

# Automotive Driving Simulators: Research, Education, and Entertainment

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## ABSTRACT

Automotive simulators offer an immersive environment to operate vehicle systems in a safe and repeatable manner. A fundamental question exists regarding their effectiveness for an identified task. For instance, driving simulators can play a significant role in evaluating vehicle designs, developing safety regulations, supporting human factors engineering research, administering driver training and education, and offering individual entertainment. Some of the driving simulator technology users include automotive manufacturers and suppliers, research laboratories at universities and government agencies, driver education and training programs, and motorsports and racing entertainment venues. In each case, the simulator capabilities and functionality must encompass the expectations of the driver to permit their perception of realistic scenarios for evaluation. This paper investigates three driving simulators in terms of their hardware and software, as well as their applications. The simulator capabilities reviewed vary from a fixed base to motion platform, desk top interface to in-vehicle cabin, and single to multiple computers to execute the software. The needs of an automotive simulator targeted to driver training and community outreach will be examined to identify the challenges and opportunities with this evolving real-time mechatronics system technology.

## INTRODUCTION

An automotive driving simulator is a virtual reality device in which the operator feels as if they are actually driving a ground vehicle [1]. The degree of operator immersion

is dependent on the integrated hardware and software which create the simulator system. It should be noted that the aviation and railroad industries have successfully used flight [2] and railroad [3] simulators for training purposes and engineering design evaluations. Inspired by these specialized transportation simulators, the use of ground vehicle driving simulators for research and other purposes has increased [4], [5]. In particular, vehicle manufacturers, automotive component suppliers, game developers, research universities, government agencies, and companies with fleet vehicles have embraced automotive simulators for a variety of reasons including occupant safety, vehicle performance, system validation, operator training, education, entertainment, and legislative efforts.

During the past few decades, automotive simulators have provided safe opportunities to recreate environments for various types of driver research, education, and training. These systems offer controlled experimental conditions, testing repeatability, ease of experimental changes through parameters or scenarios, cost efficiencies compared to in-vehicle experiments, and safety to drivers [6]. Academic institutions use driving simulators for research and development in areas such as engineering design and human factors, whereas companies with fleet vehicles often focus on education and training to improve overall driver competence. Organizations such as the U.S. Department of Transportation (USDOT), the National Highway Traffic Safety Administration (NHTSA), and the French National Centre for Scientific Research (CNRS), as well as automotive companies including Ford, Toyota, Honda, and General Motors have teamed with universities in collaborative simulator research activities.

For example, NHTSA developed a sophisticated driving simulator, located at the University of Iowa, which caters to many interdisciplinary research issues [7]. Other available driving simulators include the Ford's VIRTTEX driving simulator [8], the Toyota Driving Simulator [9], as well as the DriveSafety™ and STISIM™ Drive simulators. In some instances, custom vehicle simulators have been developed in university laboratories to satisfy specific research needs [10], [11].

In this paper, automotive driving simulators will be reviewed from a research, education, training, and entertainment perspective. This approach will establish a framework to evaluate the challenge of meeting research and training needs with simulator technology. The remainder of the paper is organized into five sections. Section 2 offers further details about the hardware and software features of driving simulators and how they operate. Section 3 expounds on the possible applications of driving simulators. Section 4 provides a case study of three driving simulators. Section 5 contains a needs assessment of driving simulators targeted to driver training and education. Finally, concluding remarks are presented in Section 6.

## SIMULATOR TECHNOLOGY

The complexity of driving increases the challenge of evaluating in-vehicle events. A driving simulator normally consist of five subsystems: a real-time vehicle simulation system executing the vehicle dynamics; motion, visual, and audio systems reproducing vehicle behavior, driving environment scenes, and noise sensed by a driver; a control force loading system which acts as an interface between the driver and the simulator; an operator console for monitoring system operation; and an information management system which coordinates data transfer among subsystems and synchronization [4]. Each of these subsystems is contained in either the hardware and/or software of the driving simulator.

**HARDWARE** - The driving simulator hardware typically consists of the driver controls (e.g., pedals, steering wheel, gear select, etc.), computing systems, and components that aid in reproducing vehicle motion. These components comprise the physical characteristics of the simulator which allows the user to "feel" as if they are in a real car. Figure 1 illustrates an overview of the typical driving simulator technology. The operator (driver) selects inputs through the simulator hardware, which are in turn supplied to the digital I/O (DIO) or the analog-to-digital converter (ADC) channels for computer processing. After the inputs are processed, the output signals are sent through the digital-to-analog converter (DAC) or the DIO channels to the operator (driver).

