keep track of the car position relative to the visually displayed roadway network. The ONYX2 controls all peripheral simulator devices and handles the data collection for the experiment. It can also be used for scenario development when simulations are not in progress. The ONYX2 executes a model of vehicle dynamics on a per frame basis during a simulation to update the driver's eye point based on the most recent driver's input: steering wheel, gas pedal, and brake pedal. The various parameters that define the characteristics of the vehicle can be changed to simulate different vehicles or different road conditions such as a wet or icy pavement.

The key features of the Vehicle Dynamics Model (VDM) are:

- Six degree-of-freedom equations
- Simplified model of a four-speed automatic transmission
- Tire skid limits on side force and braking force
- Steering wheel disturbances
- Motion Base Control based on driver input
- Roadway Surface conditions.

The VDM portion of the real-time software updates car position, heading, and speed. These data are used in navigational calculations and are included in the collected data. Updated car position, heading and velocity are used to update the visual display by placing the eye point at the new position in the current database. The navigational routines track the current roadway for the vehicle/driver combination. A complete description of the visual portion of a scenario to be drawn is maintained in the ONYX2 display list memory. This image is projected onto the front and rear screens. Roadway signs, as projected by separate sign generators appear on the front screen only. The vehicle dynamics provides all information required to control the motion base.

The ONYX2 computer can sense the state of most of the HYSIM subsystems, which are under computer control. The computer-generated scene responds appropriately to the driver's manipulations of the car controls. As the driver depresses the gas pedal, elements in the roadway scene appear to move by more quickly. As the steering wheel is turned, the scene shifts in azimuth to simulate a heading change. Roadway signs, as displayed via the sign generators (described below), maintain registration with the roadway.

Display System

As the car is operated, the driver views a roadway scene and surrounding environment projected onto two screens, one screen to the front and sides of the car cab and one directly behind the car cab. The roadway scene and surrounding environment are computer-generated via the ONYX2 computer with an Infinite Reality 2 Graphics Subsystem. The front screen is a seamless, cylinder-shaped projection screen, centered on the driver's eye-point. This screen provides a horizontal field of view (HFOV) of roughly 270 degrees. The cylinder-shaped screen is designed to accommodate up to five seamless projection systems (i.e. five graphics channels). Figure 2 shows the car cab and the cylindrical front screen. Currently, only one channel is available providing an HFOV of about 88 degrees.

Figure 2. HYSIM car cab and cylindrical front screen.

The second screen is a rear projection screen, located behind the car cab. The driver can view this screen by looking through the rear and side-view mirrors. A high-resolution Barco 1200 video projector projects the image onto this screen. This projection unit is mounted behind the rear projection screen. Together, these display systems combine to project the roadway environment scene. The main portion of the scene comprises computer graphics as generated by the SGI Infinite Reality 2 (IR2) Graphics Subsystem. An Electrohome Marquee 9500LC video projector displays the visual information on the front screen. Collectively, the IR2 and two video projectors are responsible for displaying the roadway and roadway features (such as roadway markings, traffic cones, barricades, etc.) and all the surrounding terrain onto the projection screens. The video outputs of the IR2 are displayed to both a color monitor at the operator's console and the projection screens in front of and to the rear of the car cab.

For the front/side view, system resolution is currently 1920x1200 pixels. Vertically, the field of view is sufficient to fill the windshield for a driver of average height and with moderate pitch and roll. To the rear of the car cab, the projection screen is large enough to fill the rear view mirror and driver's side side-view mirror. The scene is rendered as a fully shaded, textured, anti-aliased image. Available roadway delineation features include solid and dashed lines, posts and cones, and barricades. The color of each feature is programmer selected. In addition to the delineations, the designer can specify trees, buildings, fog, and other vehicles at arbitrary locations. Figure 3 depicts a test subject driving the HYSIM.

Figure 3. A subject driving through a scenario in the HYSIM.

Car Cab

The central feature of the HYSIM is the 1998 Saturn SL1 Sedan car cab. Except for the engine, drive train, fuel tank and lines, and Safety Restraint System (SRS), the car is complete and subjects participating in an experiment "drive" an otherwise intact vehicle. Analog signals from the car cab to the ONYX2 include steering wheel position, accelerator position, and the brake pedal position. Based on driver input and the VDM outputs, several control signals are sent to the car cab to control the meter cluster gauges and the steering wheel centering force motor. A number of discrete signals are fed from the cab to the ONYX2 covering the turn signals, headlights, horn, and high-beam switch (drivers are often informed by an experimenter to utilize one of these signals as a response to a particular event in the scenario). If psycho-physiological measures are collected, the signals are pre-amplified and conditioned by a Gould signal-conditioning unit located in the car cab. The conditioned signals are sent to the workstation or printed simultaneously. In addition, an eight channel Grass Model 12 Neurodata Acquisition System is available to condition electroencephalograph (EEG) signals for monitoring and recording.

