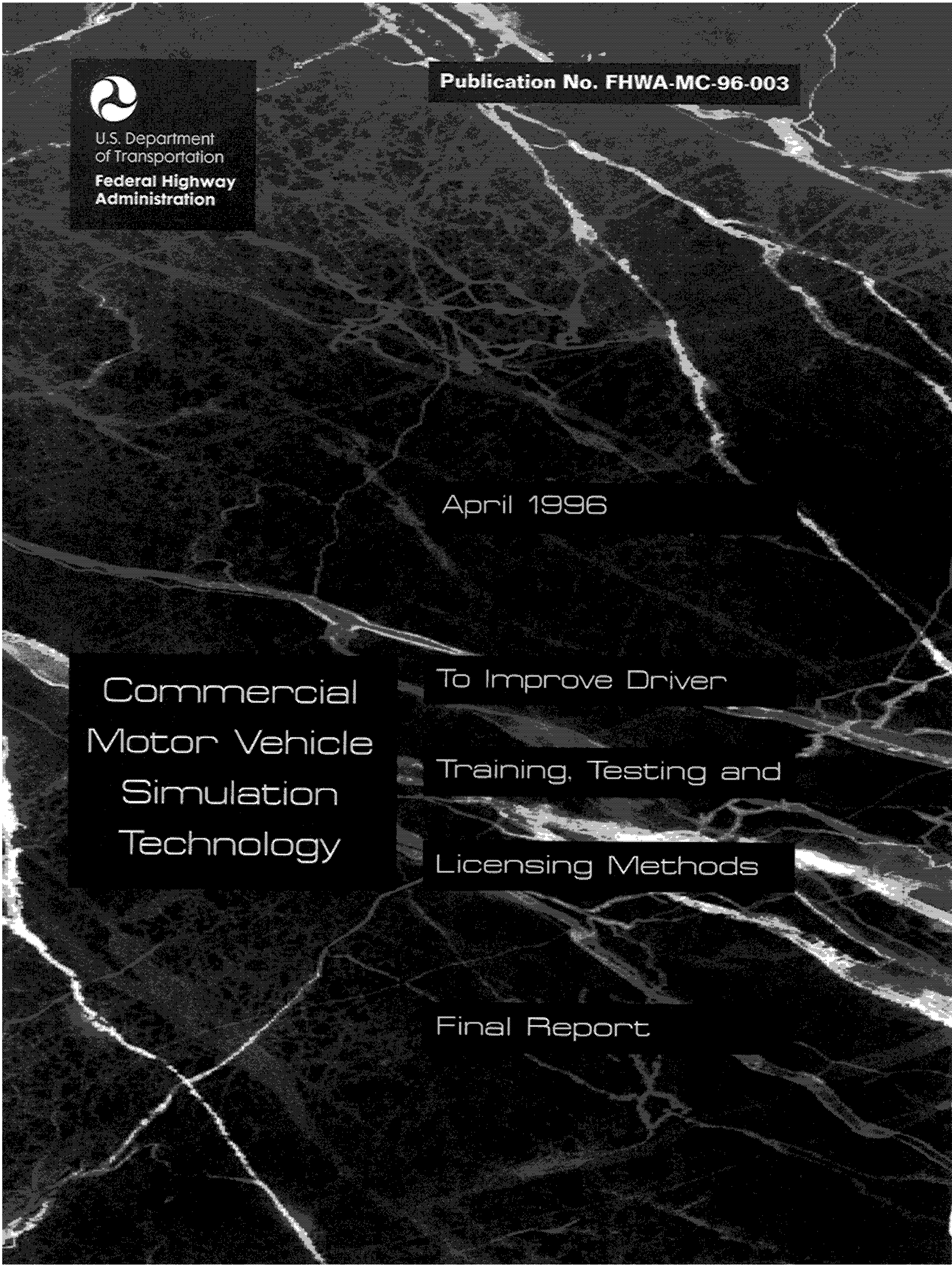

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U.S. Department of Transportation
Federal Highway Administration

April 1996

Commercial Motor Vehicle Simulation Technology

To Improve Driver Training, Testing and Licensing Methods

Final Report

FOREWORD

This report documents the results of a comprehensive study to assess the ability of currently available, and near-horizon (i.e., available within one year), Commercial Motor Vehicle (CMV) simulation technology to improve driver training, testing and/or licensing. This study involves identifying and evaluating current and near-horizon CMV driving simulator technology. The results will be used to develop recommendations for criteria (FHWA standards) for the use of simulators in training, testing and/or licensing programs.

This report discusses the relevant literature, highlights important areas where there is little or no information, and describes the results of subsequent project activities intended to obtain the missing information.

This report will be of interest to anyone interested in the use of simulation technology in the training and licensing of heavy truck and bus drivers in both the Federal civilian and private sectors.

NOTICE

U.S. Department
of Transportation
Federal Highway Administration

400 Seventh St., S.W.
Washington, D.C. 20590

JUL 30 1996

EDITORS AND CORRESPONDENTS

The Federal Highway Administration (FHWA), Office of Motor Carriers (OMC) has issued a report titled "Commercial Motor Vehicle Simulation to Improve Driver Training, Testing, and Licensing Methods, Final Report" (FHWA-MC-96-003).

In the report, the contractor, Applied Science Associates (ASA), Inc. (Butler, PA), evaluated truck driver simulators in the United States and Europe, and assessed the feasibility of using simulation technology in the trucking industry. The report recommended that FHWA validate this technology, which could greatly improve driver proficiency. A Validity Study is underway which will involve a Phase 1 research design, and a Phase 2 actual validation experiment. The Science Application International Corporation (SAIC, McLean VA), FHWA's Turner-Fairbank Research Facility on-site human factors support contractor, will conduct Phase 1.

Based on the ASA research, the Digitran SafeDrive 1000 (Logan, Utah) will be the testbed for the validation initiative. The device has high visual, auditory and motion system fidelity and appears most readily adaptable for truck driver training, testing and licensing. Before beginning the validation experiment, OMC will assess new developments in the simulator field. Anyone with information on new truck driver simulators should call Mr. Jerry Robin, OMC Project Manager, 202-366-2985 or Mr. Ron Finn, Project Co-Manager, 202-366-0647.

Copies of the report are available by writing or faxing your request, which specifies the publication number and desired quantity, to:

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Sincerely yours,

George L. Reagle
Associate Administrator
for Motor Carriers

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16. Abstract

The purpose of this study was to assess the feasibility and extent to which commercial motor vehicle (cmv) simulator technology is being used in the training, testing, and/or licensing of CMV drivers.

This report documents the results of a comprehensive effort that includes: a literature review, the development of functional requirements for CMV driving simulators, the experiences of other government agencies and private sector organizations with training simulators, and a description and assessment of United States and foreign CMV driving simulators.

Conclusions and recommendations are presented for further research and development.

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COMMERCIAL MOTOR VEHICLE SIMULATION TECHNOLOGY TO IMPROVE DRIVER TRAINING, TESTING AND LICENSING METHODS: FINAL REPORT

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EXECUTIVE SUMMARY

A study was undertaken to explore the application of simulation technology to the training testing, and/or licensing of commercial motor vehicle (CMV) drivers. This study surveyed existing technology and addressed the feasibility of applying current and near-horizon driving simulation technology to the CMV driver training and licensing environment.

The study, conducted under the auspices of the Federal Highway Administration Office of Motor Carriers (FHWA/OMC), was designed to address the following objectives.

- Compare existing CMV driver training/testing requirements (based primarily on skill and knowledge objectives derived from the FHWA *Model Curriculum for Training Tractor-Trailer Drivers*[20]) to elements which can be trained/tested by existing or near horizon simulator technology.

- Develop a set of functional requirements, using the Model Curriculum skill and knowledge objectives, that describe the physical/functional characteristics that a simulator must possess in order to effectively train and/or test the CMV driving objectives.

- Determine the relative benefit of training/testing each CMV driving objective using simulator technology. That is, given the objectives that could potentially be trained/tested on a simulator, which ones would show the greatest benefit from simulator training/testing?

- Examine and evaluate CMV simulator technology that is currently in use and prototype simulator technology that will soon be available. Determine the ability of existing simulators and the potential of the prototype simulators to meet the physical and functional characteristics identified for high-benefit CMV driving objectives.

- Identify and recommend a simulator to be used in a possible follow-up FHWA study for the purpose of validating the use of simulation technology in CMV driver training and/or licensing, and make recommendations for potential future research.

A review of the simulation and CMV literature identified and provided descriptions of many of the existing CMV simulators. However, there were several prototype devices that were not identified in the literature. There were also no CMV driver training simulator evaluations studies published in the literature. Information about prototype devices was obtained by attending two international conferences devoted to CMV driving simulators and through conversations with, and visits to, manufacturers and experts in the fields of CMV driver training and simulation.

Criteria in the form of functional requirements were developed to assess simulators against a common standard. The primary sources used in the development of the functional requirements were an unpublished truck driving task analysis sponsored by FHWA in 1990 and the *FHWA Model Curriculum for Training Tractor-Trailer Drivers*. The functional requirements were derived from these sources with the assistance of Dr. James McKnight, a recognized expert in driving simulation. Two reviews of the functional requirements were conducted by experts in CMV driver training and simulation.

The final functional "requirements" (see Section 3) were developed solely for the purpose of comparing simulators on functional capabilities during the site visits and are not intended to serve as mandated federal, state, or local government standards.

Twelve simulators (six U.S. and six foreign) were assessed by interviewing manufacturers and/or users and driving each of the simulators to assess their capability with respect to the functional "requirements". Given that the functional "requirements" are in the form of simulator capabilities and not human performance criteria, the simulators were rated on whether or not the capabilities assessed were "adequate" with respect to the functional requirements. A rating of adequate implies that the simulator has all/most of the visual and response system capabilities called for by the functional requirement. A distinction was made between features that were rated as adequate/inadequate and "not available." This study presents an assessment of the simulators in their stage of development at the time of the review. It does not present manufacturers' comments asserting that they can/will provide a missing capability or improve an inadequate one, nor does it postulate on the potential of a given device. There is no doubt that the designers and manufactures interviewed have the technical expertise and capability to add or improve features of their simulators. However, such decisions are typically driven by market and resource considerations that are privy to the manufacturers and outside the scope of this effort.

Manufactures in both the United States and Europe have reported that they are working with, or have been approached by, trucking companies interested in utilizing driving simulators in the training of their drivers. This current interest appears to be focused on the high-fidelity, full-mission simulators. This interest is attributed to the fact that potential buyers (i.e., training organizations, including trucking companies) are inexperienced with training simulators and in the absence of information on driving simulator cost-training effectiveness gravitate toward devices that most resemble an actual truck. Although trucking companies are expressing interest in the high-end simulators, they have to date only purchased some of the low- to mid-fidelity devices.

That there is interest in, but few purchases of, the high-fidelity, full-mission simulators is attributed to the prices of these devices, which range between $700,000 and $900,000 dollars. There are many advantages to using a simulator versus an actual truck for driver training. However, it is assumed that it is the absence of empirical data on cost-training effectiveness that inhibits carriers and other potential buyers from making such a large financial commitment.

Based on the findings of this study, four recommendations were made:

1. *If FHWA elected to select a single simulator for validation, then the Digitran SafeDrive 1000 should be used as the test bed for further study of the feasibility of applying simulator technology to CMV driver training and/or licensing.* The SafeDrive 1000 offers the following advantages. It is fully developed and commercially available. It is a full-mission, high-fidelity simulator and thus is more likely to satisfy validation and training effectiveness criteria. This recommendation is subject to review, pending technological advancements prior to the conduct of the actual validation effort.

2. *The FHWA should conduct/sponsor research on CMV simulator fidelity and training effectiveness.* This can be examined for each subsystem, i.e., motion, visual, and sound.

3. *The FHWA should conduct/sponsor a study of the training effectiveness and cost effectiveness of part task simulators.*

4. *The FHWA should conduct/sponsor an effort to establish performance criteria for simulator-based driver training tasks.*

The rationale for these recommendations and supporting information are contained in the body of this report.

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SECTION 1

INTRODUCTION

Simulation in the Training and Licensing of Commercial Motor Vehicle Drivers

The Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA) support research, development, testing, and evaluation programs that are designed to improve the safety of the nation's highways. Improved training, testing, and licensing methods are an important part of that effort. There are a number of studies and development efforts that have been investigated or are currently attempting to demonstrate the applicability of training devices, i.e., driving simulators, for these purposes. It is possible that driving simulators may play a significant role in the areas of truck driver training, testing, and licensing. This report presents the results of research conducted to help determine the potential of driving simulators in these areas.

The study reported herein surveys existing technology and addresses the feasibility of applying current and near-horizon driving simulation technology to the training, testing and/or licensing of Commercial Motor Vehicle (CMV) drivers. As defined in 49 Code of Federal Regulations, Part 383.5, CMV is defined as a vehicle, or combination of vehicles, that:

- Is used to transport passengers or property, if the vehicle or combination of vehicles has a gross vehicle or combination weight rating (GVWR or GCWR) of 26,001 pounds or more; or

- Is designed to transport 16 or more passengers, including the driver; or

- Is of any size and is used in the transportation of hazardous material requiring placarding.

Simulators have been widely utilized for training, licensing, and performance assessment in the airline industry, but have been relatively recently introduced to CMV driver training. Simulating the operation of a CMV or other road vehicle requires the representation of far more complex visual stimuli to model the increased density and interactions with objects and other vehicles encountered on the road. Those simulators or training devices that were available for CMV driver training are what are known as *part task trainers*, i.e., designed to impart training on a specific subset of driving skills.

Recent developments in CMV driver training technology have resulted in increased capabilities in existing part task trainers. In addition, new driver training simulators have emerged that utilize motion systems and advanced visual imaging technologies, and purport to address all or most of the CMV driving tasks. These "full-mission" simulators and the enhanced part task trainers have kindled an increased interest from trucking companies, driver training schools, and the FHWA in the utilization of this technology for driver training. Consequently, the FHWA Office of Motor Carriers (OMC) decided to explore the feasibility of utilizing simulation technology in the training and licensing of CMV drivers.

Objectives

To explore the feasibility of utilizing simulation technology in CMV drivers' training and licensing, the study was focused on meeting five objectives. These objectives, which were defined in FHWA's original Statement of Work and expanded as the result of the literature review, are to:

1. Compare existing CMV driver training/testing requirements (i.e., skill and knowledge objectives) to elements which can be trained/tested by existing or near-horizon simulator technology.

2. Develop a set of functional requirements describing the physical/functional characteristics that a simulator must possess in order to effectively train and/or test the CMV driving objectives.

3. Determine the relative benefit of training/testing each of the CMV driving objectives, using simulator technology. That is, given the objectives that *could* be trained/tested on a simulator, which ones would show the greatest potential benefit from simulator training/testing?

4. Examine and evaluate CMV simulator technology in the U. S. and Europe that is currently in use or will be available soon. Determine the ability of existing simulators, and the potential of prototype simulators, to meet the physical and functional characteristics identified for the high-benefit CMV driving objectives.

5. Identify and recommend one or more driver training simulators to be used to conduct a validation study of an application of simulation technology to CMV driver training and/or licensing, and make recommendations for further research.

Background

FHWA previously initiated a research effort, *Performance Requirements of Simulators Used in Commercial Driver Training and Testing*. However, the project was canceled in 1991 because there were significant innovations being introduced in the simulator industry at that time.

The present study examines and reports on the state-of-the-art CMV simulator technology, and the capabilities that are expected to be available in the near future. The focus of the effort was on assessing current and near-horizon developments in simulator technology in order to make recommendations with respect to the use of simulators in CMV training and licensing.

Report Organization

The remainder of this report consists of five sections.

The next section, Section 2, presents the findings from a literature review of CMV driver training and licensing issues.

Section 3 describes the process used to satisfy the first three objectives (i.e., determining the training/testing objectives a CMV simulator should satisfy) and presents the CMV driver training simulator functional requirements that were developed.

Two sections address the fourth of the five objectives (i.e., examine simulator technology). Section 4 presents the findings from a survey and review of U.S. and European CMV driver training simulators. Section 5 presents the results of a telephone survey of other simulator manufacturers, researchers and government agencies.

The final section (Section 6) presents a summary of the study and recommendations for future research (i.e., Objective 5).

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SECTION 2

LITERATURE REVIEW

Introduction

The literature review was the first task in the project. It was designed to achieve three main objectives:

- Gather descriptive information on existing and near-horizon CMV simulators.
- Abstract information relevant to four research questions.
- Create a bibliography of sources addressing the use of simulators in CMV driver training, testing, and/or licensing.

The principal purpose of the task was to identify, review, and summarize relevant literature that addressed the following four research questions.

- What kinds of Commercial Motor Vehicle (CMV) driving simulators are now available?
- What are the new technologies and prototype designs that will impact CMV technology in the near-horizon?
- What are the characteristics and prevalence of simulators currently employed in CMV driver training?
- What are the performance characteristics and prevalence of simulators currently employed in CMV driver testing and licensing?

Methodology

Relevant studies and other information were identified primarily from on-line database searches, subject matter experts, and driving simulator manufacturers.

To identify pertinent on-line reports and other published documents, the Transportation Research Information System (TRIS), the University Microfilms International's ABI/Inform, and InfoTrac Business Index databases were searched via on-line terminals. To conduct the on-line database searches, key descriptors (i.e., words or phrases) and combinations of descriptors were identified.

The following descriptors and combination of descriptors were used in conducting the TRIS database searches.

- Truck drivers
- Simulator
- Simulation
- Truck drivers and simulators
- Truck drivers and simulation
- Bus drivers and simulators
- Bus drivers and simulation
- Motorcoach drivers and simulators
- Motorcoach drivers and simulators
- Motorcoach drivers and simulation
- Motorcoach drivers and simulation
- School bus and simulators
- School bus and simulation

The ABI/Inform database was searched using the following key words and key word combinations:

- Trucks and simulators/simulation
- Heavy vehicles and simulators/simulation
- CMV and simulators/simulation
- Driver education and simulators/simulation
- Bus and simulators/simulation
- Motorcoach and simulators/simulation
- Motorcoach and simulators/simulation
- School bus and simulators/simulation

While the broad individual descriptors (e.g., truck driver, simulator, and simulation) generated many citations, the more relevant combined descriptors (e.g., truck drivers and simulators or simulation) yielded only a dozen pertinent citations. Neither the individual nor the combined descriptors for motorcoach or school bus generated pertinent citations from either of the on-line services.

Abstracts for potentially pertinent citations were obtained, followed by the acquisition and review of each source deemed relevant to the literature search objectives previously stated. A listing of these citations is provided in the *Bibliography* section.

Simulation for Motorcoaches and School Buses

The literature review yielded no information that applied specifically to motorcoaches. All of the existing and prototype driving simulators reported in the literature are for truck driving simulators. Consequently, the remainder of this section addresses simulation in the context of truck driving training, testing, and licensing.

Driver Training Simulators

The Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA) support research, development, testing, and evaluation programs that are designed to improve the safety of the nation's highways. Improved training, testing, and licensing methods are an important part of that effort. There are several studies and development efforts that have investigated or are currently attempting to demonstrate that training devices, i.e., driving simulators, may play a significant role in the areas of truck driver training, testing, and licensing.

Truck driving simulators have the potential to enable training and testing of driving performance under conditions that would otherwise be too costly or too dangerous. For example, a truck driver could be made to "drive" a simulator over a simulated icy hill or curve at night with a full load with no chance of injury or equipment damage.

A special report in a 1991 issue of Heavy Duty Trucking points out that, "Cost-effective training simulators are becoming technologically possible—there have been astounding leaps in computer graphics and realism—at the same time the driver shortage and the Commercial Drivers License (CDL) are forcing the trucking industry to seek more effective methods for driver training, selection and screening."[1] (Superscripted numbers throughout this report refer to citations in the *References* section.)

Thus, if there are simulators that can provide the necessary cues and performance characteristics, then truck driver training would be greatly enhanced, and testing/licensing via simulator would be highly desirable.

This report examines the relevant literature in these areas. The literature review was guided by an attempt to address the four research questions introduced earlier in this section:

- What kinds of Commercial Motor Vehicle (CMV) driving simulators are now available?
- What are the new technologies and prototype designs that will impact CMV technology in the near-horizon?

- What are the characteristics and prevalence of simulators currently employed in CMV driver training?

- What are the characteristics and prevalence of simulators currently employed in CMV driver licensing?

This section is organized into the following six subsections which present the findings from the literature with respect to the four research questions.

- Simulator Technologies
- Current and Near-Horizon Training Devices
- Description of Existing Simulators
- State of-the-Art Driving Simulator Technology
- Utilization of CMV Simulators in Current Training Programs
- Utilization of CMV Simulators For Testing

The first of these subsections introduces a classification scheme that groups simulators by their technology type. This classification provides a useful background for the subsequent descriptions of existing truck driving simulators.

Simulator Technologies

Since 1991, researchers at the University of New Brunswick, under the auspices of the Canadian Trucking Research Institute (CTRI), have been conducting an investigation into the feasibility of employing simulators for truck driver training and testing in Canada.[2,3,4] The CTRI, along with other Canadian research and industry groups, developed a set of simulator criteria. These criteria encompass a number of conditions, capabilities, and considerations that they believe should be required of a device used for training and/or testing drivers of heavy trucks.

The CTRI researchers conducted a review of existing truck driving simulators and evaluated them against the research criteria. The study identified four basic elements that were incorporated in all of the simulators reviewed:

- Driving Station. Hardware components of the student station which include the seat, steering wheel, gear control, brake, instruments, etc.

- Visual Scene. Includes forward, side and rear views, and mirror views. Some may include traffic control devices such as signs and signals.

- Ambient Traffic (overlaying the visual system). Opposing traffic, overtaking traffic, and side-road traffic are just some of the possibilities here.

- Vehicle Model. This model defines the dynamics of particular vehicle types with various loading conditions.

Another significant element of a driving simulator is a motion platform that enables the simulator to rotate about the horizontal and vertical axes. These systems provide motion feedback to the driver who is braking, turning or "driving" up or down hills. This feature exists on only a few of the driving simulators currently available.

In addition, the CTRI's researchers defined four categories of simulators, based on the technologies they employed - Film, Videodisc, Computer Simulation, and Model-Based Simulation. The four categories are not mutually exclusive, but they provide a convenient classification scheme for driving simulators.

Film. A film-based simulator utilizes a 16 mm film projector which projects driving scenarios on a screen in the front of the classroom. The images are presented from the driver's viewpoint and students respond, via the simulator controls, to the projected images. An important limitation of film-based devices is that the film does not change in response to actions taken by the driver. Thus, the film displays its given images even when an incorrect student action (e.g., a wrong turn) would have caused a change in what the driver would be viewing. The Doron L-300 HGV (described below) is an example of a film-based simulator.

Videodisc. Videodisc-based simulators utilize images from film that are stored on a disk and are under computer control. Unlike film, the videodisc can respond to some driver inputs, e.g., increasing or decreasing the rate at which images are presented in response to the driver increasing or decreasing speed. Examples of videodisc-based simulators are the Doron L-301 and the DuPont TDS (described below).

Computer Simulation. Devices utilizing computer simulation are able to respond to student inputs (e.g., steering, shifting, accelerating, braking, etc.) in real time. The computer is able to determine the vehicle position at all times and instantaneously change the view presented to the driver in response to driver actions.

There can be many variations of this type of device, with widely differing capabilities. They can present realistic-looking front, side, and rear views that are synchronized with the simulated motion of the vehicle, and they can simulate different types of trucks and traffic conditions. However, the price of these devices increases dramatically with increases in the level of realism. An example of this type of device is the Digitran SafeDrive 1000 (described below).

Model-Based. Model-based simulators have their images created by a video camera that is driven around a scale model of a specific area or region. The student is shown the camera images on the simulator screen. The student's driving inputs will change the position of the camera and, as a result, give an illusion of driving. An example of a model-based simulator is the Doron L-300 VMT (described below).

This approach of classifying simulators by their underlying technology is useful since, as the CTRI investigators pointed out, devices within a category have similar capabilities and limitations. The magnitude of the development costs associated with the devices is also similar within a technology category.

Current and Near-Horizon Training Devices

The literature review was specifically designed to address driving simulators that can be used in truck driving training. Not all of the simulators identified are currently available for purchase. Those that are available are identified by an asterisk in Table 2.1. At present, driving simulators are designed to function either as training devices or research devices. Research devices were not considered for this study, since they are used primarily to explore alternative highway and vehicle designs and driver performance under various conditions. In addition, the high cost of research devices prohibits their use for commercial driver licensing, training and testing.

Research devices are also Although small in number, the driving simulators included in this report vary greatly in function, configuration, and underlying technology. Table 2.1 lists the truck driving simulators identified during the literature search, their manufacturers, and technology type.