Driving simulators can feature either a fixed-based or motion-based platform. A fixed-based driving simulator has no platform movement and subsequently, lower levels of required technical support which make them suitable for use in many training and entertainment

venues. In contrast, motion-based driving simulators can range from one to six degrees of freedom (longitudinal, lateral, bounce, roll, pitch, yaw) with electric, hydraulic, and/or pneumatic actuators. The most common type of field application is research and development within industry, education, and government agencies due to their complexity and engineering support requirements.

**SOFTWARE** – Real-time executing software that provides the vehicle dynamics, projected environment scenarios, and data acquisition are essential to an effective driving simulator (refer to computer block in Figure 1). Accurate vehicle dynamics and user-defined test scripts with traffic and specific automotive platforms assist in the creation of believable, immersive environments. The driving simulator algorithms are also responsible for feedback and motion cueing in concert with the simulator hardware. Finally, the software must have integrated safety features (especially in motion-based driving simulators) to ensure occupant safety.

## DRIVING SIMULATOR APPLICATIONS

Automotive simulators have been applied in research, development, education, training, assessment, licensing, certification, and entertainment [12]. Industries use driving simulators for training; whereas, most colleges and universities apply simulators for research. Some of the automotive research involving driving simulators consists of vehicle system development, safety improvement, and human factors engineering studies [4]. The complexity of the driving simulator and its interaction with research studies is shown in Figure 2. For example, a complex motion-based driving simulator may be needed for vehicle development in comparison to driver education and training (Figure 2a). However, human immersion (i.e., human-interface interaction) with the driving simulator is important for driver education and training since it must replicate a vehicle to the operator. The inverted pyramid (Figure 2b) displays the research that may be typically performed using an actual vehicle. The use of automobiles is more likely for vehicle development activities than human factors engineering research due to safety and cost concerns in the latter.

**VEHICLE DEVELOPMENT** - Driving simulators are often used for developing and improving vehicle subsystems. Shiiba and Suda [6] developed a multibody-based driving simulator for vehicle analysis. The effects of suspension geometry and the mechanical characteristics of the vehicle's components can be evaluated before any prototyping using multi-body analysis. The driving simulator had a six-axis motion-based platform which emulated the lateral acceleration of an automobile in cornering, and longitudinal acceleration in braking and accelerating. The vehicle dynamics calculation was performed by two PCs – real time multi-body dynamics calculation; and engine, transmission, brake, and tire/road forces calculations. Three computers were used to create the graphics, control the motion system, and generate the reactive force. Chen and Usui [13] evaluated the use of