Motion Base

The HYSIM car cab is mounted to an electronically actuated motion base that is state-sensed and controlled through the VME bus by the ONYX2 computer. The motion base is fully electric (as opposed to hydraulic or pneumatic) and utilizes three electric motors with actuator arms extending from the motor shaft to the motion base platform (to which the car cab is directly mounted). The motion base offers three degrees of freedom and responds to the driver's actions by adjusting the pitch, roll, and heave of the car cab. The rotational range for pitch and roll is approximately +/- 10 degrees. The linear heave motion range is approximately +/- 5 cm. This system, under computer control, is primarily utilized to generate car cab pitch under positive or negative acceleration and body roll during cornering maneuvers. In addition, it can be utilized to generate low frequency car cab vibrations due to road surface imperfections.

Sound Generators

The sound effects are provided by a nine-channel system. A speaker and bass shaker are mounted in each of the wheel wells of the car cab, to simulate engine noise, tire squeal, and to provide roadway vibrations. The motion

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base, speakers, bass shakers, as well as a powerful subwoofer mounted under the car cab act as a vibration unit that activates when the car operates on uneven terrain (i.e., rumble strips, roadway delineators, possibly even the texture of the road itself). There is also a group of four speakers that are positioned around the car, providing a real-world three-dimensional ambient sound field to the driver. The sound generation system will, when fully operational, utilize the ONYX2 to fully control sound effects. Currently, HYSIM uses analog voltage output to control sound cards whose output is fed to amplifiers, and then to speakers in the car cab.

Sign Generators

The most unique aspect of the HYSIM is its capability to integrate high-resolution road signs into its simulated driving scenarios. While most simulators struggle to offer readable road signs at relatively short distances, the HYSIM offers high-resolution road signs that are readable at a range of 100 to 200 meters, depending on the size of the sign. This range approaches that of human visual acuity. The sign generators consist of four 35mm slide projectors that display overhead and shoulder mounted road signs, and can project phased traffic signals to the front screen. Each sign generator consists of a random access slide projector, a computer controlled zoom lens, a yaw mirror to move the projected image vertically and laterally across the screen, and shutter controls to modulate sign brightness. The images from the sign generators are projected directly on to the cylindrical screen mounted in front of the car. The images are synchronized and superimposed on the image from the ONYX2 to form a composite image of the roadway and signs. This feature was part of the original HYSIM configuration and will be incorporated into the upgraded HYSIM as well.

The zoom lens allows a sign’s image to grow as the driver approaches. The usable zoom ratio is 18:1 for each sign generator. Thus, the sign’s “distance” from the driver could range from 50 to 900 meters. But when larger viewing ratios are required, two or more sign generators can work in a sequence to achieve a longer viewing range. The yaw mirror maintains the sign in the proper relationship to the driver's eye-point as the driver navigates through the database. The Sign Generator shutter mechanisms are under direct control of the ONYX2. By rapidly switching one Sign Generator shutter off and another on, the system allows for the addition of changing signal lights (up to four traffic signal phases in sequence) and signs with flashing lights to the scenario.

In-vehicle Information Sources

Highway Advisory Radio Module/Message System

The HYSIM can simulate Highway Advisory Radio (HAR) messages by utilizing a digital audio system. A series of messages are digitally prerecorded and stored in separate disk files. An SGI OCTANE2 workstation (a separate HYSIM support computer) then randomly accesses an appropriate message at a preprogrammed point in the scenario as directed by the ONYX2 computer. The message is played to the driver as if through the car radio. This system is also used for querying the subject regarding perceptions of a test variable or for task-loading a subject.

In-Vehicle Video Display

The HYSIM can display various types of navigation or other visual aids in the car cab. The display is shown on a 26.4cm LCD monitor mounted on the car cab dashboard to the right of the driver. Generation of the video is handled by the same OCTANE2 that outputs HAR messages. The HAR and in-vehicle video display can be concurrently active. The OCTANE2 is controlled over a LAN by the SGI ONYX2 host to select and update the displayed image. While this feature is not currently available, it will be implemented in the future when the FHWA research program calls for such capabilities.