Note: There are other devices available in other countries that were not identified in the literature review. Information about such devices was gathered later in the study. These devices are identified and described in Section 4.

Description of Existing Simulators

Table 2.1 lists and provides a brief description of the devices identified from the literature review. Most of the information about existing simulators reported here was taken from the Canadian Trucking Research Institute review and product literature obtained from simulator manufacturers.

Table 2.1

Truck Driving Simulators

Simulator Name	Manufacturer	Technology	Approximate Cost[1]
*Doron L-300 HGV	Doron Precision Systems, Inc. Binghamton, NY	Film-based	$250,000
*Doron L-300 VMT	Doron Precision Systems, Inc.	Model-based	$130,000
*Doron L-301	Doron Precision Systems, Inc.	Videodisc-based	$ 55,000
STISIM	Systems Technology, Inc. Hawthorne, CA	Computer Simulation Research and Performance Screening Device	$19,750 to $24,750
I*SIM	I*SIM Murray, Utah	Computer Simulation (Motion System) Pre-prototype Stage of Development	No price established at this time. (see Section for recent price and configuration developments)
*TT150 Trucking Drive Training Simulator	Professional Truck Driving Simulators, a Joint Venture of FAAC, Inc. and Perceptronics, Inc. Ann Arbor, MI	Computer Simulation	$250,000 (Available for lease)
DuPont TDS	DuPont Company, Safety Services Wilmington, DE	Videodisc No longer available for purchase.	$75,000 No longer available
Truck Driver Screening Simulator and Driver Performance Testing System	NBS Computer Assisted Testing Fort Wayne, IN	Videodisc	No longer available
MicroSim Model 100-Roadmaster	MicroSim, Inc. Sterling, VA	Computer Simulation Pre-prototype Stage of Development	Estimated Cost $50,000

Table 2.1 (Continued)

Truck Driving Simulators

Simulator Name	Manufacturer	Technology	Approximate Cost[1]
*SafeDrive 1000 Truck Driving Simulator	Digitran Simulation Systems Logan, Utah	Computer Simulation (Motion System)	$900,000
Iowa Driving Simulator (IDS)	Center for Computer Aided Design The University of Iowa Iowa City, IA	Computer Simulation (Motion System) Research Device	$10 million
National Advanced Driving Simulator (NADS)	Center for Computer Aided Design University of Iowa Iowa City, IA	Computer Simulation (Motion System) Research Device	Under development at an estimated cost of $32 million.
Daimler-Benz Driving Simulator	Daimler-Benz AG Germany	Computer Simulation (Motion System) Research Device	Price not available in literature.
VTI Driving Simulator	Swedish Road and Traffic Research Institute Likoping, Sweden	Model-based (Motion System) Research Device	Price not available in literature.

* Simulator is currently available for purchase as a training device.

[1] Cost estimates may no longer be accurate, but are provided to facilitate relative comparisons among simulators and simulator types.

The following pages describe, in more detail, each of the driving simulators presented in the preceding table.

The **L-300 Heavy Goods Vehicle (HGV)** trainer, developed and produced by DORON Precision Systems, Inc., consists of a truck seat, steering wheel, instrument panel, a five-speed manual gear shift and an automatic gear shift lever, clutch, brake, and accelerator pedals. The company literature states that bus and school bus programs are also available. There is no surrounding cab enclosure or windshield. The trainees view a 16 mm film strip and respond to the changing road and traffic scenes. The film is projected onto a screen in the classroom, allowing up to 24 student stations to operate simultaneously. An operator station records student responses. Doron produces a model version of this system that consists of eight driver stations in a 48-foot trailer.[5]

CTRI researchers concluded that the L-300 HGV is a part-task trainer that falls far short of meeting their criteria. They characterize the device as follows.

> The major strength of the system is its ability to help an instructor evaluate and train students in defensive driving and attitude. It also incorporates a complete, well-packaged training system in specific subjects such as the fundamentals of shifting. A notable benefit of the L-300 HGV is that it allows an instructor to teach up to 24 students simultaneously.
>
> On the negative side, the system suffers from an intrinsic limitation of its technology - the lack of a connection between the scene shown in the film and the actions of the student drivers. Because of this open-loop design, the system is limited in its ability to provide extended interaction between the driver, the vehicle, and the environment. Even on the relatively simple questions of speeding and tailgating, for example, the system does not allow the instructor to properly evaluate the students. As noted above, a portable version of the Doron L-300 HGV requires a dedicated trailer. However, in view of the initial system cost and its classroom space requirements, this is probably not a significant disadvantage. Beyond the essential restrictions of its technology, the L-300 HGV appears to be a well-developed, mature product that can help an instructor meet a limited number of initial training and evaluation requirements.[3]

The **Doron L-300 Vehicle Maneuvering Trainer (VMT)** is an interactive, model-based driver training simulator. The simulator is used to teach trainees to maneuver a tractor-semitrailer in a close quarters docking area. The company literature states that school bus and commercial bus programs are also available. The driver views two large screens that represent the outside view as would be seen through a truck windshield. The screens show TV images projected from a scale model truck traversing a scale model loading area (5 x 6 meters). The scale model truck moves around the model docking area in response to the simulator driver's inputs. Side-mounted and rear cameras on the model give realistic side window and rear view mirror images that are also projected on simulator screens.

The simulator consists of a truck cab with realistic functional steering wheel, gear shift, and accelerator and brake pedals. The simulator requires approximately 183 square meters of floor space. The L-300 VMT system includes a microprocessor in every cab that permits performance scoring. An instructor control panel allows instructors to monitor and evaluate a trainee's performance.[3, 5]

The CTRI study reported the following evaluation of the L-300 VMT:

> This system is a good part-task trainer for teaching maneuvering in a loading dock area and more specifically for backing up. The high level of realism is a result of a well detailed and well lit model. In addition, the drive train modeling and engine noise generation require only a small amount of additional modelling to be quite realistic.
>
> While the L-300 VMT's 5 x 6 meter model board works well in this part-task application, size is clearly a limiting factor in other driver training situations. Even the size of the existing system with its cab screens and model board is likely to be a problem for many training school and carrier premises. In addition, the size is such that the system cannot really be considered portable. A further problem was noted regarding the two front screens. Some members of the evaluation team felt that the driver's view out the front of the full-size cab was rather distorted, and everyone found the distortion from other positions in the cab quite disturbing.[3]

The Doron **L-301 System** is an interactive videodisc training/testing system and includes a fully functional driving compartment and driver analyzer. The Doron L-301 system provides part-task training for truck, commercial bus, and school bus driving. The L-301 system consists of three primary elements: a control center, audiovisual materials, and driving simulators designed to duplicate the driving controls of typical trucks, cars, and vans. The driver analyzer provides a standardized method for evaluating a driver's perceptual and reaction skills in a variety of traffic situations.[3, 5]

The simulator is a self-contained, single user, video game size module. The system presents the student with images from a computer-controlled videodisc player. The CTRI study provides the following assessment of this device:

> The L-301 derives much of its imagery and training from the films in the Doron L-300 HGV film-based system described above. As such, Doron has not really developed this system to the full capabilities of the technology. With many of the scenarios, for example, the driver does not control the speed of the vehicle with the accelerator. In addition, the system does not provide either side view or a rear view. The L-301 does have several features that are not part of the L-300 HGV. For example, it includes a question and answer session designed to test a driver's knowledge of items relevant to the Commercial Driver License (CDL) system being implemented in the United States.[3]

The **STISIM** driving simulator is a personal computer-based, interactive simulator designed to represent a range of psychomotor, divided attention, and cognitive tasks involved in driving. The simulation includes vehicle dynamics, visual and auditory displays, and a performance measurement system. Driving tasks and events are programmable with a unique Scenario Definition Language (SDL) that allows the user to specify an arbitrary sequence of tasks, events, and performance measurement intervals. Up to 30 different tasks can be specified.

STISIM runs on a 486 IBM/AT compatible computer with a 200 Mb hard drive and two high-density floppy drives. A standard 14" color VGA monitor provides the computer and experimenter's display. A 19" color, multiple frequency monitor is used for the driving display. An optical projection display system is available. The auditory stimuli are presented using conventional home stereo components.

The STISIM is commercially available. However, it is not a training device. It is utilized primarily for performance screening (e.g., assessing performance decrement under driver fatigue conditions). Overall performance measurements, such as the total number of traffic law violations, speed limit exceedances, accidents, and total driving time, are collected throughout the driving session. During divided attention task sequences, response times and correct and missed responses are recorded.[6]

I*SIM, Inc. is currently developing the **I*SIM Driving Simulator.** This device is intended to have a modular configuration allowing for the exchange of the driver cab/chassis on top of a motion platform. It will be able to accommodate a wide range of vehicle cabs. However, the two principal applications are that of a generic semi-trailer tractor cab and a generic passenger car cab. The unique parts of each simulator configuration are the cab, vehicle dynamics software code, and the specific roadway areas and database features which can be used for different types of training applications. It can be used in a fixed-facility system or with a motion base. The motion base is comprised of an X-Y platform with a rotating yaw base on which the driver cab is mounted.

The cab is a single-seat, enclosed "cockpit," using real instrumentation, steering wheel, pedals, transmission levers, and seat; it contains visual display CRTs, audio speakers, seat-belt and safety interlocks, and vehicle dashboard instrumentation.

The simulator requires four separate databases: visual, roadway, tire, and audio. The roadway and tire databases interact, via parallel processors, to provide high fidelity, realistic simulations of the performance characteristics of different surfaces. The uses a 25-inch CRT for visual displays. It covers an 180-degree field-of-view for trucking applications, including rear-view mirror insets in the side CRTs.

The scenario controller software in 's host computer complex can control the motion of more than 250 other vehicles in traffic patterns specific to training scenarios. Traffic patterns and conditions of all other vehicles are programmable. It is estimated to be completed sometime in the summer of 1996.[7]

The **TT150 Truck Driving Simulator** was developed by Professional Truck Driving Simulators (PTDS), a joint venture between FAAC, Inc. and Perceptronics, Inc. The device simulates tank truck and tractor-trailer driving. It has three large screen television displays in front of and to the sides of the student. There is a separate instructor station. The instructor can also sit immediately behind the student. In the driver's seat, the TT150 looks and feels almost identical to a standard truck cab with instruments and gauges; safety items; and typical steering, pedal and gear shift equipment.

The computerized systems are menu-driven and require minimal computer knowledge to operate. Instruments and gauges provide the same information and warnings that one would receive from an actual driving experience. The TT150 brochure states that it can be installed in a 48-foot, air-ride van, thus providing mobile configuration with fully self-contained power, air-conditioning, and a 12 student classroom area.[8]

The CTRI study provides the following assessment of the TT150:

> The existing image-generating system in the prototype operates at 14 Hertz - a rate too slow for realistic simulation. This is soon to be replaced. The TT150 does not use a motion system in any form.
>
> The 'world' in which the vehicle will eventually be operated is one of a number of attractive features of the TT150. Plans call for 87 miles of road in a 50 square mile area of flat terrain, mountains, highway interchanges, and city streets.
>
> The TT150 ... uses software-generated views and a software model of a tractor-semitrailer to produce the apparent motion. PTDS plans to allow the users to alter a large number of parameters that will adapt the system to a variety of training needs.[3]

The **DuPont TDS** is no longer offered by DuPont. The inventor of the device, Mr. Hershell O'Dell has obtained marketing rights and indicates that he would like to update and reintroduce the device in the future. However, it is currently unavailable for purchase. The TDS uses videodisc technology. The simulator's physical features are similar to those of the Doron L-301. As with the L-301, a computer retrieves images of traffic, road signs, etc., from a videodisc and monitors student responses. The TDS differs from the L-301 in that its display has a driving condition indicator and an on-screen speedometer.

Student performance is assessed and feedback is presented immediately on the TDS. If a student performs an unsafe action during one of the simulator's 10 driving scenarios, the system stops and displays the correct action, before moving on to the next scenario.[9]

The CTRI's evaluation of the TDS resulted in the following comments.

> As with the two Doron systems described above, the TDS Trainer provides a good evaluation and training device for defensive driving, attitude and situational awareness. It is also likely to be suitable for educating truck drivers about speeding and tailgating. It has a useful, if not very sophisticated, treatment of different driving conditions. The system certainly meets the industry requirement for portability.
>
> As with all videodisc-based devices, the scenarios presented to students in the TDS are limited in the sense that the students must follow pre-determined video sequences. The system's proclivity to randomly select a new scenario, after an error has been committed in a particular scenario, may cause some problems from a tutorial 'point of view.' The TDS ignores all aspects of shifting gears, even to the point of not including a shift lever.[3]

The TDS was introduced in 1989 and withdrawn from the market in 1993 due to low demand. However, one of TDS's developers, Mr. Hershell O'Dell, has obtained rights to the simulator and may seek sponsorship to update the device.[10]

The **Truck Driver Screening Simulator and Driver Performance Testing System** (no longer available) from NBS Computer Assisted Testing consisted of a simulated truck cab, computer system and examiner's scoring console, driver analyzer and printer, visual display/monitors, and interactive video/laser disc players. It also included an automated driver license testing unit. The NBS device exposed students to a variety of road conditions and emergency situations. The Truck Simulator and Driver Performance System contained the following sub systems:

- Simulated Truck Cab
- Computer System and Examiner's Scoring Console
- Driver Analyzer and Printer
- Visual Display/Monitors
- Interactive Video/Laser Disc Players
- Automated Driver License Testing Units
- Electronic Vision Screener
- Interactive Video Testing Software
- NBS Real-Time Simulation Software.

The Simulator introduced realistic sound with interactive visuals to complement the real-time operation of the driver's cab instrumentation and multi-range gearshift.

The Interactive Video Projection system allowed the closed circuit television scenes to change to reflect the reactions and maneuvers of the driver. Front and rear view projection systems create the illusion of true life situations.

The simulator employed interactive video testing software and NBS's proprietary real-time simulation software.[11]

The MicroSim Inc. Model 100 - Roadmaster truck driver training simulator is a prototype system. It makes use of three PCs to generate a vehicle model and to define its motion in a driving environment of roads, buildings, and other vehicles. CTRI reports that MicroSim intends to replace its slow image generator with a custom one capable of displaying more complex images. The graphics images are displayed on a single television screen in front of what the CTRI researchers refer to as a "rudimentary driving station." The Model 100 has two large rear-view mirrors that are superimposed on the single screen. The CTRI researchers felt that this mirror image placement, "interfered with the driver's view in an unrealistic manner." They went on to provide the following assessment of the Model 100:

> While MicroSim appears to possess the technical capabilities to meet many of CTRI's research criteria, the existing levels of model scenes and training scenarios require significant additional efforts. The Model 100 might be suitable for teaching some form of defensive driving and certainly meets the requirement of portability.[3]

MicroSim does not appear to be marketing this device at this time.

The SafeDrive 1000 truck driving simulator provides training on tractor-trailer, double trailer, triple trailer and tank trailer configurations. The SafeDrive 1000 is a computer simulation device that includes a motion base. The device can monitor each trainee's progress and provide immediate performance feedback. Unlike training on actual equipment, where performance assessments are subject to human judgment, simulator training can be analyzed and assessed in an objective and unbiased manner. The manufacturer suggests that the simulator can also serves as an excellent screening tool for identifying trainees ill-suited for professional driving.

SafeDrive 1000 offers wrap-around, real-time, photo-textured graphics and realistic cab motion. It consists of the following components:

- Simulator Cab. The simulator cab features realistic, working controls and instruments. The cab offers a full view of the driving environment with a windshield, right and left windows, and rear view mirrors. The simulator can be configured for left-hand or right-hand drive.

- Instructor Station. The Instructor's Station is used to set up simulation exercises and record trainee performance reports. It consists of a monitor, keyboard, and mouse for exercise setup; a color monitor from which the instructor can watch the trainee's view of the simulation session; and a laser printer for generation of performance reports.

- Visual System. The simulator features high-resolution, computer-generated textured graphics on a wrap-around screen. Adjustable rear-view mirrors with correct perspective are also included.

- Motion System. An optional hydraulic motion system provides vibrations present under normal driving conditions, jolts during rough road driving, and motion caused by braking, acceleration, turning, and skidding.

- Sound System. The simulator's sound system provides realistic engine, braking, and gearing sounds typical in an operating environment, as well as a variety of sounds from both inside and outside the cab.

- Host Computer. SafeDrive 1000 is powered by a high-speed computer system, which provides real-time synchronization of the truck's controls with visual images and cab motion.[12]

The Iowa Driving Simulator (IDS), developed by the University of Iowa Center for Computer-Aided Design, under the auspices of the National Highway Traffic Safety Administration (NHTSA), is a computer simulation-based device that is near completion. It is designed to be a research device. Combining a very high-resolution, realistic visual system with an advanced motion platform, it is currently the most advanced driving simulator available in the United States. The driver will sit in an actual vehicle mounted on a motion platform. The university plans to develop several automobile and heavy truck configurations in order to conduct research studies. At an estimated final cost of $10 million, this is a research device and is not intended as a training or licensing device.

NHTSA is sponsoring the development of another research driving simulator, the **National Advanced Driving Simulator (NADS)**. This device, scheduled for completion in 1998, will also be located at the University of Iowa. The planned system configuration includes a motion platform and provides the computer power to perform real-time dynamics and complex scenario control. The visual system includes a high-performance computer image generator, visual databases and modeling tools, and visual data management software. Realistic audio cuing will be provided. When completed, at an estimated cost of $32 million, the NADS will be the most advanced driving research simulator in the world.[13]

The **Daimler-Benz Driving Simulator**, a German device, is a computer simulation system with a projection dome, a motion platform, a digital sound system, a projection system for displaying inside the dome, a color digital image generator, and digital computer system with parallel CPUs for real-time simulation (i.e., the simulator responds instantly to student driving actions). The Daimler-Benz driving simulator is a research simulator. Vehicle behavior and important environmental information for the driver are simulated in such a way as to give the research and development engineers a basis for the testing of new vehicle design.[14]

The **VTI Driving Simulator**, built by the Swedish Road and Traffic Research Institute, is a computer-generated image-based system. The device is equipped with a moving base system and is controlled by a computer program, which also contains the equations for the vehicle dynamics. The visual system uses three TV-projector screens mounted at angles in front of the driver to provide a wide angle picture in full color.[15] The VTI Driving Simulator is intended as a research device to study driver-vehicle interactions.

State-of-the-Art Driving Simulator Technology

In this sub-section we will discuss new technologies and prototype designs that will impact the state-of-the-art in CMV driving simulator technology.

Three of the simulators described above represent what is the current state-of-the-art truck driving simulator technology:

- The Iowa Driving Simulator (IDS)
- The Daimler-Benz Driving Simulator (DBDS)
- The National Advanced Driving Simulator (NADS).

These devices are designed to function primarily as research tools. As such, they have the potential to provide valuable insights to such issues as the levels of functional and physical fidelity necessary to provide training for specific tasks and skills. They introduce advances in technologies, such as visual and motion systems that, while advancing the state-of-the-art, are prohibitively expensive for driver training or licensing applications.

The Transportation Research Board (TRB) Committee on Simulation and Measurement of Vehicle and Operator Performance identified 54 research areas in which driving simulators could be employed to reduce vehicle accident rates, increase the quality of driver licensing and certification, and provide lower-cost, higher-quality highway systems.[16]

Appendix A of this report presents the TRB research areas. The appendix shows that, of the three advanced technology simulators, only the NADS is capable of fully addressing all of the identified driver and vehicle related-research areas.

In a study of issues related to the National Advanced Driving Simulator, the Government Accounting Office (GAO) compared the NADS, IDS, and DBDS simulators on their ability to satisfy the TRB research areas.[17]

The GAO authors developed a simulator capabilities checklist and interviewed IDS, DBDS, and NHTSA officials to compare the three simulators on these capabilities. The results show that NADS, when completed, will have visual and motion systems that are superior to those of the IDS and the DBDS, which is currently the most advanced driving simulator in the world.

Utilization of CMV Simulators in Current Training Programs

The literature review revealed very little information regarding the use of CMV simulators in training programs. An FHWA-sponsored study identified six simulators being used for training in 1990.[18]

The authors reported that five of the six simulators were Doron devices. Unfortunately, the authors failed to identify the simulator models.

Utilization of CMV Simulators for Commercial Driver Licensing

Federal Motor Carrier Safety Regulations (49 CFR 383.113(e)) allow states to utilize simulators to perform skills testing but not as a substitute for the road test. However, in the FHWA-sponsored study, the authors report having found no instances of simulators being used for testing or licensing.[18] Furthermore, there is no evidence in the literature that any state or school has utilized a simulator for testing or licensing purposes.

Discussion

Two topics that are essential to the establishment of criteria upon which to evaluate truck driving simulators are a simulator's training requirements (i.e., tasks to be trained via driving simulators) and the corresponding functional fidelity a simulator would require to meet the training requirements. The following is a discussion of two research efforts that addressed these issues. The remainder of this section provides a discussion of these two topics, and conclusions resulting from the literature review.

Truck Driving Tasks Inventory and Analysis

In 1985 the FHWA developed training requirements for tractor-trailer drivers and published a set of training guidelines, the FHWA'S *Model Curriculum for Training Tractor-Trailer Drivers*.[20] Subsequently, the Professional Truck Drivers Institute of America (PTDIA) developed a voluntary certification program for tractor-trailer training programs.[21, 22] Essentially, the PTDIA's curriculum requirements cover the same content as the FHWA's Model Curriculum, but differ in the distribution of hours of training conducted "behind-the-wheel." PTDIA's curriculum requires more hours of "behind-the-wheel" training than the FHWA model curriculum.

In a 1990 FHWA-sponsored study, the contractor produced a report defining a Truck Driving Task Inventory. This inventory was a listing of truck driving tasks that the contractor had previously identified when developing the Commercial Driver's License (CDL) test.[19] The objectives of the study were to:

- Develop various performance standards for a series of different simulator training and testing applications
- Gather information on other actual/potential applications of simulator technologies in the motor carrier industry, such as human factors engineering and driver fatigue studies.

The report lists tasks that a CMV driver would likely perform while driving. Tasks are organized by activities within phases. Task lists are included for the following phases:

- Preoperation
- Routine Driving
- Special Driving
- Transporting Cargo Safely
- Transporting Hazardous Materials
- Demanding Conditions
- Emergency Activities
- Terminal Operations

Although the organization differs from FHWA's Model Curriculum, many of what are referred to as "activities" in the inventory correspond to training components contained in the FHWA Model Curriculum.

The researchers analyzed the truck driving task inventory list to identify which tasks could be trained and/or tested via a driving simulator. They based their analysis on the opinions of several experts in the areas of simulation and truck driving. They determined, for each task, its appropriateness for training and/or testing via simulators. A second report presented the Truck Driving Task Analysis, i.e., the analyses of the tasks identified in the task inventory report.[23]

In addition to items describing the task, the task analysis included the following items.

- Initiating Cues — the stimuli that cause the driver to react
- Feedback — type of return stimulus that the driver uses to monitor the degree to which a task or step is executed
- Terminating Cues — feedback that indicates a task or step is coming to closure or has been terminated
- Standards — identification of criteria that State Departments of Motor Vehicles may be using to evaluate commercial motor vehicle (CMV) drivers. Many standards cited were taken from the *Examiners Manual for Commercial Drivers*.[24] Standards may differ by state
- Task Segment — trip segment in which the task is performed (i.e., pre-trip, enroute, post-trip, or as required)
- Task Duration — elapsed time to complete the task
- Time of Day
- Weather Conditions
- Type of Road — road surface normally encountered for the task
- Traffic Level — light (normal highway conditions), medium (moderate urban conditions with minimal slowdowns), and heavy (heavily congested urban rush hour traffic)
- Criticality — criticality rating for task. Ratings used were:

  — Highly Critical — must be done to ensure the safety and efficiency of operations

  — Moderately Critical - should be done

  - Less Critical — may be omitted without seriously endangering the safety and efficiency of operations

- Workload — the cognitive workload the driver undergoes to perform the task. Workloads were designated as follows,

  - Low — performing a single task at own pace or without conflicting cognitive demands

  - Medium — performing multiple tasks, but tasks do not significantly conflict with each other

  - High — performing multiple tasks, some of which conflict with others

- Skill and Knowledge Elements — skills and knowledge elements required to perform the task

- Truck Type (Class A, B, or C)

- Test — whether or not the task is tested by the general population of Driver Licensing Administrations

- Endorsements — CDL endorsements

- Effectiveness — subjective rating of the degree of relationship between the behavior learned, in the simulator, and the behavior required to perform on the job

Included in the description of the task are conclusions regarding whether or not the task is appropriate for training/testing using a simulator. The majority of the tasks were deemed appropriate for using a simulator. Those tasks not deemed appropriate usually involved a non-driving task.