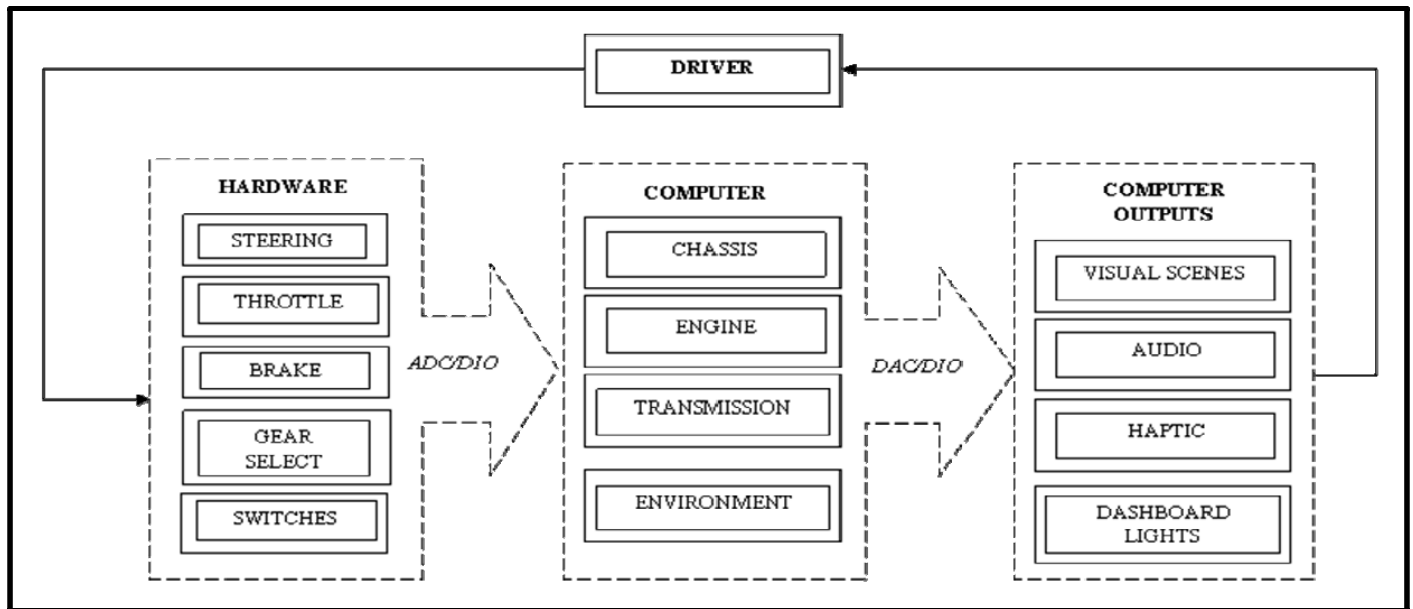


Figure 1: Integration of Human-Vehicle and Mechatronic Features in a Driving Simulator

a steering assistant controller to reduce vehicle road departure crashes. A desktop computer based driving simulator was applied in the research. The steering wheel featured a commercially available force feedback game pad from Microsoft.

**IN-VEHICLE SYSTEM DESIGN** - A number of in-vehicle systems provide drivers with information and services to assist in the operation of their automobile. Vashitz *et al.* [14] used a driving simulator to evaluate the safety benefits and risks of in-vehicle displays for driving in long tunnels. The variables measured in the experiment included driving performance, distraction, mental workload, and physiological characteristics. Fifteen participants experienced three driving sessions: high-information display, low-information display, and no display. The authors concluded that in-vehicle systems improve safety and their benefits offset their distraction. The study was completed using a Systems Technology (STI) STISIM fixed-based simulator featuring a 1995 Rover sedan. The virtual simulation tunnel was presented on a wide screen in front of the vehicle. A number of loud speakers were placed around the vehicle to create the necessary audio experience. Takayama and Nass [15] investigated in-car vehicle services (traffic and road conditions, navigation assistance, weather) and concluded that they were highly favored among drivers. A STI driving simulator was again used which featured a rear projection screen, a gas pedal, a brake pedal, a forced feedback steering wheel, and a driver's seat.

A study by Hatfield and Chamberlain [16] examined the effect of radio and audio sounds from an audio visual entertainment system on drivers. The authors concluded that these in-vehicle systems do not pose a serious risk on driver safety. Using a driving simulator, twenty-seven participants completed vehicle drives under three different conditions: without audio materials, with audio materials from a movie, and with audio materials from a

radio. The driving simulator consisted of a car body with a steering wheel, an automatic transmission, and accelerator and brake pedals. Visual scenes were projected on three screens, providing a 135° field of view. Engine noise, tire screeches, and collision sounds were provided by the STI simulator software.

**PSYCHOLOGY AND HUMAN FACTORS RESEARCH** - A popular research topic for driving simulators examines the behavior of drivers in various age brackets. Young *et al.* [17] used a driving simulator to measure the effects of eating and drinking while driving. The driving simulator was fixed-based with a Ford Mondeo as the chassis. The vehicle's original controls were connected to a computer, running STISIM Drive software version 2.06.04. A haptic feedback steering wheel was integrated into the steering column, and audio was produced in Dolby Pro Logic with a low frequency subwoofer placed under the car for vibration. The computer was equipped with a 1.2 GHz processor, CreativeT 3D video and audio cards, and NVIDIA GeForce2GTST hardware. The visual scene was projected onto a large forward screen at 1024x768 pixel resolution. The field of view was at the driver's eye point of approximately 60° horizontal and 40° vertically.

Boyle *et al.* [18] examined whether individuals with obstructive sleep apnea syndrome (OSAS) had impairments in driving performance. A STI selected simulator offered a fixed-based with a 150° forward view and a 50° rear view. The components were a game controller steering wheel, accelerator pedal, brake pedal, and a LCD monitor to display the roadway scenes. The authors noted the effects of distraction and experience on situational awareness.

**EDUCATION AND TRAINING** - The use of automotive driving simulators for education and training assessment are becoming more common for novice and older drivers. Driving simulators offer a safe and controlled