Operator's Control Console

The last major HYSIM module is the Operator's Console that provides a central location for running and monitoring an experiment. The experimenter and the HYSIM staff can monitor simulator operations from the central control console. The experimenter and staff can also verify that the experiment is progressing according to plan, observe the driver and the roadway scene, and check to assure the data are being properly collected and recorded. The console includes a light panel that allows the experimenter to continuously monitor any of the psycho-physiological measures, but not the vehicle performance measures (braking, speed, etc.). Power switches for the major HYSIM modules and status indicators of modules are currently or will be located at the operator's console.

The operator's computer terminal is located at the operator's console, along with a two monochrome monitors. One monitor is connected to a closed circuit TV camera mounted in the vicinity of the car for viewing the subject's movements. The second monitor provides a view of the front projection screen, which allows the operator to monitor the composite computer-generated and sign generator image for proper sign sequencing. An intercom system allows communication between the driver and the console.

SOFTWARE

The HYSIM software is comprised of three main categories: development software, real time software, and support software. The development software consists primarily of the MultiGen-Paradigm MultiGen Pro II or the MultiGen-Paradigm Creator Graphics Database Tool. This application generates the graphics data for use by the OYNYX2 in real-time scene generation. The program also can provide a roadway centerline file (Path File) that is utilized by the real time software to maintain information on the driver's progress through the graphics (visual) database. This information is used to trigger events such as turning a sign on or off. The visual database is rendered by the ONYX2 using the SGI Performer Tool.

The real-time software, called hydrive, assumes complete control of all HYSIM subsystems while the HYSIM car cab is being driven. Hydrive is responsible for initialization of devices, reading the state of and/or controlling all HYSIM devices, controlling the rendering of the visual scene, generating the car cab and ambient sounds via control of the auditory subsystem, and control of the motion base. It is also responsible for the restoration of devices to a fixed, determined state at the end of the program.

The support programs are for calibration and diagnostics. All HYSIM programs are written in C programming language. The calibration program "recal" is used to calibrate analog-to-digital converters and digital-to-analog converters to the devices they sense or control, respectively. There are a large number of diagnostic routines that are used to control and test individual HYSIM subsystems (e.g., HAR) in isolation. Controlling and testing in isolation allows specific hardware problems to be located more easily than during a real-time drive.

The HYSIM software is dynamic. It is continually modified and upgraded as necessary to improve performance and to add new capabilities. These new capabilities may be enhancements to the visual system or the integration of an entirely new hardware subsystem into the HYSIM.

SCENARIO DEVELOPMENT

Scenario development is a complex task where the experimenter must first define, in detail, the roadway geometry for the entire scenario, the desired roadway markings for each section of roadway, the type and location of roadway signs, data collection zones, and any other special hardware requirements. Typical data available for collection are: (1) speed, (2) elapsed time between events, (3) steering wheel position, (4) number and pressure of brake applications, (5) accelerator position, (6) lateral placement, (7) discrete event occurrences (experimenter defined responses to stimuli), and (8) various psycho-physiological measures (heart rate, galvanic skin response, respiration rate, EEG, etc.). The HYSIM accepts and provides all measurement data in standard metric units.

The HYSIM staff then translates the information provided by the experimenter into a form suitable for use with the MultiGenII Pro or Creator software to generate the graphics file (.flt file) and navigation (Path file) databases. The process of scenario development is iterative and usually requires several test drives by the experimenter and several modifications to the graphics database to achieve the desired roadway appropriate for the study at hand. In addition, optimization of the Graphics Database and, possibly, the real-time software is performed to ensure a fixed frame rate.

The development process, while complex, is nonetheless simple enough to allow tailoring of a scenario to the requirements of each individual study. New scenarios and driving situations are generally created for each study. Some studies may require the development of a new HYSIM capability such as a new in-vehicle information source (device), which may result in the development of both new hardware and software capabilities for the HYSIM.

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Once the experimenter accepts a scenario, pilot subjects are run to ensure that the protocol developed for running subjects works well for the current study. After the scenario has been confirmed and the protocol completed, data collection commences. Each developed scenario is catalogued in a library. Subsequently, any previous scenario, or portion, can easily be added to a new scenario to save development time for future studies.