This type of task information is necessary to develop a set of simulator training requirements. Once training requirements are defined, simulator functional requirements can be established.

Simulator Fidelity

Driving simulators range in cost from a few thousand dollars to several million dollars. The NHTSA is currently overseeing the development of a driving simulator at an estimated cost of $32 million (see the previous discussion of NADS). The primary determinant of cost is what is known as simulator "fidelity." Fidelity is a qualitative measure of the degree to which the device replicates the "real-world" situation, i.e., the extent to which the visual, auditory, and motion systems provide the sights, sounds, and vehicle movement that the driver would experience on the road in an actual vehicle.

Since the level of simulator fidelity has the most impact on the ultimate cost of the device, it is imperative to focus on the cost (fidelity required)/benefit (training requirements met) of including a given task in the group of tasks to be simulated -- not just the "appropriateness" of the task for simulation.

Some driving simulators provide relatively high-fidelity on all the three of the major subsystems (i.e., visual, auditory, and motion), while others provide high fidelity on one subsystem (e.g., a high-fidelity visual system employing advanced computer-generated imagery) and little or no fidelity on another dimension (e.g., the same simulator may have no motion capability). There appear to be no empirical studies of the level of fidelity required on any of the subsystems to affect a positive transfer of training for any given driving task. All of the published discussions on required, or desired, fidelity levels are based on the opinions of simulator subject matter experts.

While the truck driving task analysis study addressed the truck driving tasks to be trained via a driving simulator, the TRB's Committee on Simulation investigated the characteristics and subsystem fidelity requirements of driving simulators.

The Committee on Simulation recently developed a comprehensive list of driving simulator "utilizations" - ways in which "a motor vehicle simulator may be utilized to reduce the accident rate; to increase the quality of licensing and/or certification without increasing costs; and to provide lower-cost, higher-quality vehicle-highway systems."[16]

The TRB committee identified four categories of utilization -- Driver Related, Vehicle Related, Environment Related, and General. Nineteen specific utilizations were identified within the four categories. Table 2.2 lists these utilizations by category.

The TRB Committee assigned fidelity ratings of high, medium, and low to each utilization. The ratings were derived from a survey of the addressees on the Committee's 100-plus mailing list, which included simulator experts from other countries. In the absence of empirical data, these ratings constitute the best available information on driving simulator fidelity requirements for the applications rated. The TRB Committee rated the required fidelity for the following specific driving simulator training applications.

- Emergency vehicle (fire, ambulance, police) operator training systems.
- Law enforcement (FBI, DEA, police) driver training programs.
- Rehabilitation driver training programs.
- Special driver training programs for elderly, physically impaired, mentally impaired, "high-risk" drivers, and other special subsets of the general population with special training needs.

The four driving simulator training applications addressed in the TRB report clearly share many requirements in common with CMV driver training; however, it is widely believed that CMV driving imposes some unique demands on the operator. Thus, while some of the simulator fidelity information presented in the TRB report is of value to the current effort, additional information is needed to determine the fidelity requirements of a simulator design that would permit training/testing of CMV driving tasks.

Table 2.2

Potential Utilization of the National Advanced Driving Simulator

	GROUP I - Driver Related Utilization
I-1.	Driver Behavior Studies
I-2.	Driver Performance Measures for Driver-Vehicle-Highway Systems Evaluation
I-3.	Design of Driver Screen and Licensing Tests
I-4.	Vehicle Training Systems and Programs
I-5.	Skill Transfer: Vehicle - Vehicle
	GROUP II - Vehicle Related Utilization
II-1.	Directional Control Studies
II-2.	Longitudinal Control Studies
II-3.	Vibration and Noise Studies
II-4.	Aids for Path Keeping and Way Finding
II-5.	Human Factors Evaluations of Vehicle Interiors
	GROUP III - Environment Related Utilization
III-1.	Highway Design
III-2.	Construction Zone Safety
III-3.	Effects of Natural and Built Environments
III-4.	Effects of Weather
III-5.	Underground Highway Systems
	GROUP IV - General Utilization
IV-1.	Simulator Design Studies for Developing Other Simulators
IV-2.	Skill Transfer: Simulator - Vehicle
IV-3.	Simulator Sickness
IV-4.	Accident Reconstruction and Analysis

Conclusions

The literature relating to truck driving and driving simulation produced a surprisingly small number of studies dealing with the applicability of simulation for truck driver training, testing, and licensing.

The literature review identified only seven truck driver training simulator designs currently available for purchase in the U.S. As far as can be determined from the literature review, only two new truck driver training simulator designs may be available within the next 18 months: MicroSim and . (It was later discovered that a decision was made not to develop MicroSim.) Some European companies were said to be developing devices that may be available in the near future. Although this was not corroborated through the published literature, it was later confirmed through other sources (see Section 4).

There were no empirical studies reported that investigated the level of task fidelity or simulator fidelity required to provide training/testing on a given task. In addition, none of the currently available truck driving simulator designs appeared to be based on training requirements derived from task analysis. The recommended method of simulator design is to develop simulator functional specifications from a training objectives hierarchy and comprehensive task analysis. This approach has been employed by the U. S. military, which has made extensive use of training simulators over the past 20 years.[25]

Although there is virtually no empirical data upon which to determine requisite CMV driver training simulator characteristics (i.e., no transfer of training studies), there is a documented consensus of expert opinion on the subject. In the absence of empirical data, we must for now, and possibly for the foreseeable future, rely on expert opinion in determining requisite simulator characteristics.

Simulator fidelity, particularly for the visual subsystem, is potentially the most costly component of a driving simulator. While there is no question that high-fidelity visual systems provide a more realistic "feeling" for the student, there is no empirical evidence that they are, or are not, required for most tasks. For evaluation purposes it is more important to have a valid set of training requirements and fidelity criteria associated with simulator functional requirements, than to rely on the comparison of simulator features.

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SECTION 3

FUNCTIONAL REQUIREMENTS FOR A CMV DRIVING SIMULATOR

This section describes CMV driver training simulator functional requirements* derived from the established CMV driver training objectives. The section begins with an overview of the objectives in developing the functional requirements and the approach used to develop them. The last four subsections overview and describe the functional requirements themselves.

Objectives

This task was designed to meet the first three of the five project objectives, as listed in Section 1. These objectives (in summarized form) were to:

- Identify CMV driver skill training objectives that can be trained and tested using simulators.
- Develop functional requirements for each of the CMV driving objectives. In addition to the statement of the objective, each functional requirement was to specify the characteristics of the simulator display system and response system required to meet that training objective.
- Determine the relative benefit of training/testing/licensing each CMV driver skill training objective using simulator technology.

Approach

In developing the CMV driving simulator functional requirements, two primary sources were used: The *Model Curriculum for Training Tractor-Trailer Drivers*[20] published by the FHWA in 1985, and a subsequent (1990) study of CMV simulator technology also performed under contact to the FHWA by Essex Corporation[19]. In addition, the services of Dr. James McKnight, a recognized expert in driving simulation, were employed to help develop the functional requirements.

* "Requirements," for the purposes of this report refer to the general criteria to be used in the subsequent review of CMV driving simulators. The term does not imply federal, state, or local government standards.

The skill-based training objectives in the Model Curriculum were selected as the basis for deriving the functional capabilities that a driving simulator must possess. There were several reasons for this decision. First, the Essex study analyzed CMV simulation requirements in terms of operating tasks. *Tasks* do not provide a good basis for structuring training performance requirements in that many individual tasks pose virtually the same requirements. Moreover, the Essex analysis addressed the structural rather than functional requirements of simulation and was, therefore, not well suited to evaluating the *capabilities* of simulation to provide effective training. Finally, a comparison of the task list in the Essex study and the model curriculum revealed that most of the truck driver tasks in the Essex study were covered by the Model Curriculum's skill objectives. Therefore, it was decided that the skill-based objectives in the Model Curriculum were comprehensive enough, for the purposes of this study, to facilitate the derivation of simulator functional requirements. It should be noted that skill objectives for double-trailer and triple-trailer truck configurations had not been finalized by the FHWA at the time that these functional requirements were developed. Consequently, the functional requirements presented here are for single trailer configurations. However, those devices that accommodate double- and triple-trailers are noted.

The functional requirements are based upon skill objectives rather than knowledge objectives for two reasons. First, it is only those performances involving skills that are truly appropriate to simulation. Knowledge and attitude objectives are achieved far more efficiently through other instructional media. The second reason is that skill objectives are expressed in terms that are more readily related to the capabilities/functional requirements of simulation.

Each training objective was analyzed to determine the characteristics a CMV simulator should have, at a minimum, to properly train the driving skill. Functional requirements were identified in two areas:

- Display system
- Response system

Once the draft listing and description of functional requirements was completed, it was distributed for review to a group of 27 experts in simulation, CMV driver training, and motor carrier -- both truck and motorcoach -- operations (see Appendix B). These experts were identified, in part, from persons known to the contractor and FHWA. The objectives of the review were to identify additional functional requirements and to determine the relative importance on each requirement in terms of its training/licensing benefit. "Benefit" was defined as the cost-effectiveness of using simulation to achieve a functional requirement's training objective, as opposed to using traditional methods of training.

It was expected that the feedback received from the experts would identify functional requirements that could be dropped from the initial list. In fact, while no additional functional requirements were identified by the group, all of the functional requirements in the initial list were judged to have medium to high benefit. There was insufficient justification to drop any of the requirements.

In an attempt to better discriminate differences in benefit among the requirements, a second questionnaire was sent to the experts. This time they were asked to rank order the functional requirements in terms of their training/licensing benefit. The results of this second round of data collection were ambiguous because of the high variability in the rankings assigned to most of the requirements. For every person who ranked a given requirement low, another would rank it high.

It was decided, as the result of the two rounds of data collection, that at least some of the experts generally thought that each of the functional requirements in the initial list had high benefit. Consequently, no functional requirements were deleted from the list.

The rankings of the functional requirements are discussed in more detail in a later section of this report.

Functional Requirements -- Overview

The functional requirements themselves are listed and described in the remaining pages of this section. They are divided into three categories -- Basic Operation, Safe Operating Practices, and Advanced Operating Practices. The numbers in the Functional Requirements correspond to the driving skills' objective numbers in the Model Curriculum.

For each skill objective, the functional requirements for simulation are described. In addition, a discussion of the ability of these requirements to be met by the three major approaches to simulation is provided. The three major approaches to simulation are:

CGI: Computer-Generated Imagery.
HDTV: High-Definition Television, cassette or videodisc.
Model: Movement of a fiber optic television pickup over a model landscape.

Functional requirements were not defined for simulator motion systems. The relationship between motion cues (kinesthetic and proprioceptive) and driver training has not been well established at this time. Consequently, a comparison of the functional capabilities of fixed-base simulators and moving-base simulators, or among moving-base simulation, would be of limited value at this time.

Functional requirements include the characteristics of the visual display and the response system. The description of the display focuses upon the cues of highway and traffic as visible through the windshield, and the side and rear views, of the tractor since these are the cues that are most critical to operation of the vehicle, i.e., involve the majority of driving tasks, and are the most difficult to simulate. The three major types of simulation identified are distinguished from one another largely on the basis of the road/traffic display. The other major type of display consists of instruments, primarily speedometer and tachometer. These are referenced only where the cues they provide are essential to attainment of the skill objective being addressed.

A response system consists of primary and secondary controls. The primary controls — steering wheel, throttle, brake, and gear shift — are of most importance since they control the motion of the vehicle and require an interaction between response system and display. The presence or absence of this interaction distinguishes between CGI and HDTV systems and is of obvious importance in the attainment of skill objectives. Secondary controls are those that operate auxiliary equipment, the most important being turn signals and windshield wipers. They are mentioned only where they play a role in attainment of the specific skill discussed.

Functional Requirements -- Basic Operation

The unit numbers and skill objectives listed below are taken from the FHWA Model Curriculum. There are gaps in the numbering sequence because not all of the objectives in the Model Curriculum were deemed critical for simulator-based training.

Unit 1.4 Basic Control

1.4.1 Accelerating

Skill Objective

"The student must be able to coordinate the use of accelerator and clutch to achieve smooth acceleration and avoid [inappropriate] clutch use."

Functional Requirements

Display — The display need only present a straight path representing the pavement surface with lane delineations, pavement texture, or roadside objects to display longitudinal motion to the student. A tachometer and a speedometer must be visible and engine sounds audible.

Response System — The response system would consist of throttle, clutch, and gear shift. Only one shift pattern is necessary since the vehicle can remain in first gear while meeting this objective. Motion must have high-fidelity; that is, forward motion must respond accurately to throttle, clutch, and shift manipulations. Resistance to control inputs should be representative of a "typical" transmission. Simulated engine sound should correlate with RPM, as well as provide audible cues of stalling or stalled engine.

1.4.2 Braking

Skill Objective

"The student must be able to properly modulate air brakes to bring the vehicle to a smooth stop."

Functional Requirements

Display — The display must present surface texture with sufficient resolution and richness to provide visual motion cues representing speeds continually decreasing to zero. The display should also include tachometer, speedometer and simulated engine sound. Some type of feedback is needed to represent "lurching" to a stop from failure to modulate the brakes correctly. Options include screeching of tires and/or incipient motion of the seat.

Response System — The response system for this objective requires only a brake pedal that responds according to inputs.

1.4.3(a) Driving Forward

Skill Objective

"The student must be able to coordinate steering, braking, and acceleration to take the vehicle through a desired path forward."

Functional Requirements

Display — The display must provide a combination of straight and curved road surfaces by means of coloration, texture, and/or edge markings and lane delineaters, and must respond accurately to steering corrections made by the student.

Response System — The response system must provide, in addition to throttle and brakes, a steering wheel of the general diameter and horizontal orientation of the particular type of heavy vehicle to be operated. The angle and position relative to the display must respond accurately to steering inputs.

1.4.3(b) Driving Backward

Skill Objective

"The student must be able to coordinate steering, braking, and acceleration to back the vehicle into a straight line."

Functional Requirements

Display — The display must provide forward and rearward views. The forward display must provide the cues described in 1.4.3(a) in order to permit control of speed, position, and direction while backing, and to control forward motion during pullups. The rearward display must consist of right and left mirrors with ideally both flat and convex surfaces to enable the student to practice with each type of mirrors. The mirrors must display the edge of the trailer, roadway edge markings, and surface texture. Motion of the trailer must respond realistically to steering corrections.

Response System — The response system must provide all primary controls, i.e., a steering wheel, clutch, brake, throttle, and gear shift capable of at least neutral, reverse, and one forward gear position.

1.4.4 Turning

Skill Objective

"The student must be able to adequately judge the path the trailer will take (off-tracking) if the vehicle negotiates left or right curves, turns, and lane changes."

Functional Requirements

Display — The forward display must provide a 180° field of view, to include road edge markings and lane delineaters, corresponding to the four possible combinations of two- and four-lane roads. It must also provide stimuli leading to turns, including established routes for turns, and lane changes to go around slower vehicles. Simulated mirrors must provide a display of the trailer, edge markings, and delineaters normally visible.

Response System — The steering wheel, clutch, throttle, brake, and gear shift (same as 1.4.2).

Unit 1.5 Shifting

Skill Objective

"The student must be able to coordinate use of hands, feet, sight, hearing, and shifting to achieve maximum performance consistent with economy, safety, and smoothness of operation."

Functional Requirements

Display — To develop skill in shifting, the display only need present speed, RPM, and the sound of varying engine pitch. If a display of the path ahead is provided, it needs to present motion to the degree necessary to avoid conflicting with engine displays.

Response System — The response system should include a clutch, throttle, and gear shift. The gear shift must provide a full range of gears for a manual transmission and may provide for alternative manual shift patterns and semiautomatic operation. Non-synchronized transmissions must require double clutching.

Unit 1.6 Backing

Skill Objectives

"The student must be able to coordinate speed and direction controls to achieve the desired path while backing in a straight line, into an alley dock, or parallel park, or parking in a jackknife position."

Functional Requirements

Display — The display requirements in developing skill in the backing maneuvers indicated are the same as those involved in straight line backing (1.4.3(b)) with one exception. In a sight-side jackknife backing maneuver, a driver is often able to benefit from a view of the rear of the trailer gained from the left window. Providing this view would require a visual field extending approximately 120° (from the straight-ahead) to the left. Added to the 90° visual field to the right, the visual field would total approximately 210°. So far as we can determine, a sight-side jackknife parking or alley dock maneuver is the only task that would make use of this extended visual field.

The degree of resolution required for backing maneuvers would exceed that available from most simulator displays, necessitating the use of oversized mirrors in providing images of sufficient size to permit judging clearances.

Response System — The response system shall include a clutch, throttle, brake, and gear shift. The gear shift must provide a full range of gears for the type of transmission simulated. The motion of the simulated trailer must respond accurately to steering inputs.

Unit 1.8 Proficiency Development: Basic Control

1.8.1 Maneuvering in Restricted Quarters

Skill Objectives

"The student must be able to coordinate acceleration and braking to maneuver the vehicle in restricted quarters."

Functional Requirements

The requirements of simulation for tight quarters maneuvering are largely the same as those required in meeting previous objectives. The uniqueness of this objective comes not in the maneuvering, but in the judging of clearance. The facility of simulation is not sufficient to permit precise judgment of clearance, nor would drivers in an operating environment depend upon their own visual capabilities in situations where clearance is marginal. However, simulation can help students distinguish passable from impassable situations, and provide training in maneuvering where clearances are minimal.

Display — The display must present objects in close proximity to the path of the vehicle including objects to either side (vehicles, curb, road signs, buildings) or overhead (bridges, overpasses, tollbooths, marquees). While the two-dimensional display provided by simulation limits the degree to which students can acquire skill in judging clearances, sufficient cues of size and distance can be provided to facilitate developmental proficiency and tight-quarters positioning. Structures in the driving scene can contribute to development of skill in judging lateral and overhead clearance.

Response System — The response system requires only the standard primary controls, i.e., clutch, throttle, brake, and gear shift.

1.8.2 Upgrades and Downgrades

"The student must be able to coordinate clutch, throttle, and gear shift to maintain engine and proper speed when shifting on upgrades and downgrades."

Functional Requirements

Display — Visual simulation of upgrades and downgrades does not provide sufficient fidelity to serve as a basis for shifting. Displays can, however, provide cues of change of simulated motion that would lead to recognition of the need to downshift, including (1) motion of objects in the roadway/traffic display, (2) readings in the tachometer and speedometer displays, and (3) pitch of engine sound. Cues must be provided with sufficient fidelity to require appropriate downshifting, acceleration, and braking to maintain speed. The road/traffic display should also provide signs to allow students to anticipate upgrades and downgrades.

Response System — Primary controls are sufficient.

Functional Requirements -- Safe Operating Practice

Unit 2.1 Visual Search

2.1.1 Attention Sharing

Skill Objectives

"The student must be able to search the highway traffic environment while maintaining directional control of the vehicle."

Functional Requirements

Display — The display must be capable of presenting, within the road/traffic scene, stimuli representing the situations to which students must respond by changing the speed or direction of the vehicle. Only through such responses is the simulation system capable of determining whether appropriate search patterns have been employed. The highway/traffic situations depicted must be sufficiently inconspicuous as to be detectable only through appropriate visual search. A road/traffic image that encompasses the roadway and roadside environment as well as the rear-view mirrors is sufficient to permit development of skill in visual search associated with general visual surveillance, lane changing, and merges. (Note: Visual search at intersections requires a wider visual field, but does not demand the attention-sharing skill that makes up the objectives).

Response System — In meeting this objective, vehicle controls serve two functions: (1) to require control of the vehicle's motion coincident with visual search, and (2) provide a means by which students can register their perception of highway/traffic situations revealed by appropriate search patterns. Fidelity of the display response interaction is not critical.

2.1.2 Mirror Interpretation

Skill Objective

"Student must be able to read and interpret the images presented by flat and convex mirrors."

Functional Requirements

Simulation must provide students an opportunity to view images from a combination of flat and convex mirrors (or the equivalent simulated display image) in order to integrate them into a picture of what is happening behind the vehicle.

Display — The road/traffic display must include mirrors on both sides of the vehicle displaying following vehicles of various types, sizes, and position relative to the student. The mirror must present images as they ordinarily appear as either flat or convex mirrors. Traffic situations must be created to cause images of other road users to disappear from the flat mirror, yet still be visible in a convex mirror, in order that the student can learn to reconcile the two images. With the limited resolution of simulator displays and the compressed image provided by a convex mirror, it will be necessary to enlarge the actual size of the convex portion of the mirror if images are to be interpretable.

Response System — This objective is limited to a perceptual skill and does not require any display-control interaction. However, traffic scenes must be configured such that correct interpretation of mirror images will lead to some response that differs from that which would otherwise occur (e.g., inhibiting a lane change because a motorcycle is visible in a convex mirror). As with other elements of visual search, the vehicle control response is just a means of registering a correct perceptual response.

Unit 2.3 Speed Management

Skill Objective

"Students must be able to judge the maximum safe speed for coping with any combination of roadway configuration (e.g., turns) surface friction, traffic, visibility, cross wind, and vehicle weight distribution."

Functional Requirements

Display — The display must be capable of simulating cues associated with each of the speed-influencing conditions enumerated in the objectives to include:

Roadway
Curvature: hills, curves
Elevation: upgrades and downgrades
Surface: water, ice, snow, rough pavement

Traffic
Pedestrians, slow-moving vehicles

Environment
Visibility: night, rain, snow, fog
Control: cross-wind

Vehicle

Weight and Length
Center Of Gravity
Load Stability

Response System — In meeting this objective, the response system needs only to permit students to adjust simulated speed to conditions. It is not necessary that the vehicle's response represent the effects of the various conditions described, e.g., skid on slippery surface or roll with a high center of gravity. Students should be expected to adjust speed to conditions *before* they have a chance to affect the handling of a vehicle. While such responses may help demonstrate the hazards of excessive speed, there are less expensive demonstrations on slippery roads, or a high center of gravity, than simulation.

Unit 2.4 Space Management

2.4.1 Gap Judgment

Skill Objective

"Student must be able to judge the adequacy of gaps for passing, crossing and entering traffic, and changing lanes."

Functional Requirements

The overall length and low acceleration of tractor-trailer combinations require larger gaps than passenger vehicles. Simulation provides an opportunity to develop skill in judging without danger to or interference with traffic.

Display — The road/traffic scene must be capable of presenting approaching vehicles with accurate changes in size, and distance relationships. Gaps for passing are within the scope of any display, while gaps for lane changes require the presence of side mirrors, and crossing/entering gaps require a minimum 180° visual fields. Display must provide cues of closure with oncoming and intersecting vehicles having sufficient clarity and fidelity to permit accurate gap judgment. The sole cues of speed and distance are, respectively, the absolute size and rate of change for the stimuli representing the approaching vehicle.

Response System — To develop skill and gap judgment, the response system needs only to provide the means by which students can indicate acceptance of a gap: a throttle for acceptance of gaps and passing, crossing, or entering traffic, and a steering wheel for acceptance of gaps and lane changing. The lack of any response indicates rejection of a gap. An interactive response system is not necessary.

2.4.2 Following Distance

Skill Objective

"The student must be able to maintain a following distance appropriate to traffic, road surface, visibility, vehicle weight, and the law."

Functional Requirements

Display — The display must present the image of the lead vehicle in a way that accurately represents headway, i.e., following distance. At a minimum, the student must be able to count the interval between the time when the lead vehicle and the student's vehicle pass some landmark (i.e., pavement seam, lane delineator, roadside object). It is also desirable that the image be sufficiently detailed as to communicate the actual size of the vehicle, thus allowing image size to be used as a cue of inter-vehicle distance. Some type of forcing function must be employed to alter the speed of the lead vehicle relative to that of the student vehicle and thus necessitate speed adjustments on the part of the student in maintaining appropriate headway. It is also desirable that conditions of road surface, traffic, and visibility be varied in order that students may adjust the following distance/time accordingly.

Response System — Since the only objective involves primarily perceptual skill, response mechanisms serve primarily to indicate recognition of insufficient headway. Normal primary controls would be sufficient.

Unit 2.5 Night Operation

Skill Objective

"The student must be able to judge speed, distance, and separation under nighttime conditions."

Functional Requirements

The functional requirements are the same as for Unit 2.4, Space Management, except that the road/traffic display will simulate darkness, with cues of other vehicles being confined to headlights.

Unit 2.6 Extreme Driving Conditions

2.6.1 Handling Slippery Surfaces

Skill Objective

"The student must be able to adjust rate of change in speed and direction to road conditions in order to avoid skidding on slippery surfaces."

Functional Requirements

Display — The road/traffic display must provide cues of surface friction as well as feedback to students to indicate when the combination of speed and steering input makes the vehicle unmanageable on the simulated surface. Conditions would include wet surface, ice, snow, and running tar.

Response System — Response system requirements are the same as those required in normal vehicle operation: throttle, clutch, brake, and gear shift. The system need not, however, be interactive in visually displaying the actual consequences of improper vehicle handling.

2.6.2 Overcoming Surface Resistance

Skill Objective

"The student must be able to coordinate acceleration and shifting to overcome the resistance of snow, sand, or mud."

Functional Requirements

Display — The road/traffic display must present the characteristics of road surfaces in two ways: (1) by reproducing the visual cues associated with mud, sand, snow, or deep water; and (2) by presenting the motion cues associated with operating on a restive surface, including inhibited forward motion and, where appropriate, a slight upward movement as the vehicle.

Response System — Clutch, throttle, and gear shift are required. Torque characteristics of simulated transmission must be accurate. The speedometer, tachometer, and engine noise should respond in a manner corresponding to spinning drive wheels. This requires high-fidelity vehicle modeling.

2.6.3 Downhill Braking

Skill Objective

"The student must be able to coordinate gears, throttle, brake, and shifting to handle steep upgrades and downgrades."

Functional Requirements

The simulation must be able to create conditions requiring students to shift into appropriate gears for ascending and descending, respectively, upgrades and downgrades.

Display — The road/traffic scene must be capable of communicating to students the appropriate gear for a particular grade before starting to ascend or descend it. Unfortunately, it is difficult to provide suitable elevation cues through a two-dimensional image alone. Signs posted at the crest or foot of upgrades, indicating the severity of the grade, provide the only reliable cues to guide initial gear selection.

The display must provide cues to initiate downshifting or upshifting while on the grade, where initial gear selection is incorrect or a change in grade necessitates a gear change. Stimuli representing the road surface and roadside objects did provide appropriate motion cues, while speedometer, tachometer, and simulated engine pitch could evidence the effect of grades upon vehicle and engine speed.

Response System — All primary controls are required, and display motion characteristics must respond to control inputs in simulated grade with sufficient fidelity to allow a desired speed to be maintained with selection of the appropriate gear.

Functional Requirements -- Advanced Operating Practices

Unit 3.1 Hazard Perception

Skill Objective

"Students must be able to perceive immediately a potential threat from visible characteristics and actions of other road users and initiate prompt defensive or evasive action."

Functional Requirements

Display — The road/traffic display must be capable of presenting cues associated with a wide range of hazards involving characteristics of the road, characteristics of road users, and actions of road users. A "hazard" in this context refers to any situation representing a threat to the safety of the driver or other road users that could be lessened by a preventive response on the part of the driver. Hazards include vehicle motions of inattentive or confused drivers, pedestrians near the roadway, tailgaters, construction, parked vehicles with indication of impending motion, and trailer/cargo problems.

Hazards are not restricted to clear and present dangers. On the contrary, most are quite subtle, particularly hazards that grow out of the interaction among other road users (e.g., the action of one road user could force another road user into the driver's path). Satisfaction of this objective is closely tied to objective 2.1, "Visual Search," in that it is through response to hazards that drivers manifest proper search patterns.

Response System — In developing hazard perception skill, response systems need only provide a means of registering whether or not a particular hazard has been perceived. It is not necessary that the hazard actually materialize to the point of requiring an avoidance response on the part of the student. Relaxation of the throttle input is sufficient to register perception of a hazard. An interactive display-response system has the advantage of allowing for even more decisive responses (braking or swerving) without causing a cue conflict, which might be disconcerting to the student even if it does not interfere with the perception of hazards.

Unit 3.2 Emergency Maneuvers

3.2.1 Emergency Braking

Skill Objective

"The student must be able to use brakes in a manner that will stop the vehicle in the shortest possible distance while maintaining directional control."

Functional Requirements

Display — The display must create a stimulus requiring emergency braking as well as a path along which the braking must take place, e.g., vehicle pulling in the path ahead, with vehicles on the left side and sidewalk on the right side. The distance of the stimulus relative to the simulated speed of the vehicle should be sufficient to allow the rig to be brought to a stop with proper braking technique.

Response Systems — Visual cues must respond accurately to control input. Over-application of the brakes must result in audible squealing of brakes as well as loss of directional control resultant with a tractor-trailer jackknife or, for a single vehicle, a change in the single vehicle-road orientation. Under-application of the brakes should result in a collision with the stimulus object. Only correct steering and braking inputs should allow the truck to be brought to a straight stop within the available distance. Also, because of the precision of driver control responses required, it is particularly important that the resistance and travel of control mechanisms (wheel, throttle, brake, clutch) be similar to those of an operational tractor-trailer. This type of response requires high-fidelity vehicle dynamics modeling.

3.2.2 Emergency Steering

Skill Objective

"The student must be able to turn the steering wheel quickly in either direction in order to steer around a vehicle or another road user."

Functional Requirements

Skill in evasive steering involves not only the motor skill involved in executing maneuvers, but the perceptual skill involved in judging available stopping distance and recognizing available escape routes while, at the same time, suppressing a strongly learned braking response. There is evidence that repeated practice is needed to maintain an evasive steering response at high resistance, owing perhaps to the greater frequency of brake application over evasive steering in everyday driving. The value of simulation is the ability to provide the periodic refresher instruction needed to maintain an evasive steering response at high strength.

Display — The display must provide for the sudden appearance of a stimulus in the student's path that is too close to permit the rig to be brought to a stop, but with available lanes to permit a collision to be avoided through an evasive maneuver.

Response System — The road/traffic scene must respond accurately to control inputs so as to (1) require large rapid, evasive steering and counter-steering to avoid the stimulus obstacle yet remain within the limits of the escape path; and (2) lead to loss of directional control if the brakes and/or throttle are inappropriately applied. As with 3.2.1, control resistances and travels should approximate those found in tractor-trailers. Fidelity is particularly important in the relation between degree of steering wheel rotation and extent of direction change.

3.2.4 Brake Failure

Skill Objective

"The student must be able to bring the vehicle to a stop in event of a brake failure."

Functional Requirements

Satisfying this objective requires (1) finding an acceptable escape path along which to decelerate, and (2) using downshifting to bring the vehicle to a stop.

Display — The road/traffic display serves two functions: (1) defining the roadway traffic environment in which the student must operate when the brakes have failed, and (2) the display, along with the speedometer, provides the primary cue of brake failure by failing to show a speed reduction when the brake is applied.

The road/traffic display must provide escape routes along which the student may downshift to reduce speed: an escape ramp, paved or unpaved shoulder, side road, field, slight incline, curb.

Response System — All primary controls are required, along with the speedometer. The response system must be programmed to render the brake response inoperative at a point where the student would ordinarily brake and where suitable escape routes are available. Once the vehicle has been brought to a stop, the brake system should be restored to normal operation for continued use of the simulation.

Unit 3.3 Skid Control and Recovery

3.3.1 Skid Control

"The student must be able to steer and brake on extremely slippery surfaces without loss of control."

Functional Requirements

Simulation requirements are similar to those specified in 2.6.1, except that simulated surfaces are far more slippery, and much finer steering and braking control is needed.

Display — While it is desirable that cues of surface friction be realistic, the objective involves the vehicle control responses to slippery surfaces rather than the process of identifying them. What is important is that the extremely low surface friction be clearly identified to the student in some manner (e.g., captions), so that appropriate responses can be applied. Road surface and road delineations are the only cues required.

Response System — Only the primary controls are required. However, brake and steering must have extremely high-fidelity with respect to both mechanical feedback and vehicle motion. Over-application of brakes and/or steering relative to surface friction must result in the visual simulation of a skid.

3.3.2 Skid Recovery

Skill Objective

"The student must be able to recover from tractor and trailer skids and to bring the vehicle to a straight-line stop."

Functional Requirements

Attaining this objective requires simulation of tractor skids and trailer skids under conditions in which students can, by detecting the presence of a skid early enough and initiating appropriate steering corrections, recover from the skid. Simulation exercises applied to this objective can be linked to those involved in 3.2.1 to require skid recovery either (1) when students respond incorrectly to a skid control situation, or (2) when simulated surface friction is reduced to a point that a skid is virtually unavoidable. The simulation exercise would be similar to range exercises carried out on skid pads, where instructors initiate skids by deliberately locking up trailer wheels or tractor drive wheels.

Display — The display requirements include those described in connection with Objective 3.3.1. In addition, the display must provide cues indicating the presence, nature, and magnitude of a skid, including (1) discrepancy between apparent tractor heading and direction of motion, and (2) the apparent motion of the trailer as visible in mirrors.

Response System — The response system must involve motion of sufficient fidelity to both (1) bring about an apparent skid through misapplication of brakes, steering, acceleration; and (2) permit recovery from the skid (i.e., realignment of rig) with appropriate steering and relaxation of acceleration or braking.

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SECTION 4

CMV DRIVER TRAINING SIMULATOR REVIEW

Introduction

This section presents the results of a detailed review and evaluation of the operational and prototype CMV simulators in the United States and Europe, as identified from the literature review and other sources. This data collection effort was carried out to accomplish the fourth project objective listed in Section 3, i.e., to determine how well the existing and near-horizon CMV simulator technology satisfied the functional requirements. As described in Section 3, the functional requirements used to assess the simulators were derived, with input from experts in the area of driver training simulators (see Appendix B), from the FHWA *Model Curriculum for Training Tractor-Trailer Drivers* and a recent unpublished Truck Driving Task analysis developed for the FHWA. The numbers in the Functional Requirements (e.g., 2.1.2 Mirror Interpretation) correspond to the driving skills objective numbers in the Model Curriculum. The Functional Requirements establish the driving tasks that a simulator should be able to re-create during training sessions and the minimum fidelity level required for each task.

Site visits were conducted to observe the simulators in operation and to collect information not available from the literature. The project team observed and operated the simulators. An attempt was made to evaluate the simulator on the following dimensions:

- Conformance to the Training Tasks Specification, i.e., how many of the tasks in functional requirements can be taught/tested using the simulator (CDL test requirements are encompassed by the functional requirements).

- Fidelity, i.e., the extent to which the simulator provides the minimum level of realism for the training tasks it simulates.

- Instructional features, i.e., what features the simulator has to facilitate the training/testing process (for example, provision for tracking student performance and/or providing instruction tailored to individual student needs).

- Evidence of transfer of training, i.e., what studies have been done linking performance in the simulator to actual CMV driving skill.

- Ease of programming, operation, and maintenance.

- Acquisition, operating and maintenance costs.

- Acceptability to students, i.e., what studies, if any, have been done to determine the students' attitudes toward the simulator.

FHWA requested that the contractor team attend the **Third International Forum on the Use of Simulation for the Evaluation and Training of Professional Drivers** held in Cergy, France on May 5 through May 7, 1994. While in Europe, the team visited the manufacturers of commercial motor vehicle simulators in France, Sweden, Switzerland, England, and Germany. The findings from this trip, as well as those from the visit to U.S. manufacturers, are presented in this section.

Twelve simulators were identified, six in the United States and six in Europe, that are either currently available or have the potential to provide CMV driver training, skills testing or licensing in the near future. The simulators were examined during the period between April 6, 1994 and May 18, 1994. Additional follow-up contacts were made as recently as December 31, 1995 to obtain information any new developments.

Each of the twelve simulators discussed in the following subsections is described in terms of cost, availability, physical, and functional characteristics. **Prices are presented as approximations only.** Prices will vary depending upon the number of devices purchased, cost of components, degree of customizing, options selected, maintenance agreements, and a number of other factors.

Each simulator description includes a Functional Capabilities table. These tables represent subjective assessments made by the contractor team during their examination and "test drive" of the devices. This was not a formal evaluation of the simulators, merely a means of describing the domain of CMV driver training simulators at the time.

Each Functional Capabilities table shows, for each functional requirement, an assessment of the simulator's capabilities at the time of the visit. A simulator could be in one of three categories:

- Not Present. A check in this category means that the simulator does not have most/all of the visual system and response system capabilities listed for that functional requirement. This may be because the simulator was not designed to meet the functional requirement. Also, many of the devices examined were functioning prototypes that did not have all of their features implemented at the time of our visit.

- Adequate. A check under "Adequate" means that the simulator has all/most of the visual and response system capabilities called for by the functional requirement. It is important to remember that a check under "Adequate" **does not necessarily mean that the simulator can achieve the training objective for the functional requirement.** To determine "functional adequacy" in terms of training requirements would require a transfer of training study. As noted previously, it was beyond the scope of this study to make such in-depth evaluations.

- Not Adequate. This category was used if the simulator manufacturer indicated the intention to meet the objective for the functional requirement, but the simulator at the time of the visit did not, in our judgment, have the visual/response system capabilities to meet the requirements of the objective. For example, all but one of the simulators were noted as "Not Adequate" under 2.1.2 Mirror Interpretation, because they did not have convex mirrors (judged critical for this functional requirement).

CMV Driver Training Simulators in the United States

The six U.S. simulators that were identified as having the potential to provide CMV driver training, testing, and/or licensing in the near future (i.e., within one year from the time they were observed) are listed in Table 4.1.

Table 4.1

CMV Driver Training Simulators in the U.S.

SIMULATOR NAME	TYPE	MANUFACTURER
Doron L-300 HGV	Low-Fidelity Part-Task Simulator	Doron Precision Systems, Inc.
Doron L-300 VMT	Low-Fidelity Part-Task Simulator	Doron Precision Systems, Inc.
Doron L-301	Low-Fidelity Part-Task Simulator	Doron Precision Systems, Inc.
TT150 Truck Driving Simulator	Mid-Level Fidelity Part-Task Simulator	Professional Truck Driving Simulators, FAAC, Inc.
SafeDrive 1000	High-Fidelity Full-Mission Simulator	Digitran, Simulation Systems
Time Warner Interactive Driving Simulator	Low-Fidelity Part-Task Simulator	Time-Warner Interactive

Each simulator is described in terms of its physical characteristics, instructional features and functional capabilities on the following pages.

DEVICE: Doron L-300 HGV (Heavy Goods Vehicle) System

COMPANY: Doron Precision Systems, Inc.

P.O. Box 400
Binghamton, NY 13902-0400
Contact: Mr. David Lindsey

DATE EXAMINED: April 6, 1994

DESCRIPTION:

The DORON L-300 HGV is a part-task truck driver training simulator. DORON also has commercial bus and school bus versions of the L-300. It is a low cost (relative to the other simulators examined) part-task trainer. It utilizes a relatively inexpensive laser videodisc-based projection system and wide-screen display as its visual system. This configuration has the added cost advantage of accommodating up to eight trainees per session with only one instructor. Although the L-300 HGV overall is a low-fidelity device, given the absence of a vehicle cabin and the non-interactive nature of the display medium, it has a very high-fidelity visual system: filmed footage of actual driving scenes stored on videodisc. The L-300 HGV is commercially available and costs approximately $170,000 (with eight trainee stations).

INSTRUCTIONAL FEATURES:

The L-300 HGV has an instructor station which records and monitors student performance. It keeps a record of, and scores performance (e.g., braking reaction time).

PHYSICAL CHARACTERISTICS:

The DORON L-300 HGV has the following physical characteristics.

CABIN:

The L-300 HGV consists of one or more driver stations consisting of an unenclosed truck or bus seat with dashboard controls, a steering wheel, foot pedals, and transmission gear shift.

MOTION SYSTEM:

An optional yaw-direction motion system is available for the L-300 HGV. However, this system was not demonstrated during our visit.

SOUND SYSTEM:

The L-300 HGV employs recording of actual engine, traffic, and other ambient sounds. The sounds are presented to the trainees via headphones.

VISUAL SYSTEM:

The L-300 HGV utilizes a laser videodisc-based projection system to display footage of driving scenes (e.g., road curves, traffic signs, other traffic) on a 2:1 wide-angle projection screen in the front of the room. This wide-screen projection system allows several trainees to be operating at the same time, responding to the same driving scenes.

FUNCTIONAL CAPABILITIES:

The Table 4.2 provides a general assessment of the functional capabilities of the Doron L-300 HGV simulator. *It should be noted that this assessment was based on observation of an earlier version of the system which utilized a 16mm projection system.*

Table 4.2

Observations of the Functional Capabilities of the L-300 HGV Truck Driving Simulator

Capability	**Judgement of Capability**		
	Not Provided	**Adequate**	**Not Adequate**
1. Basic Operation 1.4 Basic Control			
1.4.1 Accelerating	✓		
1.4.2 Braking	✓		
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward	✓		
1.4.4 Turning		✓	
1.5 Shifting		✓	
1.6 Backing	✓		
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters	✓		
1.8.2 Upgrades and Downgrades		✓	
2. Safe Operating Practice 2.1 Visual Search			
2.1.1 Attention Sharing		✓	
2.1.2 Mirror Interpretation	✓		
2.3 Speed Management	✓		
2.4 Space Management			
2.4.1 Gap Judgment			✓
2.4.2 Following Distance			✓

Table 4.2 (Continued)

Observations of the Functional Capabilities of the L-300 HGV Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.5 Night Operation		✓	
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces	✓		
2.6.2 Overcoming Surface Resistance	✓		
2.6.3 Downhill Braking			✓
3. Advanced Operating Practices			
3.1 Hazard Perception		✓	
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking		✓	
3.2.2 Emergency Steering		✓	
3.2.4 Brake Failure	✓		
3.3 Skid Control and Recovery			
3.3.1 Skid Control	✓		
3.3.2 Skid Recovery	✓		

SUMMARY:

The HGV is a part-task trainer, designed to train only a certain set of skills. As such, it does not have many of the capabilities in the Functional Capabilities table. It affords the trainee experience in steering and situational awareness in response to a non-interactive video road and traffic scenes. While its lack of interactivity is a major shortcoming, it has the advantage of low acquisition and maintenance cost and a low instructor-trainee ratio. Doron also offers an extensive library of films and additional instructional materials for the system.

DEVICE: Doron L-300 VMT (Vehicle Maneuver Trainer) System

COMPANY: Doron Precision Systems, Inc.

P.O. Box 400
Binghamton, NY 13902-0400
Contact: Mr. David Lindsey

DATE EXAMINED: April 4, 1994

DESCRIPTION:

The DORON L-300 VMT is a part-task (truck and bus) driver training simulator. In this simulator the driver sits in a mockup of a truck cabin. The windshield view is a high-definition television (HDTV) image projected onto a screen in front of the cab. The video image comes from a small camera mounted onto a small scale model truck that moves through a scale model street and loading dock environment in response to the student's inputs to the simulated truck controls. The VMT is designed for practice of low-speed maneuvers, such as starting/stopping, backing, and docking. It is not designed for training on highway driving. It is commercially available and costs approximately $160,000.

INSTRUCTIONAL FEATURES:

The L-300-VMT has an instructor station which records and monitors student performance. It keeps a record of, and scores, performance.

PHYSICAL CHARACTERISTICS:

The DORON L-300 VMT has the following physical characteristics.

CABIN:

The L-300 VMT consists of a mockup of a truck or bus cabin, consisting of standard controls, e.g., steering wheel, transmission shift, accelerator and brake pedals.

MOTION SYSTEM:

The L-300 VMT does not have a motion system.

SOUND SYSTEM:

The L-300 VMT utilizes synthesized engine, traffic, and other ambient sounds.

VISUAL SYSTEM:

The windshield view is a high-definition television (HDTV) image projected onto a screen in front of the cab. The images are transmitted from cameras mounted onto a small scale model truck. The screen projection shows front, side, and [projected] mirror views, providing a simulated 180-degree field of view. There is no other traffic shown in the visual system. There are a few stationary vehicles.

FUNCTIONAL CAPABILITIES:

The following table provides a general assessment of the functional capabilities of the Doron L-300 VMT simulator.

Table 4.3

Observations of the Functional Capabilities of the L-300 VMT Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
1. Basic Operation			
1.4 Basic Control			
1.4.1 Accelerating		✓	
1.4.2 Braking		✓	
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward		✓	
1.4.4 Turning		✓	
1.5 Shifting		✓	
1.6 Backing		✓	
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters		✓	
1.8.2 Upgrades and Downgrades	✓		
2. Safe Operating Practice			
2.1 Visual Search			
2.1.1 Attention Sharing	✓		
2.1.2 Mirror Interpretation			✓
2.3 Speed Management		✓	
2.4 Space Management			
2.4.1 Gap Judgment	✓		
2.4.2 Following Distance	✓		

Table 4.3 (Continued)

Observations of the Functional Capabilities of the L-300 VMT Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.5 Night Operation	✓		
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces	✓		
2.6.2 Overcoming Surface Resistance	✓		
2.6.3 Downhill Braking	✓		
3. Advanced Operating Practices 3.1 Hazard Perception	✓		
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking	✓		
3.2.2 Emergency Steering	✓		
3.2.4 Brake Failure	✓		
3.3 Skid Control and Recovery			
3.3.1 Skid Control	✓		
3.3.2 Skid Recovery	✓		

SUMMARY:

The VMT is another part-task trainer with a restricted mission. It is designed to provide practice on docking tasks. The maneuvers seem realistic. A motion system does not appear to be necessary for this task. It was interesting to note that this device was easier to back up to a dock than the simulators with the computer-generated, high-fidelity visual systems. It appears that the presence of shadows in the model environment is not as well replicated by the computer-generated imagery.

DEVICE: Doron L-301 System

COMPANY: Doron Precision Systems, Inc.

P.O. Box 400
Binghamton, NY 13902-0400
Contact: Mr. David Lindsey

DATE EXAMINED: April 6, 1994

DESCRIPTION:

The DORON L-301 is built around an interactive laser videodisc/CD-ROM-based system. It is a part-task (truck and commercial/school bus) driver training simulator. The driver/trainee station is a modified version of the Doron HGV L-300. It displays digitalized footage, stored on videodisc, on a video screen mounted in a hooded enclosure on top of the dashboard mockup. Like the Doron HGV L-300, this system displays TV quality scenes which we would classify as high-fidelity. Overall, however, the system's very limited interactivity results in what would be considered a low-fidelity part-task trainer.

The L-301 is commercially available. The truck version with no programs costs about $58,000. A $3,000 maintenance agreement, $2,500 assessment program, $5,000 Discover Safe Driving program, and other programs are available. Most are custom programs.

INSTRUCTIONAL FEATURES:

The L-301 has an instructor station which records and monitors trainee performance. It keeps a record of, and scores, the trainees' performance.

PHYSICAL CHARACTERISTICS:

The DORON L-301 has the following physical characteristics.

CABIN:

The L-301 contains an unenclosed truck seat and mockup dashboard controls, steering wheel, foot pedals, and transmission gear shift. It is a similar driver/trainee station to that used in the Doron L-300 HGV with the addition of a video monitor enclosed within a hooded structure above the dashboard.

Motion System:

The L-301 system does not have a motion system.

Sound System:

The L-301 employs digitalized recordings of actual engine, traffic, and other ambient sounds.

Visual System:

The L-301 displays digitalized footage, stored on videodisc, of actual road scenes on a video monitor, which provides what Doron describes as the perspective of a 60-degree field of view.

FUNCTIONAL CAPABILITIES:

The following table provides a general assessment of the functional capabilities of the Doron L-301 simulator.

Table 4.4

Observations of the Functional Capabilities of the L-301 Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	**Adequate**	**Not Adequate**
1. Basic Operation 1.4 Basic Control			
1.4.1 Accelerating		✓	
1.4.2 Braking			✓
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward	✓		
1.4.4 Turning		✓	
1.5 Shifting		✓	
1.6 Backing	✓		
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters	✓		
1.8.2 Upgrades and Downgrades	✓		
2. Safe Operating Practice 2.1 Visual Search			
2.1.1 Attention Sharing	✓		
2.1.2 Mirror Interpretation			✓
2.3 Speed Management		✓	

Table 4.4 (Continued)

Observations of the Functional Capabilities of the L-301 Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.4 Space Management			
2.4.1 Gap Judgment			✓
2.4.2 Following Distance			✓
2.5 Night Operation		✓	
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces	✓		
2.6.2 Overcoming Surface Resistance	✓		
2.6.3 Downhill Braking	✓		
3. Advanced Operating Practices			
3.1 Hazard Perception		✓	
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking		✓	
3.2.2 Emergency Steering		✓	
3.2.4 Brake Failure	✓		
3.3 Skid Control and Recovery			
3.3.1 Skid Control	✓		
3.3.2 Skid Recovery	✓		

SUMMARY:

The Doron L-301 is a videodisc-based version of the L-300 HGV previously discussed. Like the other Doron simulators, this device is a part-task trainer. It is designed to train the same skills as the L-300 HGV. Its primary disadvantage is in the lack of interactivity. Its advantages are that it is relatively inexpensive and requires much less facility space than the other devices.