HYSIM RESEARCH APPLICATIONS

Together, the modules equip the HYSIM with capabilities that include the simulation of: (1) various road surfaces and roadway surface conditions, (2) various sets of vehicle dynamics to simulate different vehicle types, (3) fog and other atmospheric effects, (4) wind and road noises, (5) a siren sound activated when the driver exceeds a certain preset speed, (6) HAR or other messages, and in vehicle video displays of, for example, in-vehicle navigation aids, (7) sloped driving surfaces, and (8) rumble strips or tire vibration. An important part of FHWA's work is the evaluation of road signs for the Manual of Uniform Traffic Control Devices (MUTCD) and other resources. However, as previously mentioned computer-generated road signs in simulators generally do not have adequate resolution to test signs in the simulated environment. As a result, the HYSIM's unique capability to display high-resolution road signs and phased traffic signals in the roadway scene using computer-controlled 35mm slide projectors is extremely valuable for FHWA's research program.

In the past, the HYSIM has been a useful tool for FHWA researchers studying safety and operations issues. Now the upgraded HYSIM, with its new motion base, will continue that tradition utilizing modern technology. The HCS team at the FHWA currently has a research agenda addressing issues in the areas of run-off-road, speed management, intersections, and safety management. A brief description of each of these areas and the role that the HYSIM will play in addressing the specific human centered issues follows.

Run-Off-Road

The run-off-road program area is concerned with traffic events where a vehicle unintentionally leaves the roadway, and can result in vehicle rollovers or crashes with fixed objects. These types of crashes are a significant source of highway-related fatalities, injuries and property damage. The FHWA is conducting a high-priority program to investigate run-off-road events and the HCS team is supporting this program by investigating the relevant human factors. The role of the HYSIM in the run-off-road program will be to help determine driver abilities to stay within traffic lanes and select safe speeds. The high-fidelity feedback of the HYSIM will allow the HCS researchers to investigate the causes of run-off-road events under a variety of conditions. The roadway characteristics that will be addressed include roadway signing, posted speeds, type of roadway whether urban, rural, or interstate, and the presence of a curve.

Speed Management

The risks posed by exceeding the posted speed limit or from driving too fast for the current conditions have been well documented by crash reports and research. In recognition of this problem, the FHWA has created a team to study the issues and develop systematic speed management policy. Current research activities in this area include field observations and lab studies. The high-fidelity driving environment offered by the HYSIM is required to address speed management issues due to the potentially risky situations that may be required to accurately assess causes and countermeasures.

Intersections

To decrease crashes and improve highway operations, the FHWA has a research program to understand problems and develop countermeasures for intersections. Today's ever-increasing traffic demands are resulting in increased intersection congestion and time delays. To address this problem, novel intersection treatments are being proposed to reduce signal-phasing delays, reduce conflict points, and increase system capacity. The HYSIM will be used to examine the human factors issues associated with these innovative intersection treatments, including the comprehension of signs at intersections, the identification of intersection elements that are easily misunderstood, the ability of drivers to learn new traffic patterns, and examination of driver expectancy. Some of the treatments currently under consideration are roundabouts and other novel intersections. Events at roundabouts can be grouped into three categories: failure to yield to vehicles at entry, departure from the circular roadway, and vehicles colliding with central island. Specifically, the HYSIM will be use to examine signage, yield markings, lane widths within the roundabout, and approach lane characteristics.

Visibility

The FHWA's Enhanced Driver Visibility research program is charged with the reduction of adverse events related to poor visibility on the nation's highways. Traffic control devices in various stages of disrepair, adverse weather conditions, driver age, and poor lighting all contribute to poor visibility on roadways. This reduction in visibility can result in the misperception of roadway geometry or warning and regulatory signs, and ultimately in more crashes. The capabilities of the HYSIM are currently being explored to determine its ability to address research questions about the use of retroreflective raised pavement markers. While these pavement markers are not approved for application in the United States, they are currently used in Europe. The HYSIM will be used to help determine the impact of edge line, centerline and other application combinations of raised retroreflective pavement markers to impact driver visibility.

Over the next several years, the HCS team will use the HYSIM to study specific issues in these program areas while maintaining the flexibility to address new and unforeseen issues that have yet to emerge. The overarching theme for the future of HYSIM research, as it has been in the past, will be to address the FHWA strategic goals of improved Safety, Mobility, and Productivity on American highways.