DEVICE: TT150 Truck Driving Simulator

COMPANY: Professional Truck Driving Simulators

FAAC, Inc.
825 Victors Way
Ann Arbor, MI 48108
Contact: Gene Jordan

DATE EXAMINED: April 7, 1994

DESCRIPTION:

The TT150 was a joint venture between FAAC and Perceptronics. It is currently marketed solely by FAAC. The TT150 is a mid-fidelity simulator, relative to the other existing devices that we examined. It lies between Doron's part-task trainers and the Digitran's full-mission simulator.

Its cost is about three times as much as the Doron systems, but less than 25 percent of the cost of the full-mission/full-fidelity Digitran system. FAAC states that the present visual system is capable of photo texturing, but this capability is not included in the present model. TT150 employs a low-fidelity visual system, relative to the high-fidelity/higher-cost Computer-Generated Imagery (CGI) systems available. FAAC describes the TT150 as a Part-Task Trainer. The TT150 is commercially available with an approximate cost of $250,000.

INSTRUCTIONAL FEATURES:

The TT150 instructor station has a user-friendly, graphical user interface (GUI) and allows the instructor to insert standards, replay sections of the trainees' session, and keep a record of student performance.

PHYSICAL CHARACTERISTICS:

The TT150 has the following physical characteristics.

CABIN:

The cabin of the TT150 is a mockup of a truck cabin with actual instruments and controls, e.g., the TT150 uses a Roadranger 9-speed transmission.

MOTION SYSTEM:

The TT150 does not have a motion system. However, a large, low-frequency speaker located under the driver seat provides vibration to the seat, realistically simulating the vibration resulting from a truck engine.

SOUND SYSTEM:

The TT150 provides computer-generated engine and ambient sounds.

VISUAL SYSTEM:

The visual display system consists of a three-channel image generator. The computer-generated imagery is projected onto three screens providing forward, side, and two rear view mirror images. The latter is provided by mirror images projected onto the screen in front of the driver.

The TT150 includes traffic that operates independently of the driver/trainee. The traffic behavior and density can be varied.

FUNCTIONAL CAPABILITIES:

Table 4.5 provides a general assessment of the functional capabilities of the TT150.

Table 4.5

Observations of the Functional Capabilities of the TT150 Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
1. Basic Operation			
1.4 Basic Control			
1.4.1 Accelerating		✓	
1.4.2 Braking		✓	
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward		✓	
1.4.4 Turning		✓	
1.5 Shifting		✓	
1.6 Backing		✓	
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters	✓		
1.8.2 Upgrades and Downgrades		✓	
2. Safe Operating Practice			
2.1 Visual Search			
2.1.1 Attention Sharing		✓	
2.1.2 Mirror Interpretation			✓
2.3 Speed Management		✓	
2.4 Space Management			
2.4.1 Gap Judgment			✓
2.4.2 Following Distance			✓

Table 4.5 (Continued)

Observations of the Functional Capabilities of the TT150 Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.5 Night Operation	✓		
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces			✓
2.6.2 Overcoming Surface Resistance		✓	
2.6.3 Downhill Braking			✓
3. Advanced Operating Practices 3.1 Hazard Perception	✓		
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking		✓	
3.2.2 Emergency Steering		✓	
3.2.4 Brake Failure		✓	
3.3 Skid Control and Recovery			
3.3.1 Skid Control			✓
3.3.2 Skid Recovery			✓

SUMMARY:

The TT150 can be categorized as mid-level simulator relative to all of the other devices examined. It is in the mid-range of fidelity, capability and cost. It has more functionality than the part-task trainers, but implements that functionality to a lesser degree (i.e., fidelity) than the full-mission simulators. While FAAC describes this device as a part-task trainer, we view it more as a lower-fidelity, full-mission simulator. The system's weak points were its low-fidelity graphical display and what appeared to be inaccuracies in the steering response, i.e., the steering wheel was difficult to turn resulting in over-compensation when taking turns. This latter problem seemed like something that could be corrected with minor adjustments to the steering wheel. Its major strengths lie in the sophisticated database of other traffic, including intelligent traffic, that the company was developing and its low cost relative to other full-mission simulators.

DEVICE: DIGITRAN SAFEDRIVE 1000

COMPANY: Digitran Simulation Systems

90 North 100 East
Logan, Utah 84321-4649
Contact: Susan Quick

DATE EXAMINED: April 19, 1994

DESCRIPTION:

The Digitran SafeDrive 1000 is a high-fidelity, full-mission commercial truck driver training simulator. It can be configured for tractor-trailer, tank-trailer, double- and triple-trailer driving. It has the highest visual and motion system fidelity of the simulators examined in the United States. It is also the highest priced simulator designed for CMV driver training in this country. It is commercially available and sells for approximately $900,000 or more, depending upon features and amount of customizing required.

Digitran has entered into a joint venture with a consortium of Canadian trucking companies to set up a training center in Western Canada. The purpose of the center is to provide simulator-based truck driver training to companies on a fee-per-student basis. The first center became operational in March 1995 and has provided training for over 200 students, as of December, 1995.

INSTRUCTIONAL FEATURES:

The Digitran instructor station also employs a user-friendly graphical user interface (GUI) and allows the instructor to insert malfunctions (e.g., blowouts) and replay sections of the trainee's session. It keeps a record of student performance. Digitran also has a stand alone CDL course on Computer-Based Training (CBT), which does not utilize the simulator.

PHYSICAL CHARACTERISTICS:

CABIN:

The Digitran SafeDrive 1000 utilizes a simulated truck cabin with most of the operational controls found in an actual truck.

MOTION SYSTEM:

The SafeDrive 1000 includes a three-degree (e.g., roll, pitch, and yaw) hydraulic motion platform.

SOUND SYSTEM:

The SafeDrive 1000 provides computer-generated engine, braking, and gearing sounds.

VISUAL SYSTEM:

The high-fidelity, computer-generated imagery of the SafeDrive 1000 is produced by a Star Technologies image generator. The imagery is projected onto a 180-degree curved screen in front of the cabin. There are front and side views, as well as software adjustable rear view mirrors projected onto the side view screen.

The simulator includes pre-programmed traffic. The density of the traffic can also be varied by the instructor.

FUNCTIONAL CAPABILITIES:

The following table provides a general assessment of the functional capabilities of the Digitran SafeDrive 1000 simulator.

Table 4.6

Observations of the Functional Capabilities of the SafeDrive 1000 Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
1. Basic Operation			
1.4 Basic Control			
1.4.1 Accelerating		✓	
1.4.2 Braking		✓	
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward		✓	
1.4.4 Turning		✓	
1.5 Shifting		✓	
1.6 Backing		✓	
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters		✓	
1.8.2 Upgrades and Downgrades		✓	
2. Safe Operating Practice			
2.1 Visual Search			
2.1.1 Attention Sharing		✓	
2.1.2 Mirror Interpretation		✓	
2.3 Speed Management		✓	
2.4 Space Management			
2.4.1 Gap Judgment		✓	
2.4.2 Following Distance		✓	

Table 4.6 (Continued)

Observations of the Functional Capabilities of the SafeDrive 1000 Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.5 Night Operation	✓		
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces		✓	
2.6.2 Overcoming Surface Resistance	✓		
2.6.3 Downhill Braking			✓
3. Advanced Operating Practices			
3.1 Hazard Perception			✓
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking		✓	
3.2.2 Emergency Steering		✓	
3.2.4 Brake Failure		✓	
3.3 Skid Control and Recovery			
3.3.1 Skid Control		✓	
3.3.2 Skid Recovery		✓	

SUMMARY:

The SafeDrive 1000 was in a more advanced stage of development than the other high-fidelity, full-mission simulators examined (see European simulators in the next section, *CMV Driver Training Simulators in Other Countries*). It was only one of the high fidelity simulators that was beyond the prototype stage of development and commercially available at the time we examined it. It is now in operation at a truck driver training center in Canada.

The primary drawbacks that we observed were that the images generated did not seem to be able to generate smooth curves, and the system has a slightly exaggerated motion system. You could also easily slip the transmission into a gear even though a gear clashing sound was audible (i.e., when attempting to down-shift on a down-grade).

Its advantages are a high-fidelity visual system, audio system and extensive scenario development. The simulator's computer-generated imagery allowed good quality mirror images for backing, although it was not quite as good as the Doron VMT for that task.

Overall, the SafeDrive 1000 created the greatest degree of realism across the largest number of functional requirements of all the simulators examined. It should be noted, however, that the SafeDrive 1000 is in a more advanced developmental stage than the other high-fidelity, full-mission simulators.

DEVICE: Time-Warner Interactive Advanced Mobile Operations Simulator (AMOS)

COMPANY: Time-Warner Interactive
Contact: Jerry Wachtel
The Veridian Group
226 E. Montgomery St.
Baltimore, MD 21230

DATE EXAMINED: April 18, 1994

DESCRIPTION:

Time-Warner Interactive states that the purpose of its device is to "provide a 'part-task' training resource which can be integrated into a driver skills and judgment curriculum as a bridge between classroom-delivered instruction and actual operation of a motor vehicle ..." The company's focus has been on law enforcement automobile and van training. They have experimented with their vehicle dynamics model to simulate both a truck and car-camper combination vehicle which could lead to the development of a part-task simulator to train backing and docking skills, but have not developed these potential capabilities to date.

The AMOS is a full-mission (non-truck) simulator. It utilizes a computer-generated graphics display system with no motion except some vibration feedback through the seat and steering wheel. Its most unique feature is its modular screen design. It can be purchased with three, five, or eight screens. The latter configuration places three rear-view screens behind the driver which provides the driver with a 360-degree field of view, allowing the driver to see the rear view through actual mirrors or by turning around. The AMOS is commercially available, although not with tractor-trailer simulation capability at this time. The company has a cement truck and dump truck vehicle dynamics models, and is working on a hook-and-ladder fire truck.

The approximate cost for a five-screen system is $70,000. Additional simulators, after an initial purchase, would cost $55,000 each. The three-screen rear module costs an additional $25,000.

INSTRUCTIONAL FEATURES:

The system comes with an Instructor's Workstation where instructors can select and initialize each exercise, as well as create exercises and collect and analyze student performance data.

PHYSICAL CHARACTERISTICS:

CABIN:

The device includes a split-bench (bucket seat) type adjustable seat, shoulder harness, audio speakers, and functional automobile controls: a steering wheel with column-mounted directional signals, transmission shift levers, accelerator, brake, and parking brake.

MOTION SYSTEM:

The AMOS does not have a motion system.

SOUND SYSTEM:

The device provides audio cues (e.g., engine sounds) and tactile feedback, synchronized with the vehicle dynamics, through the steering wheel. The simulator produces computer-generated engine, road, tire, and braking sounds.

VISUAL SYSTEM:

The AMOS uses a proprietary image generator. The standard AMOS system has five monitors providing a 225-degree field of view. The AMOS uses 25-inch diagonal color CRTs as the displays. The monitors have imbedded side and rear view mirror images. An optional set of three rear monitors, which provide a 360-degree field of view, is also available. Each monitor has its own graphics generator.

The AMOS has interactive, programmable, but no random vehicles. However, the company plans to incorporate random vehicles capability in 1996. The vehicles currently in the device's database are reactive (e.g., try to get out of your way and stop at lights).

FUNCTIONAL CAPABILITIES:

The following table provides a general assessment of the functional capabilities of the Time Warner Interactive AMOS simulator.

Table 4.7

Observations of the Functional Capabilities of the Time-Warner AMOS Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
1. Basic Operation 1.4 Basic Control			
1.4.1 Accelerating		✓	
1.4.2 Braking		✓	
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward			✓
1.4.4 Turning		✓	
1.5 Shifting		✓	
1.6 Backing			✓
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters		✓	
1.8.2 Upgrades and Downgrades		✓	
2. Safe Operating Practice 2.1 Visual Search			
2.1.1 Attention Sharing		✓	
2.1.2 Mirror Interpretation			✓
2.3 Speed Management		✓	

Table 4.7 (Continued)

Observations of the Functional Capabilities of the Time-Warner AMOS Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.4 Space Management			
2.4.1 Gap Judgment		✓	
2.4.2 Following Distance		✓	
2.5 Night Operation	✓		
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces		✓	
2.6.2 Overcoming Surface Resistance		✓	
2.6.3 Downhill Braking			✓
3. Advanced Operating Practices 3.1 Hazard Perception		✓	
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking		✓	
3.2.2 Emergency Steering		✓	
3.2.4 Brake Failure	✓		
3.3 Skid Control and Recovery			
3.3.1 Skid Control	✓		
3.3.2 Skid Recovery	✓		

SUMMARY:

The Time-Warner AMOS was designed as an automobile simulator for law enforcement officers. Later, a van simulation capability was added. Now, the company is adding a hook-and-ladder fire truck simulation capability and is considering entering the truck driver training simulator market. The AMOS is not a truck simulator at this time. Consequently, it is not possible to compare it on the same features/capabilities as the other simulators. Its most interesting feature is the modular screen design it employs. A customer can choose a three-, five-, or eight-screen configuration. The common five screen configuration provides a 225-degree field of view. The additional three screen option provides a 360-degree field of view. This is, however, of no value to truck driving trainees who are learning to drive with a trailer obstructing their rear field of view. The graphic display system was, at the time it was observed, a relatively low-fidelity system. However, Time-Warner reports to have developed a more advanced chip for the AMOS visual system of the AMOS since it was observed for this report. The company states that the new chip provides texture-mapped graphics which would provide high-fidelity, photo-realistic images.

CMV Driver Training Simulators in Other Countries

In the previous subsection, we reviewed six simulators that met the study requirement of having the potential to provide CMV driver training and/or licensing in the near future (i.e., within one year). In this subsection, we identify and describe six additional CMV driving simulators, meeting the same criteria, that are manufactured in countries outside of the United States. These six foreign driving simulators are listed in Table 4.8. Each simulator is described in detail on the following pages.

Table 4.8

CMV Driver Training Simulators in Other Countries

SIMULATOR NAME	TYPE	MANUFACTURER
Thompson Truck Driving Simulator	High-Fidelity Full-Mission Simulator	Thompson - CSF Cergy Pontoise Cedex, France
Oerlikon-Contraves ADAMS	High-Fidelity Full-Mission Simulator	Oerlikon-Contraves AG Zurich, Switzerland
Protectum Driving Simulator	High-Fidelity Full-Mission Simulator	Swedish Road and Traffic Research Institute Likoping, Sweden
Aitec Driving Simulator	High-Fidelity Full-Mission Simulator	AITEC GmbH & Co. Dortmund, Germany
ATLAS LVTS	High-Fidelity Full-Mission Simulator	ATLAS ELEKTRONIK GmbH Bremen, Germany
TRL Driving Simulator	High-Fidelity Full-Mission Simulator	Transportation Research Laboratory Crowthorne, England

DEVICE: Thompson Truck Driving Simulator

COMPANY: Thompson, CSF
26 Chaussee Jules Ceser
OSNY
BP 226
95523 Cergy Pontoise Cedex
France
Contact: Mr. Philippe Bouquet

DATE EXAMINED: May 11, 1994

DESCRIPTION:

The Thompson Truck Driving Simulator Demonstrator is a functioning prototype device that the company uses to demonstrate its capabilities and from which to develop design specifications for custom-built devices. The "Super Truck" simulator Thompson is building for the French Army and another simulator it is proposing in response to a Request for Proposal (RFP) from the Swiss Army are examples of Thompson's custom approach to simulator design. Thompson states that it is not locked into the present prototype and could develop part-task systems. The company does not plan to build "off-the-shelf" systems at this time.

The prototype is designed to be a full-mission simulator, although only a few scenarios were available at the time of our review. No price was given for the device since the prototype is not available for sale, per se. It utilizes a proprietary image generator and a four projector/screens system. The simulator, or designs based on it, also includes an optional 3-axis electric motion platform. The prototype simulates a two-axle straight truck.

INSTRUCTIONAL FEATURES:

The prototype simulator was operated via a computer and monitor, but the company did consider this an instructor station.

PHYSICAL CHARACTERISTICS:

The Thompson Truck Driving Simulator has the following physical characteristics.

CABIN:

The simulator includes a full Mercedes-Benz 1017 truck cabin mockup with actual controls. While driving, resistance feedback is experienced through the steering wheel.

MOTION SYSTEM:

An optional 3-axis electric motion platform is available for the Thompson simulator. However, we cannot comment on it at this time, because the system was not demonstrated during our visit. Thompson also reported that it is developing a less expensive 2-axis motion platform.

SOUND SYSTEM:

The simulator provided simulated engine sounds, as well as brake, clutch, and gear sounds, but no wind or other external sounds.

VISUAL SYSTEM:

The Thompson Truck Driving Simulator utilizes a proprietary image generator and four-projector system to display the visual system. The screens provide a 140-degree field of view, including side window and two mirror views. Images of driving scenes (e.g., road curves, traffic signs, other traffic) are provided.

FUNCTIONAL CAPABILITIES:

The following table provides a general assessment of the functional capabilities of the Thompson Truck Driving Simulator.

Table 4.9

Observations of the Functional Capabilities of the Thompson Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
1. Basic Operation			
1.4 Basic Control			
1.4.1 Accelerating		✓	
1.4.2 Braking		✓	
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward		✓	
1.4.4 Turning		✓	
1.5 Shifting			✓
1.6 Backing		✓	
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters		✓	
1.8.2 Upgrades and Downgrades		✓	
2. Safe Operating Practice			
2.1 Visual Search			
2.1.1 Attention Sharing		✓	
2.1.2 Mirror Interpretation			✓
2.3 Speed Management		✓	

Table 4.9 (Continued)

Observations of the Functional Capabilities of the Thompson Truck Driving Simulator

Capability	Judgment of Capability		
		Adequate	Not Adequate
2.4 Space Management			
2.4.1 Gap Judgment		✓	
2.4.2 Following Distance		✓	
2.5 Night Operation		✓	
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces		✓	
2.6.2 Overcoming Surface Resistance		✓	
2.6.3 Downhill Braking		✓	
3. Advanced Operating Practices 3.1 Hazard Perception		✓	
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking			✓
3.2.2 Emergency Steering		✓	
3.2.4 Brake Failure	✓		
3.3 Skid Control and Recovery			
3.3.1 Skid Control			✓
3.3.2 Skid Recovery			✓

SUMMARY:

This device did not rate as highly on the functional capabilities as some of the other full-mission simulators. This is primarily due to the fact that Thompson uses this device as a demonstrator and engineering test bed. Although we refer to it as a prototype, Thompson's designation of "demonstrator" is more accurate, since the device is not intended to be developed into a commercial product, but rather to serve as a platform for demonstrating capabilities which can be included in custom devices.

DEVICE: Oerlikon-Contraves ADAMS

COMPANY: Oerlikon-Contraves AG
Birchstrasse 155
Postfach
CH-8050 Zurich, Switzerland
Contact: Mr. Peter Bertschinge

DATE EXAMINED: May 10, 1994

DESCRIPTION:

The Oerlikon-Contraves Advanced Driving and Maneuvering Simulator (ADAMS) is a full-mission, tractor-trailer driving simulator. We examined a prototype device. However, a production version will be available in the near future at a cost of approximately $700,000.

The ADAMS has a uniquely small footprint for a full-mission device. This size reduction is due primarily to the collimated display system employed which can, through the arrangement of optics and mirrors, project an image on a display less than a meter from the driver that is perceived in the same manner as it would be if it were projected several meters away. The ADAMS visual system employs computer-generated imagery displayed on the wide-angle collimated display.

INSTRUCTIONAL FEATURES:

The ADAMS has an instructor station that can accommodate up to five simulators at one time. The instructor can select and create exercises, monitor student performance, and record and print performance evaluations and training statistics. The instructor can communicate with the trainee from the instructor station during simulation. Traffic can be selected and density can vary, but only a few vehicles had been implemented in the simulation database at the time of our review.

PHYSICAL CHARACTERISTICS:

CABIN:

The ADAMS has a completely enclosed, simulated truck cabin. It includes functioning displays and controls.

MOTION SYSTEM:

Oerlikon-Contraves provides motion to the seat of the ADAMS, which simulates the effects of acceleration and deceleration. There is realistic torque response in the steering wheel.

SOUND SYSTEM:

The ADAMS has simulated engine sound and the sound of gears meshing.

VISUAL SYSTEM:

The ADAMS employs computer-generated imagery displayed via a wide-angle collimated display system. It provides forward and side views with two rear view mirror displays. The system has a few other vehicles as traffic which can be implemented with variable density. The system has limited road environments -- only city with no traffic and a practice area.

FUNCTIONAL CAPABILITIES:

The following table provides a general assessment of the functional capabilities of the Oerlikon-Contraves ADAMS Truck Driving Simulator.

Table 4.10

Observations of the Functional Capabilities of the ADAMS Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
1. Basic Operation			
1.4 Basic Control			
1.4.1 Accelerating		✓	
1.4.2 Braking		✓	
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward		✓	
1.4.4 Turning		✓	
1.5 Shifting		✓	
1.6 Backing		✓	
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters			✓
1.8.2 Upgrades and Downgrades	✓		
2. Safe Operating Practice			
2.1 Visual Search			
2.1.1 Attention Sharing		✓	
2.1.2 Mirror Interpretation			✓
2.3 Speed Management			✓
2.4 Space Management			
2.4.1 Gap Judgment			✓
2.4.2 Following Distance			✓

Table 4.10 (Continued)

Observations of the Functional Capabilities of the ADAMS Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.5 Night Operation			✓
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces	✓		
2.6.2 Overcoming Surface Resistance	✓		
2.6.3 Downhill Braking	✓		
3. Advanced Operating Practices			
3.1 Hazard Perception		✓	
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking			✓
3.2.2 Emergency Steering			✓
3.2.4 Brake Failure		✓	
3.3 Skid Control and Recovery			
3.3.1 Skid Control	✓		
3.3.2 Skid Recovery	✓		

SUMMARY:

The unique feature of the ADAMS is the manner in which Oerlikon-Contraves utilized a collimated display system to reduce the footprint (floor space required for the device). The reduced size and ability to link five simulators to one instructor station would appeal to a training organization (company or school) that was interested in installing several simulators at the same facility. The motion system -- motion to the seat only -- is an interesting approach (a driver feels acceleration forces via the seat), however, it did not feel realistic during our trials. The company reports that it is still developing this capability. At the time of our review, there were only two scenarios with a very limited road environment and only a few other vehicles (i.e., traffic) implemented. Many of our "Not Adequate" judgments resulted from these limited scenarios. Again, we were reviewing a prototype device and our examination only describes it at that stage of development.

DEVICE: Protectum Driving Simulator

COMPANY: Swedish Road and Traffic Research Institute
S-581 01 Likoping, Sweden
Contact: Mr. Steffon Nordmark

DATE EXAMINED: May 9, 1994

DESCRIPTION:

The Protectum Driving Simulator is a full-mission simulator designed by the Swedish Road and Traffic Research Institute that built the well-known VTI driving research simulator. The Protectum device is its first commercial truck driving simulator. It is commercially available from the Swedish Road and Traffic Research Institute. No price was given for the device. This is a high-fidelity device utilizing a proprietary computer-generated projection system and a motion platform.

The device is a truck driving simulator which, as VTI states, "... permits the operator to drive a truck or a truck with a trailer. It is also possible to load the truck and the trailer in different ways with regard, for example, to distribution of the cargo between the truck and the trailer, or the height of the main point [center of gravity], etc. It is also possible to drive a combination of truck and trailer where, for instance, the trailer is 'over-' or 'under-braked.'"

While only one of these devices has been sold to date, it is being used to train 10 to 15 students per day by the Protectum division of the Swedish insurance group, Trygg-Hansa.

INSTRUCTIONAL FEATURES:

The Protectum simulator includes an instructor station computer that enables the instructor to monitor and control the training exercises.

PHYSICAL CHARACTERISTICS:

The Protectum Truck Driving Simulator has the following physical characteristics.

CABIN:

The Protectum simulator includes an actual, full-size truck cabin. It includes functioning displays and controls.

MOTION SYSTEM:

The Protectum device incorporates a combination motion system, with three-degrees of freedom, and a vibration platform in its design. The platform moves sideways along a track and will tilt, roll, and vibrate to simulate truck movement.

SOUND SYSTEM:

This device has simulated engine sounds, but does not provide other vehicle sounds (e.g., gears meshing).

VISUAL SYSTEM:

The proprietary computer-generated imagery, developed by VTI, is projected onto a wide-angle screen. There are three TV projectors that provide a 120-degree forward field of view and side views. There is no rear view. The visual imagery includes traffic, but only has a few vehicle shapes. The objects were primitive polygons which did not provide a realistic enough image, in our opinion, to provide gap judgment when following one of the simulated vehicles. VTI reports, as of November 1995, that it is improving the visual system and plans to upgrade the Protectum device with the new system when it is available.

FUNCTIONAL CAPABILITIES:

The following table provides a general assessment of the functional capabilities of the Protectum Truck Driving Simulator.

Table 4.11

Observations of the Functional Capabilities of the Protectum Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
1. Basic Operation			
1.4 Basic Control			
1.4.1 Accelerating		✓	
1.4.2 Braking		✓	
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward	✓		
1.4.4 Turning			✓
1.5 Shifting			✓
1.6 Backing	✓		
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters	✓		
1.8.2 Upgrades and Downgrades		✓	
2. Safe Operating Practice			
2.1 Visual Search			
2.1.1 Attention Sharing		✓	
2.1.2 Mirror Interpretation	✓		
2.3 Speed Management		✓	
2.4 Space Management			
2.4.1 Gap Judgment			✓
2.4.2 Following Distance		✓	

Table 4.11 (Continued)

Observations of the Functional Capabilities of the Protectum Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.5 Night Operation			✓
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces		✓	
2.6.2 Overcoming Surface Resistance		✓	
2.6.3 Downhill Braking			✓
3. Advanced Operating Practices			
3.1 Hazard Perception		✓	
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking		✓	
3.2.2 Emergency Steering		✓	
3.2.4 Brake Failure		✓	
3.3 Skid Control and Recovery			
3.3.1 Skid Control		✓	
3.3.2 Skid Recovery		✓	

SUMMARY:

This simulator was custom designed to meet Protectum's requirement to provide refresher training for experienced drivers. Consequently, it does not include some of the capabilities common to the other driver training simulators, such as mirrors for backing. Other inhibiting factors include no urban environment, no over/under obstructions, and limited problem insertion on instructor station.

It performed well, however, on those capabilities that were included and it has the most advanced and realistic motion system of the devices examined. Even the slipping on snow felt realistic.

DEVICE: AITEC Truck Driving Simulator

COMPANY: AITEC GmbH & Co.
Informationstechnologie KG
Alter Hellweg 50
44379 Dortmund, Germany
Contact: Klaus Vits

DATE EXAMINED: May 4, 1994

DESCRIPTION:

The AITEC device is a high-fidelity, full-mission prototype simulator. It was among the highest-fidelity devices, along with the Digitran device, that we examined. It has the highest-fidelity visual system in terms of photo texturing and object detail (e.g., the occupants of other vehicles are visible). The prototype simulates a straight truck. AITEC is planning to add a trailer. This device is in an early prototype stage of development. Consequently, many of the functional capabilities of the simulator could not be rated.

There are no immediate plans to make the simulator commercially available. AITEC plans to establish truck and bus driver training centers that will incorporate three of its simulators as training devices, with curriculum designed and administered by an AITEC psychologist and education specialist.

INSTRUCTIONAL FEATURES:

The prototype does not have an instructor station. AITEC plans to have an instructor station in its training centers.

PHYSICAL CHARACTERISTICS:

CABIN:

The AITEC simulator incorporates an actual truck cab, control, and displays. It utilizes an automatic transmission.

Motion System:

The prototype did not have a motion system. The company is planning to develop a limited motion system, based on the results of its research.

Sound System:

The simulator provides simulated engine and ambient sounds.

Visual System:

The simulator utilizes computer-generated imagery (5-channel) via a Silicon Graphics image generator. It provides a 180 degree field of view with rear view mirror projection. The scenarios include autonomous traffic with variable traffic density.

FUNCTIONAL CAPABILITIES:

The following table provides a general assessment of the functional capabilities of the AITEC Truck Driving Simulator.

Table 4.12

Observations of the Functional Capabilities of the AITEC Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
1. Basic Operation			
1.4 Basic Control			
1.4.1 Accelerating		✓	
1.4.2 Braking		✓	
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward		✓	
1.4.4 Turning		✓	
1.5 Shifting			✓
1.6 Backing		✓	
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters	✓		
1.8.2 Upgrades and Downgrades	✓		
2. Safe Operating Practice			
2.1 Visual Search			
2.1.1 Attention Sharing		✓	
2.1.2 Mirror Interpretation			✓
2.3 Speed Management		✓	
2.4 Space Management			
2.4.1 Gap Judgment		✓	
2.4.2 Following Distance		✓	

Table 4.12 (Continued)

Observations of the Functional Capabilities of the AITEC Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.5 Night Operation	✓		
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces	✓		
2.6.2 Overcoming Surface Resistance	✓		
2.6.3 Downhill Braking	✓		
3. Advanced Operating Practices			
3.1 Hazard Perception		✓	
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking	✓		
3.2.2 Emergency Steering		✓	
3.2.4 Brake Failure	✓		
3.3 Skid Control and Recovery			
3.3.1 Skid Control	✓		
3.3.2 Skid Recovery	✓		

SUMMARY:

The functional capabilities table shows that the AITEC simulator was able to provide many of the capabilities for simple forward driving, turning, and backing. These capabilities were facilitated and enhanced by its advanced, i.e., highly detailed, visual system. However, as the table also shows, we were unable to exercise many of the capabilities on our list. This was due to the fact that the device is a prototype in an early development stage. Given the quality of what we were able to observe, we would be interested in monitoring the progress of this device as it becomes fully functional.

DEVICE: ATLAS LVTS Truck Driving Simulator

COMPANY: ATLAS ELEKTRONIK GmbH
Sebaldsbrucker HeerstraBe 235
28305 Bremen, Germany
Contact: Mr. Ralf Moldenhauer

DATE EXAMINED: May 16, 1994

DESCRIPTION:

The ATLAS LVTS is a full-mission, tractor-trailer driving simulator. The simulator is currently in the prototype stage of development, but will be commercially available within the next one to two years. The device has a high-fidelity visual and sound system and includes a motion system.

INSTRUCTIONAL FEATURES:

The ATLAS LVTS includes an instructor control station that allows control of the simulator and the recording and playback of the exercises.

PHYSICAL CHARACTERISTICS:

CABIN:

The simulator utilizes an actual truck cabin with functioning displays and controls. The gear box is a replica with actual gear shift. Requires a room nine meters by nine meters without any special air conditioning for the simulator.

MOTION SYSTEM:

The LVTS includes a motion system. The steering wheel provides realistic speed-dependent torque feedback.

SOUND SYSTEM:

The system has high-fidelity engine and external sounds.

VISUAL SYSTEM:

The visual system displays proprietary computer-generated graphics via a four-channel projection system. It provides a 180-degree field of view with rear view mirror projections. The driving scenarios in the prototype did not include other traffic.

FUNCTIONAL CAPABILITIES:

The following table provides a general assessment of the functional capabilities of the ATLAS LVTS simulator.

Table 4.13

Observations of the Functional Capabilities of the ATLAS LVTS Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
1. Basic Operation			
1.4 Basic Control			
1.4.1 Accelerating		✓	
1.4.2 Braking		✓	
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward		✓	
1.4.4 Turning		✓	
1.5 Shifting			✓
1.6 Backing			✓
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters		✓	
1.8.2 Upgrades and Downgrades		✓	
2. Safe Operating Practice			
2.1 Visual Search			
2.1.1 Attention Sharing		✓	
2.1.2 Mirror Interpretation			✓
2.3 Speed Management		✓	
2.4 Space Management			
2.4.1 Gap Judgment	✓		
2.4.2 Following Distance	✓		

Table 4.13 (Continued)

Observations of the Functional Capabilities of the ATLAS LVTS Truck Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.5 Night Operation		✓	
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces	✓		
2.6.2 Overcoming Surface Resistance	✓		
2.6.3 Downhill Braking	✓		
3. Advanced Operating Practices			
3.1 Hazard Perception		✓	
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking	✓		
3.2.2 Emergency Steering		✓	
3.2.4 Brake Failure		✓	
3.3 Skid Control and Recovery			
3.3.1 Skid Control	✓		
3.3.2 Skid Recovery	✓		

SUMMARY:

Like the AITEC simulator, the functional capabilities table shows that the ATLAS LVTS simulator was able to provide most of the capabilities for simple forward driving, turning, and backing. Also like the AITEC device, the ATLAS simulator is a prototype device that has not yet implemented many of the features in the functional capabilities table. For example there was no traffic, only stationary vehicles. Consequently, we were unable to exercise many of the capabilities on our list. This is another device that is worth monitoring as it emerges from prototype to development.

DEVICE: TRL Automobile Research Simulator

COMPANY: Transport Research Laboratory
Old Wokingham Road
Crowthorne, Berkshire RG11 6AU
England
Contact: Mr. Gary Eves

DATE EXAMINED: May 13, 1994

DESCRIPTION:

The Transport Research Laboratory has been a well-respected, government-sponsored laboratory for driving research. The TRL Driving Simulator, currently configured as an automobile simulator, is a full-mission research device. It is a high-fidelity device with a limited motion system. Although TRL is not planning to make the simulator commercially available in its current configuration, a representative told the contractor team that the British government is requiring the lab to support itself with commercial ventures. The representative informed us that they are associated with a consortium of companies who are interested in utilizing a truck simulator. Consequently, TRL is considering developing a truck driving simulator, based on the same technology as their research simulator, within one to two years. We examined the device in its current configuration and attempted to extrapolate on the potential of TRL to develop a truck driver training simulator based on this technology.

INSTRUCTIONAL FEATURES:

Designed as a research simulator, the simulator does not have an instructor station, per se. It has a personal computer that collects detailed data about the driver control and vehicle behavior. The computer also combines this data with recorded video information on the driver's eye search patterns. This information can be played back and analyzed subsequent to the driving session.

PHYSICAL CHARACTERISTICS:

CABIN:

The simulation system incorporates an actual automobile with its display and control responses controlled by the simulator's computer control system.

MOTION SYSTEM:

The limited hydraulic motion system is driven by actuators that provide vibration and affect a small degree of pitch, roll, and heave (i.e., lurching) motion. The actuators do provide yaw motion.

SOUND SYSTEM:

The audio system provides simulated engine sounds, as well as brake, clutch, and gear sounds.

VISUAL SYSTEM:

The visual system includes a Silicon Graphics image generator with four projectors and screens. It provides a 210-degree field of view with rear view mirrors. The scenarios include some other traffic.

FUNCTIONAL CAPABILITIES:

The following table provides a general assessment of the functional capabilities of the TRL simulator.

Table 4.14

Observations of the Functional Capabilities of the TRL Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
1. Basic Operation			
1.4 Basic Control			
1.4.1 Accelerating			✓
1.4.2 Braking		✓	
1.4.3(a) Driving Forward		✓	
1.4.3(b) Driving Backward		✓	
1.4.4 Turning		✓	
1.5 Shifting			✓
1.6 Backing		✓	
1.8 Proficiency Development			
1.8.1 Maneuvering in Restricted Quarters			✓
1.8.2 Upgrades and Downgrades		✓	
2. Safe Operating Practice			
2.1 Visual Search			
2.1.1 Attention Sharing		✓	
2.1.2 Mirror Interpretation			✓
2.3 Speed Management		✓	
2.4 Space Management			
2.4.1 Gap Judgment		✓	
2.4.2 Following Distance		✓	

Table 4.14 (Continued)

Observations of the Functional Capabilities of the TRL Driving Simulator

Capability	Judgment of Capability		
	Not Provided	Adequate	Not Adequate
2.5 Night Operation		✓	
2.6 Extreme Driving Conditions			
2.6.1 Handling Slippery Surfaces	✓		
2.6.2 Overcoming Surface Resistance	✓		
2.6.3 Downhill Braking		✓	
3. Advanced Operating Practices			
3.1 Hazard Perception	✓		
3.2 Emergency Maneuvers			
3.2.1 Emergency Braking	✓		
3.2.2 Emergency Steering	✓		
3.2.4 Brake Failure	✓		
3.3 Skid Control and Recovery			
3.3.1 Skid Control	✓		
3.3.2 Skid Recovery	✓		

SUMMARY:

The TRL Driving Simulator is currently configured as an automobile simulator and a research device. TRL is considering developing a commercial truck driver training simulator based on the experience acquired through this research device. Its highly sophisticated visual system, which TRL is continually upgrading, is readily transferable to a truck simulator. That it did not perform well on many of the other capabilities is not surprising, given that they are based on CMV driver training functional requirements and that this is an automobile research simulator. TRL has a reputation for conducting high-quality, simulator-based research for many years and has undoubtedly accumulated considerable knowledge in this area. While we cannot predict, based on the examination of this device, how a TRL-designed truck simulator would look and perform, they are another company/agency to watch for further developments.

Other Issues

Other areas in which we attempted to assess the simulators included:

Evidence of Transfer of Training

None of the manufacturers was able to provide evidence of transfer of training data, nor were there any studies reported in the simulation/CMV literature.

Ease of Programming, Operation, and Maintenance

All of the devices were easy to operate. The instructor stations were user-friendly. However, programming is another matter. These are complex, proprietary software systems, which are not designed for customers to maintain and update.

Acquisition, Operation, and Maintenance Costs

Approximate acquisition costs were reported with the simulator descriptions. No "hard data" on operation and maintenance costs of the simulators were obtained.

Acceptability to Students

No CMV driver training students were encountered during the visits. All of the prototypes, and the most recent upgraded versions of the devices, resided in the manufacturers' facilities where there were no students present during the visits.

Cost/Benefit With Regard to Traditional Training Methods

No objective studies were found that address the issue of the cost/benefit trade-off in providing training via driving simulators.

Summary of U.S. and Foreign Simulator Data Collection

Summary of Simulator Reviews

The devices described in the preceding pages represent the spectrum of existing and near-horizon CMV driver training simulators in the United States and other countries. The Doron devices represent the low end of the fidelity spectrum, followed by the AMOS. The TT150 represents the mid-range of the fidelity spectrum, with the SafeDrive 1000 occupying the sole place at the high end. As the report shows, the higher the fidelity, the greater the number of functional capabilities and the higher the cost. At the low (fidelity) end, however, the devices are designed to function as part-task trainers, i.e., they train on a small set of specific driving tasks. This is done at significant cost savings. However, there have been no reported cost-training benefit comparison studies to support selecting one level of simulation fidelity over another for a given set of tasks.

Although the foreign devices we observed varied in their degree of fidelity and functional capabilities, they were, in general, moderate- to high-fidelity devices. It appears that the impetus for the development of foreign simulators has been government-issued Requests for Proposals (RFPs), typically for military training.

There have been no reported cost-training benefit tradeoff studies to support selecting one level of simulation fidelity over another for a given set of tasks. Nor have there been any objective studies of the training effectiveness of the existing devices. Such empirical studies are beyond the scope of this effort. The purpose of this report is to describe what is available in CMV driver training simulator technology, what devices/technology will be available in the near future, and how these devices performed for an unbiased user.

Conclusions with Regard to the Objective

Having described each of the 12 simulators individually, we can attempt to address how well the existing and near-horizon CMV simulator technology satisfies the functional requirements.

It is necessary to begin this discussion with a description of how the simulation and driver training experts ranked the importance of the functional requirements. Then, we will discuss how this ranking maps to the actual capabilities of the simulators we examined.

As discussed in Section 3, the experts were asked to rank order the functional requirements from 1 (highest) to 23 (lowest) in terms of the training/licensing benefit achieved by using simulators to accomplish these objectives.

Table 4.15 lists the functional requirements in order of their importance to the experts, from highest to lowest. The table also shows the mean ranking for each requirement and the range of the ranks.

It is apparent from the table that:

- Backing/Driving Backward (functional requirements 1.6 and 1.4.3b) were ranked highest, followed by turning (1.4.4). The Backing and Driving Backward objectives were combined for the purpose of ranking due to their similar requirements.

- Night Operation (2.5) was the lowest ranked requirement and Overcoming Surface Resistance (2.6.2) received the next lowest ranking.

Interpretation of the rankings is complicated by the high variability among the experts, as shown by the large range of ranks for most of the requirements. The experts differed greatly among themselves concerning what requirements they thought were high benefit, and those they thought were low benefit. In fact, there were three requirements (Driving Forward, Shifting, and Attention Sharing) that spanned the entire range from highest to lowest rank. Each of these requirements was ranked as most important by at least one expert, while another ranked it as least important.

This high variability among the raters led to the decision not to drop any of the functional requirements in our original set, prior to the data collection visits. Given the differences among the experts, it was decided to examine the simulators for their conformance to all of the functional requirements.

The variability shown in the table tends to be least at the extremes of the list, and greatest for the intermediate rankings. The table shows that:

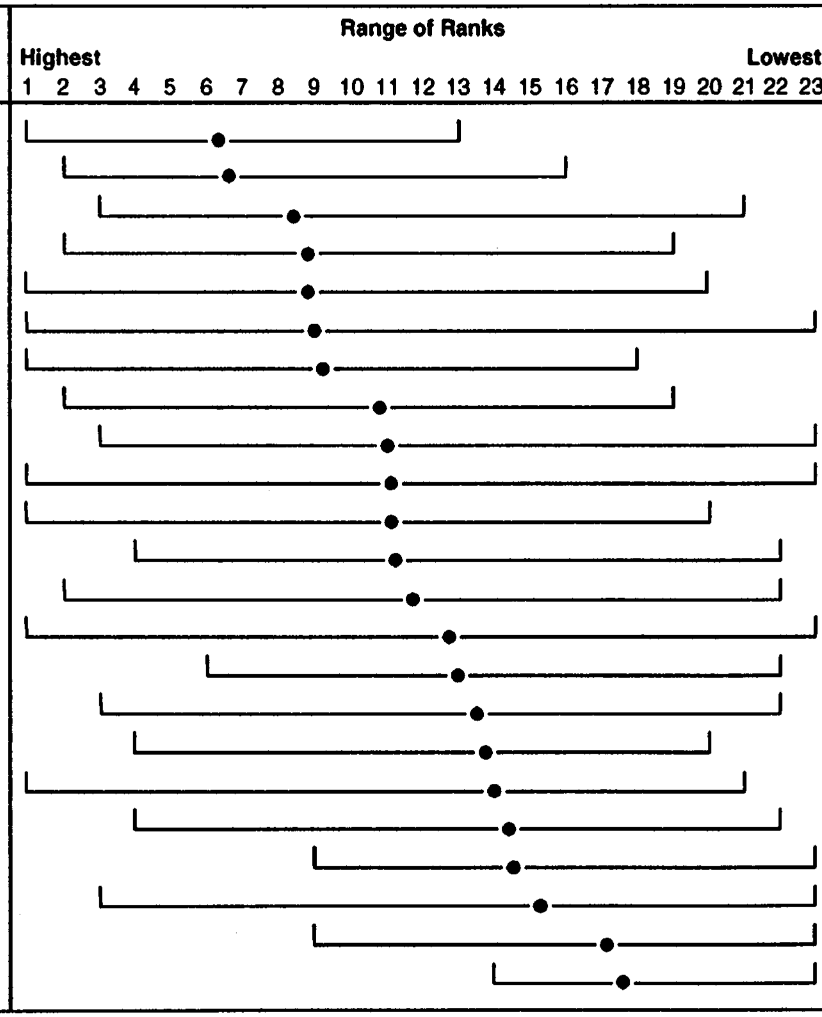
- There is greatest agreement (the smallest range of ranks) for Night Operation. The functional requirement was ranked as having the least simulation benefit.

- The next highest degree of consensus is for Backing/Driving Backward. This functional requirements ranked as having the highest simulation benefit.

Table 4.15

Range and Mean of Expert Rankings by Functional Requirement

Range and Mean of Expert Rankings by Functional Requirement



Functional Requirements (in rank order)	Mean Rank
1.6 Backing/**1.4.3(b)** Driving Backward	6.3
1.4.4 Turning	6.6
1.4.2 Braking	8.4
2.3 Speed Management	8.8
3.1 Hazard Perception	8.8
1.4.3(a) Driving Forward	9.0
2.4.2 Following Distance	9.2
3.2.1 Emergency Maneuvers	10.8
1.8.1 Maneuvering in Restricted Quarters	11.0
1.5 Shifting	11.1
2.6.3 Downhill Braking	11.1
2.1.2 Mirror Interpretation	11.2
1.8.2 Upgrades and Downgrades	11.7
2.1.1 Attention Sharing	12.7
2.6.1 Handling Slippery Surfaces	13.0
1.4.1 Accelerating	13.5
3.2.2 Emergency Steering	13.8
3.2.4 Brake Failure	14.0
3.3.1 Skid Control	14.4
2.4.1 Gap Judgement	14.6
3.3.2 Skid Recovery	15.3
2.6.2 Overcoming Surface Resistance	17.1
2.5 Night Operation	17.6

To determine how well the simulator technology satisfied the CMV driver training and licensing requirements, a comparison was made of the experts' ranking of each functional requirement to the number of simulators that rated "Adequate" on that requirement. A simulator was rated as "Adequate" on a given requirement if it had all or most of the display and response system characteristics called for in the requirement definition. This does not mean that the simulator is, in fact, successful in accomplishing the objective of the functional requirement, only that it has the requisite functionality and thus has the *potential* to do so. (See Section 3 for the definitions of the functional requirements.)

Table 4.16 provides the comparison between expert rank and the number of simulators rated adequate, for each functional requirement. It can be seen that at least one simulator rated as adequate on each of the functional requirements, but the number that rated adequate for a given requirement varied from one to twelve. For example, only one simulator rated adequate on Mirror Interpretation but all twelve rated adequate on Driving Forward.

One finding not shown in the table is that no simulator rated adequate on all functional requirements. That is, no simulator showed the potential to satisfy all of the training and licensing requirements. However, there appears to be a correlation between the experts' benefit rankings and the availability of the functionality. This correlation gives an indication of the extent to which high-ranked requirements could (potentially, at least) be satisfied by the existing/near-horizon simulator technology.

A correlation of 0.48 between the ranks and the extent of availability was calculated. Correlations in the 0.4 to 0.6 range are generally considered as "moderate." Thus, while there is a definite tendency for the more highly rated requirements to be more widely available on the simulators examined, the relationship was by no means perfect.

A closer look at the relationship shown in the table reveals that the ten most highly ranked requirements are rated "Adequate" on five or more of the simulators examined, and four of these requirements are available on ten or more of the simulators.

In light of the preceding discussion, the findings suggest that overall simulation technology appears adequate to satisfy the highest ranked driver training/licensing requirements. This conclusion is based on the following facts:

- While one cannot say for certain that a simulator rated adequate for a given functional requirement can successfully train the objective of that requirement, at least one simulator rated adequate for each of the requirements. Thus, there is the potential that the technology can successfully train all of the requirement objectives.

- There is a general tendency for availability of functionality to correlate with rank, and the most highly ranked requirements are available on several of the simulators.

Table 4.16

Comparison of Expert's Rankings and Simulator Capabilities

FUNCTIONAL REQUIREMENTS (In rank order from highest to lowest)	**Expert's Mean Ranking**	**Simulators Rated Adequate[1]**
Backing/Driving Backward	6.3	7
Turning	6.6	11
Braking	8.4	10
Speed Management	8.8	11
Hazard Perception	8.8	8
Driving Forward	9.0	12
Following Distance	9.2	6
Emergency Maneuvers	10.8	5
Maneuvering in Restricted Quarters	11.0	6
Shifting	11.1	7
Downhill Braking	11.1	2
Mirror Interpretation	11.2	1
Upgrades and Downgrades	11.7	8
Attention Sharing	12.7	10
Handling Slippery Surfaces	13.0	4
Accelerating	13.5	10

Table 4.16 (Continued)

Comparison of Expert's Rankings and Simulator Capabilities

FUNCTIONAL REQUIREMENTS	Expert's Mean Ranking	Simulators Rated Adequate[1]
Emergency Steering	13.8	8
Brake Failure	14.0	4
Skid Control	14.4	2
Gap Judgment	14.6	6
Skid Recovery	15.3	2
Overcoming Surface Resistance	17.1	5
Night Operation	17.6	5

[1] Number of simulators, out of the twelve examined, that were rated "adequate" for the specific functional requirement.

This means that, even if simulator buyers' requirements differ as much as our experts' rankings, there is a good chance that a buyer will find a simulator that satisfies his/her requirements.

- During data collection, simulator manufacturers repeatedly stated that many of the functional requirements that were not operational at the time of the visit were in the planning stages and would be added in the future. In other cases, manufacturers suggested that even though their simulators did not satisfy a particular functional requirement, adding it in response to a customer request would be "no problem." Overall it appears that while the manufacturers are confident in their ability to add features that will meet more of the functional requirements, they are ultimately market driven and are looking for direction from potential customers. This implies that simulator buyers have considerable latitude in having devices custom tailored to their unique requirements.

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SECTION 5

GOVERNMENT AND OTHER INDUSTRY ACTIVITY

The primary goal of this study was to examine existing and near-horizon CMV driver training simulators. However, a secondary goal was to contact Federal government agencies and private sector organizations that were involved with transportation simulation in general, to obtain information about their experience with, and/or new developments in, simulator technology.

The objective was to contact government agencies that had experience using simulators and simulator manufacturers, other than those already identified as having existing CMV driver training simulators. Included in the latter group were manufacturers of automobile driving and pilot training simulators, as well as other simulators used for conducting driving research. Agencies and manufacturers were identified from the literature, conferences, and networking among professionals in the simulation community. By networking within the simulator community, all or nearly all, of the major contributors to simulator technology were identified and contacted. A total of 18 organizations was identified:

- Ten (10) were manufacturers of simulators or companies involved in simulator technologies.
- Seven (7) were Federal government agencies or military units that support (or potentially could support) simulator development, and/or use simulators.
- One (1) was a non-government simulator user.

Many of these organizations have been concerned with non-CMV vehicle (e.g., locomotive, tank, aircraft, ship) simulators for training and/or research purposes. Some have been involved with CMV simulators, and others expressed an interest in future involvement.

One Canadian, one Israeli, and two European simulator manufacturers were included in the group. With the exception of three of the foreign manufacturers, a knowledgeable individual was identified within each organization to obtain information about his or her organization. The foreign manufacturers were queried by fax, an approach that had proved effective in establishing contact with, and arranging visits to, the foreign CMV simulator manufacturers earlier in the project. Given the previous success of this approach, it is possible that the manufacturers who did not respond are not presently involved in, and do not have a current interest in, developing CMV driver training devices.

It was decided not to conduct a formal interview, i.e., ask the same set of questions, with the organizations contacted. Given the differences among the organizations, this approach would not have been productive. However, even though the interviews were each unique, an attempt was made to obtain the same general categories of information from the respondents:

- The agency's/manufacturer's current or planned involvement in developing a CMV driver training simulator.
- Technical developments and experience that the agency/manufacturer might have or know about that has potential application to CMV driver training simulators.
- Other agencies or manufacturers that should be contacted.

The 18 organizations that were contacted are identified in the following subsections. The information provided by each organization (or an indication that the organization did not respond) is included.

Government Agencies

NASA - Ames Research Center, Simulation Branch
Moffett Field, Ca.
Contacts: Robert Shiner and Anthony Andre

NASA has many types of simulators, including a reconfigurable civil aviation simulator and simulators that provide training for Space Shuttle astronauts. However, the individuals contacted were unaware of any research that could be related to ground transportation.

National Highway Traffic Safety Administration
Washington, D.C.
Contact: Keith Brewer

NHTSA has no plans for truck driver training. However, NHTSA's National Advanced Driving Simulator (NADS) will become operational at the University of Iowa in the Spring of 1999. The system configuration of the NADS will include a motion platform and provide the computer power to perform real-time dynamics and complex scenario control. The visual system will include a high-performance computer image generator, visual databases and modeling tools, and visual data management software. Realistic audio cuing will be provided. When completed, at an estimated cost of $34 million, the NADS will be the most advanced driving research simulator in the world.[13]

Federal Railroad Administration (FRA), Office of R&D
Washington, D.C.
Contact: Garold Thomas

FRA has a freight locomotive cab simulator. FRA provided training on the device, at one time, but now does only research. Most of the railroads have bought their own simulators. FRA is doing research on the degradation of performance due to fatigue.

The agency contact reports that FRA is currently using a high-fidelity, video-based system. They have developed a technique, using filtering, to have scenes change from day to night and night to day. The contact believes that the higher the fidelity, the better for research purposes. Cost of filming videos goes down with an experienced photographer. They use a bank of six laser videodiscs to change scenes.

Office of Maritime Labor Training and Safety
Washington, D.C.
Contact: Alex Lansberg

The Merchant Marine Academy in New York implemented a Computer-Generated Imagery system in 1974.

The Merchant Marines has a simulator-based course to train and certify for Ship Master. According to government officials it has greatly reduced the time required for someone to receive Ship Master training. The Marine Board of the National Academy of Sciences is conducting a study of certification and training. The recommendations report is expected out in the very near future.

Army Research Institute (ARI)
Alexandria, Va.
Contact: Jonathan Kaplan

The Army is putting much emphasis in conducting training on distributive interactive systems (DIS). The ARI contact believes that this technology would benefit driver training by providing an instructor with the capability to have truck and car simulators interacting "on the road", i.e., the instructor could drive an automobile simulator and interact with the trainee who is driving a truck simulator on the same simulated highway or other type of road.

Federal Aviation Administration, Civil Aeromedical Institute
Oklahoma City, Ok.
Contact: Robert Blanchard

The Institute's lab has a general aviation simulator. It is reconfigurable and can replicate several different aircraft. The contact believes that this capability may be applicable to a truck driver training simulator.

U. S. Army Tactical Vehicles Requirements Office
Fort Eustis, Va.
Contact: Sgt. Gary Burianek

Sgt. Burianek had managed the driver training program for over three years. He reports that one of the main problems with driving simulation in the Army is that expectations exceed budgetary resources. Army leadership was disappointed with the graphics images system that comes on the FAAC TT150 but did not feel it was cost effective to pay the estimated four or more times as much for a higher quality system. He also believes that the cost of the FAAC TT150 ($250k) was not practical for the Army's large annual student throughput (44,000 students/year). He estimates that 40 to 50 simulators would be needed, since training is provided on many very different types of vehicles (10 trucks and about 20 other off-road vehicles).

He conducted an analysis of Army truck driver training instructors in an attempt to determine what they taught. He found that, regardless of the vehicle they were asked about, the training tasks described were the same - basic driving tasks (e.g., turning, braking, shifting). In training, what the instructors do is let the student drive and "get a feel for the truck." He does not believe this can be simulated. He believes that the visual system should be as real as possible and that the simulator should be reconfigurable to represent all the trucks. However, he does not believe that this is feasible for the Army given the cost of simulators and the number needed to accommodate the large volume of students trained each year.

Associations

American Trucking Association (ATA)
Alexandria, Va.
Contact: William Rodgers

The ATA spokesperson is knowledgeable about developments in the simulation community and provided the names of some of the other organizations contacted for this effort. He reported that ATA recently completed a study of elderly drivers using the FAAC TT150 simulator. He reported founding a strong relationship between age, visual acuity, and simulator sickness in his study.

Companies

I*Sim, Inc.
Murray, Utah
Contact: Reginald Wells

I*SIM, Inc. is further along in the development of the **I*SIM Driving Simulator**, than it was during the literature review phase of this study (see Section 2 for a general description of the design of this devise). The company plans to have the first device fully operational in the Summer of 1996. Three versions of the simulator will be offered. The first system will cost between $100,000 and $200.000. It will have a 100-degree field of view with no motion, but will have seat vibration and control flow sound stimuli. The second system will cost between $250,000 and $400,000, have an expanded visual system (increased field of view) and include roll and pitch motion. A third system option, will have the second system configuration mounted on an X-Y motion platform. This system will cost between $500,000 and $750,000.

I*Sim is also comparing the advantages and disadvantages of using projection versus collimated display systems and the company has developed a sophisticated software-driven capability which involves high-fidelity road-tire dynamics combined with a road database.

Illusion Technologies, L.L.C.
Vancouver, Wa.
Contact Dr. James Voorhees

As part of a consortium•of companies, Illusion Technologies designed and developed the Real Drive simulator, a high-fidelity automobile driving simulator under contract to the Australian government. Dr. Voorhees stated that he is interested in developing a CMV driver training simulator in the future, but does not have the financial resources to do so at this time.

Lockheed Martin Canada
Kanata, Ontario
Contact: Ed Derbyshire

Lockheed Martin has obtained the world-wide marketing rights to the Truck Drive commercial vehicle simulator which is based on the Real Drive automobile simulator previously mentioned. The company is also negotiating for a similar arrangement for the Real Drive automobile simulator. The spokesperson reported that negotiations for the delivery of the Truck Drive simulator were at an advanced stage and he expected the first system to be delivered in calendar year, 1996 to a truck driving school in Canada. Subsequent to delivering this first system, they expect to deliver another four systems over the next two years.

CALSPAN Corporation
Buffalo, NY
Contact: Dennis Gawera

CALSPAN is currently considering developing a truck driving simulator for research and possibly training purposes. The company has been working in the area of Distributive Interactive Systems (DIS) and is considering the applicability of that technology to truck driving research/training.

Hughes Training, Inc./Link Division
Falls Church, Va.
Contact: Paul Van Hemel

Hughes Training does not have any immediate plans to develop a truck driver training simulator, but is interested in exploring opportunities to apply the capabilities it has developed in the area of distributed interactive systems (DIS) to truck driver training simulators. DIS, the linking together via software and hardware of training simulators, has been developed by the Department of Defense to provide interactive training with team members in other (e.g., aircraft, tank, ship) simulators. Hughes' simulators are designed to be reconfigurable via what they describe as "quick-disconnect hardware panels and rapidly selectable software."

Electronic Learning Facilitators, Inc. (ELF)
Bethesda, Md.
Contact: Deborah Blank

Although the company does not plan to enter the truck driver simulator market, ELF developed a laser-disc-based interactive training device for Roadway Express to teach drivers to identify and respond to hazardous driving situations and recently developed a CD-ROM based training device designed to train teenage drivers in hazard recognition.

Systems Technology, Inc.
Hawthorne, Ca.
Contact: R. Wade Allen

Systems Technology, Inc. (STI) develops a low-cost, PC-based driving simulator, the STISIM, used in research and to screen for performance impairment, e.g., driver fatigue. STISIM is not a complete training simulator because it does not have a cab, but can be easily interfaced with cut down cabs or simulated cabs, according to Mr. Allen. The driving tasks are fairly interactive (e.g., sign recognition, gap acceptance, hazard detection, speed and lane control) and is easily programmable using the company's Scenario Definition Language. Mr. Allen states that, "STISIM could easily evolve into reliable simulation-based training and screening tool for truck drivers, given modest additional development."

Daimler-Benz
Germany
Contact: Wilfred Kading

No response was received to the request for information. However, recent company promotional materials indicate that the research device is being upgraded with more advanced visual and motion systems for the research device, but there is no indication of intent to develop a driver training simulator.

VTI
Linkoping, Sweden
Contact: Steffan Nordmark

VTI is improving the visual system on its research simulator and plans to upgrade its truck driver training simulator, the Protectum, with the new visual system. However, it has no current plans to manufacture another truck driver training simulator.

Raphael
Israel

No response was received to the request for information.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

The results from the literature review indicate that there has not been much research on the use of simulators in CMV driver training. Unlike the aviation industry, where they have been tested, validated, and required in training curricula, simulators are relatively new to the Commercial Motor Vehicle (CMV) community. There have been some part-task devices that have been utilized in training programs, but they have not been widely deployed throughout the CMV training community. North American Van Lines has been training with a FAAC simulator (a "mid-fidelity" device) for many years and Pinellas Technical Information Center has incorporated Doron (low-fidelity) devices into its tractor-trailer driver training curriculum.

Although these systems have been around for some time, interest by the trucking companies, and to some extent insurance companies, has increased recently. Several manufacturers, both in the United States and Europe, have reported that they are working with, or have been approached by, trucking companies interested in utilizing driving simulators in the training of their drivers. This current interest appears to be focused on the high-fidelity, full-mission simulators. Given the potential buyers' (i.e., trucking companies) inexperience with training devices in general, and simulators in particular, and the dearth of information on driving simulator cost-training effectiveness, it is not surprising that the carriers gravitate toward those devices which look and act most like a truck.

Digitran, which comes closest to offering an "off-the-shelf", high-fidelity simulator, has placed a simulator in a training center where, in partnership with a Canadian consortium of trucking companies, it is providing driver training utilizing the simulator. However, Digitran has not yet sold its high-fidelity, full-motion driving simulator. With some additional development and/or customization, several companies, including Aitek, Atlas Elektronik, Oerlikon-Contraves, and VTI all have high-fidelity systems which could be made available in one year or less, according to company representatives.

That there is interest but no orders is undoubtedly due to the fact that, while the potential buyers are "kicking the virtual tires," they have been reluctant to pay a "sticker price" that is on average over one million dollars for these high-end devices. It has been argued that the cost savings that a simulator potentially provides in training time, equipment damage, and other areas would more than offset the cost of a driver training simulator. However, it seems reasonable to assume that it is the absence of empirical data that makes carriers and other potential buyers reluctant to make such a large financial commitment.

As previously mentioned, sales have taken place at the other end of the fidelity spectrum (FAAC has sold one device to a commercial carrier and a dozen to the Army, and Doron has sold a number of systems). However, sales of these devices are not as robust as one might expect, given their relatively low cost when compared to the high-fidelity, full-mission simulators (approximately $80,000 for the Doron systems and $250,000 for the FAAC device). These devices do not come nearly as close to appearing and functioning like an actual truck as do the high-fidelity devices. Thus, it may well be that the carriers and other potential buyers, who are unfamiliar with the technology, are reluctant to invest in something that appears as abstract as a low-to-mid fidelity, part-task trainer. Again, there is a paucity of empirical data on driving simulator training effectiveness with which to assure the CMV driver training customer that he/she will see a return on investment.

The preceding observations and discussion lead to the first recommendation which addresses the fifth project objective: *Identify and recommend a simulator to be used to conduct a feasibility study of applying simulation technology to CMV driver training and/or licensing*. This objective implicitly requires the recommendation of a single device that has the potential to provide adequate driver training and licensing. Given this constraint, *it is recommended that the Digitran SafeDrive 1000 be used as the test bed for further study of the feasibility of applying simulator technology to CMV driver training, testing and/or licensing.*

There are several advantages that the Digitran device offers:

- The SafeDrive 1000 is currently available. FHWA can buy or lease the device for its evaluation.

- The simulator was rated adequate on the vast majority of the high-ranked functional requirements.

- It is among the highest-fidelity training devices available with respect to its visual, auditory, and motion systems.

This recommendation is subject to review, pending technological advancements prior to the conduct of the actual validation effort.

A study of a device, such as the SaveDrive 1000, should have at least two components:

- A validation study to determine if the simulator adequately performs the driving tasks, as it purports to do.

- A training effectiveness study that examine the transfer of training from the simulator to an actual truck.

The rationale for recommending a high-fidelity device is that if there is to be only one device used to address the feasibility of employing simulation technology for CMV driver training/licensing, without regard to cost, then studying the highest fidelity device will answer the question. If the intent is to evaluate feasibility of simulation technology in general, then one must study the high-end devices.

While the above recommendation addresses the objective outlined in FHWA's statement of work for the project, this approach does not address the critical issue of training/cost effectiveness. If the high-fidelity device does well in a training effectiveness study, it establishes that the device, in particular, and the technology, in general, can be used to train and/or license CMV drivers. What this approach leaves unanswered is, "What is the lowest fidelity level (and, therefore, lowest cost) at which effective training/licensing can be achieved via simulation technology?" The lower-fidelity simulators tend to be part task trainers. They are designed to provide training on a specific task or subset of driving tasks. There may be substantial cost savings achieved by using a low-fidelity part task simulator to target tasks that are responsible for the most equipment damage or require the greatest amount of training time. Given the wide range in cost from the low-fidelity simulators to the high-fidelity devices ($80,000 to $900,000), it is essential to know what is the lowest level of fidelity that will meet training objectives. It is, therefore, *recommended that FHWA conduct/sponsor research on simulator fidelity and training effectiveness.* This can be examined for each subsystem, i.e., motion, visual, and sound. One possible approach to this research would be to use the full fidelity NADS when available in 1999, then systematically reduce the fidelity of each subsystem (motion, sound, visual) and vehicle dynamics to assess how low, in terms of fidelity, each subsystem can go and still meet training the mission requirements.

The third recommendation is to examine the efficacy and effectiveness of part-task simulators. The Canadian Trucking Research Institute (CTRI) recommended that a series of part-task simulators be developed in order to meet training needs in a cost-effective manner. Their recommendation was based on:

- An evaluation conducted by researchers at the University of New Brunswick of existing low- and mid-fidelity simulators available at the time.
- Market research they conducted, which indicated that Canadian trucking companies would not pay the cost of high-fidelity, full-mission simulators.

Thus, the cost effectiveness of one, or a group of, part-task simulators versus the full mission simulator is a key issue influencing the development of driver training simulation technology.

The functional requirements developed for this study provide an initial set of criteria upon which to evaluate simulators. Consideration should be given as to which tasks to include in the studies recommended above. However, in addition to identifying the training tasks to be included in a simulator evaluation, performance criteria must be developed to define adequate/acceptable performance for each of the tasks. Thus, *the final recommendation of this study is that FHWA conduct/sponsor an effort to establish performance criteria for simulator-based driver training tasks.*

APPENDIX A

EXTENT TO WHICH TRB'S RESEARCH AREAS COULD BE ADDRESSED WITH IOWA DRIVING SIMULATOR (IDS), DAIMLER-BENZ DRIVING SIMULATOR (DBDS), AND NATIONAL ADVANCED DRIVING SIMULATOR (NADS)

Extent to Which TRB's Research Areas Could Be Addressed with IDS, DBDS, and NADS

	Portion of experiments addressed		
Research area	IDS	DBDS	NADS
Driver related			
Braking and steering behavior and motion perception	Few	Few	All
Risk perception and decision-making	Few	Some	All
Work load	Some	Some	All
Hazard perception	Some	Some	All
Effects of stressors	None	None	All
Driving characteristics of classified groups	Few	Few	All
Social interactions	Some	All	All
Multiple driver situations	Few	Some	All
Driver performance measures	None	Some	Almost all
Develop and validate a theory of driving	None	None	Almost all
Prescreen elderly (and other potentially unsafe) drivers	None	Some	All
Prescreen personnel	None	Some	All
Vehicle operator licensing tests	None	None	All
Vehicle Operator certification tests	None	None	All
"Fit-to-drive" tests/certification	None	None	All
Portable drug/alcohol intoxication test	Some	Some	All
Emergency vehicle	None	None	All
Law Enforcement	None	None	All
Rehabilitation driver training program	None	Almost all	All
Special driver training programs	None	Almost all	All
Skill transfer—vehicle to vehicle	Few	Almost all	All
Vehicle related			
Directional control system design	Few	Some	All
Directional control device development	Few	Some	All
Unexpected changes in vehicle dynamic behavior	Few	Some	All
Powertrain	None	None	All
Automated car following and braking	None	None	All

Research area	Portion of experiments addressed IDS	DBDS	NADS
Heavy truck cab design	None	Some	All
Seat Assessment	None	Some	All
Sound quality	Some	Some	All
Augmented vision systems and head-up displays	Some	All	All
Navigation or route guidance devices	Some	All	All
Lighting and visibility	Some	Almost all	Almost all
Hazard-alerting devices	Few	Almost all	All
Secondary controls and convenience devices	Some	All	All
Display quantification	Some	All	All
Systems evaluation of interior layouts	Some	All	All
Environment related			
Signs, signals, and markings	Almost all	Almost all	Almost all
Horizontal and vertical curvature	Some	Some	All
Lane and shoulder width	Some	All	All
Median and barrier design	Some	All	All
Illumination	Some	Some	Almost all
Surrounding environment	Almost all	Almost all	All
Traffic interactions	Some	Some	All
Tunnels	Some	Some	Almost all
Preconstruction overall design review	Some	Some	All
Temporary traffic control devices	Almost all	Almost all	All
Conspicuity of impending personnel and vehicle movement	Some	Some	All
Effects of natural and built environment	Some	Some	All
Effects of weather	Some	Some	All
Underground highway systems	Some	Some	All
Other			
Simulator design studies for developing other simulators	Few	Few	Almost all
Skill transfer—simulator to vehicle	Few	Few	All
Simulator sickness	Almost all	Some	All
Accident reconstruction and analysis	Few	Some	All

Source: TRB Circular 388 (Feb. 1992) and knowledgeable simulation experts.

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APPENDIX B

SUPPORTING MATERIALS FOR THE VERIFICATION OF FUNCTIONAL REQUIREMENTS DATA COLLECTION

- List of experts invited to review the Functional Requirements
- Cover letter
- Functional Requirements Rating Form
- Functional Requirements Comments Form (sample page)

List of Experts Invited to Review the Functional Requirements

Capitán Moisés Malpica
Director de Inspección y Sequimiento
del Transporte Terrestre
Secretaría de Comunicaciones y Transportes
Calzada de las Bombas 411
San Bartolo Coapa
Mexico, D.F., C.P. 04920 MEXICO

Mr. Stephen Sprague
United Bus Owners of America
Suite 1050
1300 L Street, N.W.
Washington, DC 20005

Ms. Karen Finkel
National School Transportation Assoc.
6213 Old Keene Mill Court
Springfield, VA 22152

Ms. Susan Perry
American Bus Association
1015 15th St., N.W. - #250
Washington, DC 20005

Mr. Jerry Robin
Federal Highway Administration
400 Seventh St., S.W., Room 3107
Washington, DC 20590

Mr. Reginald Welles
I*SIM Division Manager
6918 S. 185 West
Midvale, UT 84047

Mr. Jack Piehl
Pinellas Technical Ed. Centers
St. Petersburg Campus
901 34th St.
St. Petersburg, FL 33711

Ms. Rita Bontz
President
Independent Truckers & Drivers Assoc.
1109 Plover Dr.
Baltimore, MD 21227

Mr. Thomas Seery
NY Dept. of Motor Vehicles
Empire State Plaza, Rm. 524
Albany, NY 12228

Mr. Michael Calvin
Am. Assoc, of Motor Vehicle Administrators
4200 Wilson Blvd., Suite 1100
Arlington, VA 22203

Mr. Peter Nunnenkamp
Oregon Dept. of Motor Vehicles
1905 Lana Avenue N.E.
Salem, OR 97314

Mr. Alan Bullis
Crowder College-Transport Training
601 Laclede
Neosho, MO 64850

Mr. R. Wade Allen
Systems Technology, Inc.
13766 South Hawthorne Blvd.
Hawthorne, CA 90250-7083

Mr. John McFann
Fleet Dev., Project Administrator
North American Van Lines
5001 U S 30 West
Fort Wayne, IN 46818

Mr. Joel Dandrea
American Trucking Associations
2200 Mill Road
Alexandria, VA 22314

Mr. Edward E. Kynaston
Professional Truck Driver Institute of America
8788 Elk Grove Blvd., Suite 20
Elk Grove, CA 95624

Ms. Carol Cataldo
Commission of Accredited Truck Driving Schools
2011 Pennsylvania Avenue, N.W. Suite 500
Washington, DC 20006

Ms. Dodi Reagan
National Private Truck Council (NPTC)
1320 Braddock Place, Suite 720
Alexandria, VA 22314

Mr. James Johnston
Owner-Operators Independent Drivers Assoc.
311 RD Mize Rd.
Grain Valley, MO 64027

Mr. George Beaulieu
Safety Awareness Through Fleet Edu., Inc.
9415 Lost Trails Drive
Waco, TX 76712-8171

Mr. Terry Turner
Interstate Truckload Carrier Conference
2200 Mill Road
Alexandria, VA 22314

Mr. Jim McKnight
National Public Services Research
8201 Corporate Drive, 6th Floor
Landover, MD 20785

Mr. Albert Stevens
18 Dodona Place
Fredericton, N.B.
CANADA E3A 4B7

Ms. Paula Hanna
Executive Secretary
National Assoc. of Pupil Transportation
P.O. Box 745
East Moline, IL 61244

Mr. Gerald O'Neil
Atlantic Providence Trucking Assoc.
Training Program, Inc.
Suite 600
725 Champlain St.
Dieppe, NB E1A 1P6

Mr. Brad Trullinger
Federal Highway Administration
400 Seventh St., S.W, Room 3107
Washington, DC 20590

Dear ________:

Applied Science Associates, Inc. (ASA) is under contract to the Federal Highway Administration (FHWA), Office of Motor Carriers to assess the ability of available and near-horizon Commercial Motor Vehicle (CMV) simulation technology to improve driver training and testing methods. This study involves identifying and evaluating current and prototype CMV driving simulators and developing recommendations for criteria (FHWA standards) for the use of simulators in training, testing and licensing programs for both Federal civilian and private sector CMV driver training. To this end we have developed, with the help of Dr. James McKnight, a subcontractor on this effort, a list of functional specifications for CMV driving simulators. Simulator functional requirements were developed only for those tasks that require hands-on experience for effective training, i.e., perceptual-psychomotor, skill-based tasks.

To date, we have conducted a comprehensive review of the literature describing the major operational and prototype CMV simulators, attended an international conference dedicated to truck driver training simulators, and developed the enclosed functional requirements for a CMV driving simulator. These functional requirements will be used to evaluate existing CMV simulators and assess near-horizon simulators with respect to the feasibility of using each device in training, and/or licensing of CMV drivers. The criteria are being sent to a group of experts in the fields of CMV driver training, licensing and simulation. As a member of this group, we are requesting that you review the functional specifications and provide feedback to us in three areas:

1. Critical task/functional requirements that may be missing from the list,

2. Noncritical task/requirements that should be omitted from the list, and

3. Ratings of the potential training/licensing benefit to be gained by including each task on a driver training simulator.

Two tables are provided: the first provides the driving functions, functional requirements, and benefit rating scale for the driving functions; the second table provides space to comment on the display and response system functional requirements. Please indicate which requirements are not necessary, and provide any additional functional requirements that you believe should be added. Please be as specific and detailed as possible when adding requirements and keep in mind that these are requirements for how a driving simulator must function in order to train or test a CMV driver on the given driving function.

After all comments have been reviewed, we will revise the simulator functional requirements and use them as criteria to evaluate existing and prototype CMV driver training simulators. If one or more of the simulators evaluated meets a sufficient number of the functional requirements, a recommendation will be made to FHWA to conduct validation studies on the device to better determine its feasibility for training and/or licensing CMV drivers

Please follow the instructions on the enclosed Functional Requirements Review List and return it **no later than February 22, 1994** to:

Robert J. Carroll
Applied Science Associates, inc.
P.O. Box 1072
Butler, PA 16003-1072

Thank you for your time and contribution to this effort.

Sincerely,

Robert J. Carroll
Principal Scientist

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ASA

FUNCTIONAL REQUIREMENTS FOR A CMV DRIVER TRAINING SIMULATOR

INSTRUCTIONS:

Table 1 on the following page presents a list of CMV driving tasks and the corresponding simulator functional requirements that we believe are necessary to train these tasks or test proficiency on them for the purposes of licensing. Column one contains driving functions/tasks to be taught via simulation. The numbers in column one are the task numbers from the FHWA Model Curriculum for Tractor Trailer Training. The second column provides the related skill objective and the display and response system functional requirements that a simulator must possess to affect training or to test for the driving function. The third column provides a rating scale for indicating your opinion of the importance or benefit to be derived from training or testing this driving function via simulation.

The benefit rating scale allows you to rate each driving function by circling a number from "1" to "5". A rating of "1" indicates that there is virtually no training or licensing benefit (i.e., cost savings, training enhancements) to be derived from training or testing the given task on a simulator; a rating of "5" indicates that great benefit would be derived from training or testing this driving function via simulation. When determining benefit gained from training or testing on a simulator, consider both the expected cost savings related to using a simulator (e.g., vehicles left in service, reduced equipment and fuel costs, reduced instructor time, etc.) and the value, if any, of training enhancements, such as, the ability to practice dangerous maneuvers (e.g., skid recovery, jackknife avoidance), or the ability to provide a wide array of road conditions in a given time period. The five-point scale allows you to indicate the relative benefit for each driving function.

In addition to the providing a benefit rating, a comment sheet (Table 2) is included to allow you to add, delete from, or elaborate upon the functional requirements described in Table 1.

TABLE 1: FUNCTIONAL REQUIREMENTS

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
	SECTION 1: BASIC OPERATION	
1.4 Basic Control **1.4.1 Accelerating***	**Skill Objective** "The student must be able to coordinate the use of accelerator and clutch to achieve smooth acceleration and avoid [inappropriate] clutch use." ***Functional Requirements*** <u>Display</u>—The display need only present a straight path representing the pavement surface with lane delineations and pavement texture or roadside objects, to display longitudinal motion to the student. A tachometer and a speedometer must be visible and engine sounds audible. <u>Response System</u>—The response system would consist of throttle, clutch, and gear shift. Only one shift pattern is necessary since the vehicle can remain in first gear while meeting this objective. Motion dynamics must have high fidelity, that is, apparent forward motion must respond accurately to throttle, clutch, and shift manipulations. Resistance to control inputs should be representative of a "typical" transmission. Simulated engine sound should correlate with RPM and RPM changes as well as providing audible cues of stalling or stalled engine.	**Training/Licensing Benefit:** **1---2---3---4---5**
1.4.2 Braking	**Skill Objective** "The student must be able to properly modulate air brakes to bring the vehicle to a smooth stop." **Functional Requirements** <u>Display</u>—The display must present surface texture as well as near and distant objects with sufficient resolution and richness to provide visual motion cues representing speeds continually decreasing to zero. The display should also include tachometer, and simulated engine sound. Some type of feedback is needed to represent "lurching" to a stop from failure to modulate the brakes correctly. Options include screeching of tires and/or incipient motion of the seat. <u>Response System</u>—The response system for this objective requires a brake pedal and speedometer.	**Training/Licensing Benefit** **1---2---3---4---5**

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
1.4.3 Driving Forward	**Skill Objective** "The student must be able to coordinate steering, braking, and acceleration to take the vehicle through a desired path forward." **Functional Requirements** <u>Display</u>—The display must provide a combination of straight and curved road surfaces by means of coloration, texture, and/or edge markings and lane delineators, and must respond accurately to steering corrections by the student. <u>Response System</u>—The response system must provide, in addition to throttle and brakes, a steering wheel of the general diameter and horizontal orientation of the particular type of heavy vehicle to be operated. The angle and position relative to the display must respond accurately to steering inputs.	**Training/Licensing Benefit** **1---2---3---4---5**
	Skill Objective "The student must be able to coordinate steering, braking, and acceleration to back the vehicle into a straight line." **Functional Requirements** <u>Display</u>—The display must provide forward and rearward views. The forward display must provide the cues described in 1.4.3 in order to permit control of speed, position, and direction while backing, and to control forward motion during pullups. The rearward display will consist of right- and left-mirrors representing both flat and convex surfaces. The mirrors must display the edge of the trailer, roadway edge markings, and surface texture. Motion of the trailer must respond realistically to steering corrections. <u>Response System</u>—The response system must provide all primary controls, i.e., a steering wheel, clutch, brake, throttle, and gear shift capable of at least neutral, reverse, and one forward gear position.	**Training/Licensing Benefit** **1---2---3---4---5**

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
1.4.4 Turning	**Skill Objective** "The student must be able to adequately judge [predict and control] the path the trailer will take (off-tracking) if the vehicle negotiates left or right curves, turns and lane changes." **Functional Requirements** <u>Display</u>—The forward display must provide a 180° field of view, to include road edge markings and lane delineators, corresponding to the four possible combinations of two and four-lane roads. It must also provide stimuli leading to turns, including established routes for turns, and slower vehicles for lane changes. Simulated mirrors must provide a display of the trailer, edge markings, and delineators normally visible. <u>Response System</u>—The steering wheel, clutch, throttle, brake and gear shift (same as 1.4.2).	**Training/Licensing Benefit** **1---2---3---4---5**
1.5 Shifting	**Skill Objective** "The student must be able to coordinate use of hands, feet, sight, hearing, and shifting to achieve maximum performance consistent with economy, safety, and smoothness of operation." **Functional Requirements** <u>Display</u>—To develop skill in shifting, the display must present speed, RPM, and the sound of varying engine pitch. A display of the path ahead shall be provided to present motion to the degree necessary to avoid conflicting with engine displays. <u>Response System</u>—The response system should include a clutch, throttle, and gear shift. The gear shift must provide a full range of gears for a manual transmission and should provide alternative manual shift patterns (5-speed, 10-speed, 3-speed, 4 x 3, 2-speed, rear axle), as well as semiautomatic and automatic transmissions. Manual transmissions must require double clutching for non-synchronized transmission.	**Training/Licensing Benefit** **1---2---3---4---5**

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
1.6 Backing	**Skill Objectives** "The student must be able to coordinate speed and direction controls to achieve the desired path while backing in a straight line, into an alley dock, or parallel park, or parking in a jackknife position." **Functional Requirements** Display—The display requirements in developing skill in the backing maneuvers indicated are the same as those involved in straight line backing (1.4.4) with one exception. In a sight-side jackknife backing maneuver, a driver is often able to benefit from a view of the rear of the trailer gained from the left window. Providing this view would require a visual field extending approximately 120° (from the straight-ahead) to the left. Added to the 90° visual field to the right, the visual field would total approximately 210°. So far as we can determine, a sight-side jackknife parking or alley dock maneuver is the only task that would make use of this extended visual field. A high degree of resolution is required for backing maneuvers. This could be accomplished both by very high resolution actual size mirror displays or by using oversized mirrors to provide images of sufficient size to permit judging clearances. Response System—The response system shall include a steering wheel, clutch, throttle, brake, and gear shift. The gear shift must provide a full range of gears for a manual transmission and should provide alternative manual shift patterns as well as semiautomatic and automatic transmissions. The motion of the simulated trailer must respond accurately to steering inputs.	**Training/Licensing Benefit** 1---2---3---4---5

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
1.8 Proficiency Development: Basic Control **1.8.1 Maneuvering in Restricted Quarters**	**Skill Objectives** "The student must be able to coordinate acceleration and braking to maneuver the vehicle in restricted quarters." **Functional Requirements** The requirements of simulation for tight quarters maneuvering are largely the same as those required in meeting previous objectives. The uniqueness of this objective comes not in the maneuvering, but in the judging of clearance. The facility of simulation is not sufficient to permit precise judgement of clearance, nor would drivers in an operating environment depend upon their own visual capabilities in situations where clearance is marginal. However, simulation can help students distinguish passable from impassable situations, and provide training in maneuvering where clearances are minimal. Display—The display must present objects in close proximity to the path of the vehicle including objects to either side (vehicles, curb, road signs, buildings) overhead (bridges, overpasses, tollbooths, marquees) and beneath the vehicle (railroad tracks, ditches, debris). While the two-dimensional display provided by simulation limits the degree to which students can acquire skill in judging clearances, sufficient cues of size and distance can be provided to facilitate developmental proficiency and tight-quarters positioning. Structures in the driving scene can contribute to development of skill in judging lateral, overhead, and ground clearance. Response System—The response system requires only the standard primary controls, i.e., steering wheel, clutch, throttle, brake, and gear shift.	**Training/Licensing Benefit** 1---2---3---4---5
1.8.2 Upgrades and Downgrades	**Skill Objectives** "The student must be able to coordinate clutch, throttle, and gear shift to maintain engine and proper speed when shifting on upgrades and downgrades." **Functional Requirements** Display—Visual simulation of upgrades and downgrades may not provide sufficient fidelity to serve as a basis for shifting. Displays can, however, provide cues of change of simulated motion that would lead to recognition of the need to downshift, including (1) motion of objects in the roadway/traffic display, (2) readings in the tachometer and speedometer displays, and (3) pitch of engine sound. Cues must be provided with sufficient fidelity to require appropriate downshifting, acceleration, and braking to maintain speed. Response System—Primary controls are sufficient.	**Training/Licensing Benefit** 1---2---3---4---5

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
	SECTION 2: SAFE OPERATING PRACTICES	
2.1 Visual Search **2.1.1 Attention Sharing**	**Skill Objectives** "The student must be able to search the highway traffic environment while maintaining directional control of the vehicle." **Functional Requirements** <u>Display</u>—The display must be capable of presenting, within the road/traffic scene, stimuli representing the situations to which students must respond by changing the speed or direction of the vehicle. Only through such responses is the simulation system capable of determining whether appropriate search patterns have been employed. The highway/traffic situations depicted must be sufficiently inconspicuous as to be detectable only through appropriate visual search. A road/traffic image that encompasses the roadway and roadside environment as well as the rear-view mirrors is sufficient to permit development of skill in visual search associated with general visual surveillance, lane changing, and merges. (Note: Visual search at intersections requires a wider visual field, but does not demand the attention-sharing skill that makes up the objective). <u>Response System</u>—In meeting this objective, vehicle controls serve two functions: (1) to require control of the vehicle's motion coincident with visual search, and (2) provide a means by which students can register their perception of highway/traffic situations revealed by appropriate search patterns.	**Training/Licensing Benefit** 1---2---3---4---5

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
2.1.2 Mirror Interpretation	**Skill Objective** "Student must be able to read and interpret the images presented by flat and convex mirrors." **Functional Requirements** Simulation must provide students an opportunity to view images from a combination of flat and convex mirrors in order to integrate them into a picture of what is happening behind the vehicle. <u>Display</u>—The road/traffic display must include mirrors on both sides of the vehicle displaying following vehicles of various types, sizes, and position relative to the student. The mirror must present images as they ordinarily appear in a combination of flat and convex mirrors. Traffic situations must be created to cause images of other road users to disappear from the flat mirror, yet still be visible in a convex mirror, in order that the student can learn to reconcile the two images. With the limited resolution of simulator displays and the compressed image provided by a convex mirror, it will be necessary to enlarge the actual size of the convex portion of the mirror if images are to be interpretable. <u>Response System</u>—This objective is limited to a perceptual skill and does not require any display-control interaction. However, traffic scenes must be configured such that correct interpretation of mirror images will lead to some response that differs from that which would otherwise occur (e.g., inhibiting a lane change because a motorcycle is visible in a convex mirror). As with other elements of visual search, the vehicle control response is just a means of registering a correct perceptual response.	**Training/Licensing Benefit** 1---2---3---4---5

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
2.3 Speed Management	**Skill Objective** "Students must be able to judge the maximum safe speed for coping with any combination of roadway configuration (e.g., turns) surface friction, traffic, visibility, cross wind, and vehicle weight distribution." **Functional Requirements** Display—The display must be capable of simulating cues associated with each of the speed-influencing conditions enumerated in the objectives to include: Roadway **Curvature**: hills, curves **Elevation**: upgrades and downgrades **Surface**: water, ice, snow, rough pavement Traffic **Pedestrians, slow-moving vehicles, pedestrians** Environment **Visibility**: night, rain, snow, fog **Control**: cross-wind Vehicle **Weight** **Length** Center **Of Gravity** **Load stability** Response System—In meeting this objective, the response system need only to permit students to adjust simulated speed to conditions. It is not necessary that the vehicle's response represent the effects of the various conditions described, e.g., skid on slippery surface or roll with a high center of gravity. Students should be expected to adjust speed to conditions *before* they have a chance to affect the handling of a vehicle. While such responses may help demonstrate the hazards of excessive speed, there are less expensive demonstrations than simulation.	**Training/Licensing Benefit** 1---2---3---4---5

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
2.4 Space Management **2.4.1 Gap Judgement**	**Skill Objective** "Student must be able to judge the adequacy of gaps for passing, crossing and entering traffic, and changing lanes." **Functional Requirements** The overall length and low acceleration of tractor-trailer combinations requires larger gaps than passenger vehicles. Simulation provides an opportunity to develop skill in judging without danger to or interference with traffic. <u>Display</u>—The road/traffic scene must be capable of presenting approaching vehicles with accurate changes in size, distance relationships. Gaps for passing are within the scope of any display, while gaps for lane changes require the presence of side mirrors, and crossing/entering gaps require 180° visual fields. Display must provide cues of closure with oncoming and intersecting vehicles having sufficient clarity and fidelity to permit accurate gap judgement. The sole cues of speed and distance are, respectively, the absolute size and rate of change for the stimuli representing the approaching vehicle. <u>Response System</u>—To develop skill and gap judgement, the response system need only provide the means by which students can indicate acceptance of a gap: a throttle for acceptance of gaps and passing, crossing, or entering traffic, and a steering wheel for acceptance of gaps and lane changing. The lack of any response indicates rejection of a gap. An interactive response system is not necessary.	**Training/Licensing Benefit** 1---2---3---4---5

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
2.4.2 Following Distance	**Skill Objective** "The student must be able to maintain a following distance appropriate to traffic, road surface, visibility, vehicle weight, and the law." **Functional Requirements** <u>Display</u>--The display must present the image of the lead vehicle in a way that accurately represents headway, i.e., following distance. At a minimum, the student must be able to count the interval between the time the lead vehicle and student's vehicle passes some landmark (i.e., pavement seam, lane delineator, roadside object). It is also desirable that the image be sufficiently detailed as to communicate the actual size of the vehicle, thus allowing image size to be used as a cue of inter-vehicle distance. Some type of forcing function must be employed to alter the speed of the lead vehicle relative to that of the student vehicle and thus necessitate speed adjustments on the part of the students in maintaining appropriate headway. It is also desirable that conditions of road surface, traffic, and visibility be varied in order that students may adjust the following distance/time accordingly. <u>Response System</u>--Since the only objective involves primarily perceptual skill, response mechanisms serve primarily to indicate recognition of insufficient headway. Normal primary controls would be sufficient.	**Training/Licensing Benefit** **1---2---3---4---5**
2.5 Night Operation	**Skill Objective** "The student must be able to judge [relative] speed, distance, and separation under nighttime conditions." **Functional Requirements** The functional requirements are the same as for Unit 2.4, Space Management, except that the road/traffic display will simulate darkness, with cues of other vehicles being confined to headlights and taillights.	**Training/Licensing Benefit** **1---2---3---4---5**

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
	Unit 2.6 Extreme Driving Conditions	
2..6 Extreme Driving Conditions **2.6.1 Handling Slippery Surfaces**	**Skill Objective** "The student must be able to adjust rate of change in speed and direction to road conditions in order to avoid skidding on slippery surfaces." **Functional Requirements** <u>Display</u>—The road/traffic display must provide cues of surface friction as well as feedback to students to indicate when their combination of speed and steering input is such to overcome the coefficient of friction. Conditions would include wet surface, ice, snow, and running tar. <u>Response System</u>—Response system requirements are the same as those required in normal vehicle operation: throttle, clutch, brake, and gear shift.	**Training/Licensing Benefit** **1---2---3---4---5**
2.6.2 Overcoming Surface Resistance	**Skill Objective** "The student must be able to coordinate acceleration and shifting to overcome the resistance of snow, sand, or mud." **Functional Requirements** <u>Display</u>—The road/traffic display must present the characteristics of resistive surfaces in two ways: (1) by reproducing the visual cues associated with mud, sand, snow, or deep water; and (2) by presenting the motion cues associated with operating on a resistive surface, including inhibited forward motion and, where appropriate, a slight upward movement as the vehicle. <u>Response System</u>—Steering wheel, clutch, throttle, and gearshift are required. Torque characteristics of simulated transmission must be accurate. The speedometer, tachometer, and engine noise should respond in a manner corresponding to spinning drive wheels.	**Training/Licensing Benefit** **1---2---3---4---5**

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
2.6.3 Downhill Braking	**Skill Objective** "The student must be able to coordinate gears, throttle, brake, and shifting to handle steep upgrades and downgrades." **Fnctional Requirements** The simulation must be able to create conditions requiring students to shift into appropriate gears for ascending and descending, respectively, upgrades and downgrades.	**Training/Licensing Benefit** **1---2---3---4---5**
	<u>Display</u>—The road/traffic scene must be capable of communicating to students the appropriate gear for a particular grade before starting to ascend or descend it. The display system must provide suitable elevation cues. Signs posted at the crest or foot of upgrades, indicating the severity of the grade, are reliable cues to guide initial gear selection. The display must provide cues to initiate downshifting or upshifting while on the grade, where initial gear selection is incorrect or a change in grade necessitates a gear change. Stimuli representing the road surface and roadside objects can provide appropriate motion cues, while speedometer, tachometer, and simulated engine pitch could evidence the effect of grades upon vehicle and engine speed. <u>Response System</u>—All primary controls are required, and display motion characteristics must respond to control inputs in simulated grade with sufficient fidelity to allow a desired speed to be maintained with selection of the appropriate gear.	**Training/Licensing Benefit** **1---2---3---4---5**

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit

SECTION 3: ADVANCED OPERATING PRACTICES

3.1 Hazard Perception	**Skill Objective** "Students must be able to perceive immediately a potential threat from visible characteristics and actions of other road users and initiate prompt defensive or evasive action." **Functional Requirements** Display—The road/traffic display must be capable of presenting cues associated with a wide range of hazards involving characteristics of the road, characteristics of road users, and actions of road users. A "hazard" in this context refers to any situation representing a threat to the safety of the driver or other road users that could be lessened by a preventive response on the part of the driver including vehicle motions of inattentive or confused drivers, pedestrians near the roadway, tailgaters, construction, parked vehicles with indication of impending motion, trailer/cargo problems. Hazards are not restricted to clear and present dangers. On the contrary, most are quite subtle, particularly hazards that grow out of the interaction among other road users (e.g., the action of one road user could force another road user into the driver's path). Satisfaction of this objective is closely tied to objective 2.1, "Visual Search," in that it is through response to hazards that drivers manifest proper search patterns. Response System—Relaxation of the throttle input is sufficient to register perception of a hazard. An interactive display-response system allows for decisive responses (braking or swerving) without causing cue conflicts, which might be disconcerting to the student and interfere with learning even if it does not interfere with the perception of hazards.	**Training/Licensing Benefit** 1---2---3---4---5

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
3.2 Emergency Maneuvers	**Skill Objective** "The student must be able to use brakes in a manner that will stop the vehicle in the shortest possible distance while maintaining directional control." **Functional Requirements** <u>Display</u>—The display must create a stimulus requiring emergency braking as well as a path along which the braking must take place, e.g., vehicle pulling in the path ahead, with vehicles on the left and sidewalk on the right. The distance of the stimulus relative to the simulated speed of the vehicle should be sufficient to allow the rig to be brought to a stop with proper braking technique. <u>Response Systems</u>—Visual cues must respond accurately to control input. Over-application of the brakes must result in audible squealing of brakes as well as loss of directional control resultant with a tractor and/or trailer jackknife. Under-application of the brakes should result in a collision with the stimulus object. Only correct steering and braking inputs should allow the brake to be brought to a straight stop within the available distance. Also, because of the precision of driver control responses required, it is particularly important that the resistance and travel of control mechanisms (wheel, throttle, brake, clutch and gearshift) be similar to those of an operational tractor-trailer.	**Training/Licensing Benefit** 1---2---3---4---5

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
3.2.2 Emergency Steering	**Skill Objective** "The student must be able to turn the steering wheel quickly in either direction in order to steer around a vehicle or another road user." **Functional Requirements** A skill in evasive steering involves not only the motor skill involved in executing maneuvers, but the perceptual skill involved in judging available stopping distance and recognizing available escape routes while, at the same time, suppressing a strongly learned braking response. There is evidence that repeated practice is needed to maintain an evasive steering response at high strength, owing perhaps to the much greater frequency of brake application compared to evasive steering in everyday driving. The value of simulation is the ability to provide the periodic refresher instruction needed to maintain an evasive steering response at high strength. Display—The display must provide for the sudden appearance of a stimulus in the student's path that is too close to permit the rig to be brought to a stop, but with available lanes to permit a collision to be avoided through an evasive maneuver. Response System—The road/traffic scene must respond accurately to control inputs so as to (1) require large rapid, evasive steering and counter-steering to avoid the stimulus obstacle yet remain within the limits of the escape path; and (2) lead to loss of directional control if the brakes and/or throttle are inappropriately applied. As with 3.2.1, control resistances and travels should approximate those found in tractor trailers. Fidelity is particularly important in the relation between degree of steering wheel rotation and extent of direction change.	**Training/Licensing Benefit** **1---2---3---4---5**

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
3.2.4 Brake Failure	**Skill Objective** "The student must be able to bring the vehicle to a stop in event of a brake failure." **Functional Requirements** Satisfying this objective requires (1) finding an acceptable escape path along which to decelerate, and (2) using downshifting and other desperation devices (scrubbing tires against curb) to bring the vehicle to a stop. <u>Display</u>—The road/traffic display serves two functions: (1) defining the roadway traffic environment in which the student must operate when the brakes have failed, (2) the display, along with the speedometer, provides the primary cue of brake failure by failing to show a speed reduction when the brake is applied. The road/traffic display must provide escape routes along which the student may downshift to reduce speed: an escape ramp, paved or unpaved shoulder, side road, field, slight incline, curb. <u>Response System</u>—All primary controls are required, along with the speedometer. The response system must be programmed to render the brake response inoperative at a point where the student would ordinarily brake and where suitable escape routes are available. Once the vehicle has been brought to a stop, the brake system should be restored to normal operation for continued use of the simulation.	**Training/Licensing Benefit** **1---2---3---4---5**

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
3.3. Skid Control & Recovery 3.3.1 Skid Control	**Unit 3.3 Skid Control and Recovery** **Skill Objective** "The student must be able to steer and brake on extremely slippery surfaces without loss of control." **Functional Requirements** Simulation requirements are similar to those specified in 2.6.1, except that simulated surfaces are far more slippery, and that much finer steering and braking control is needed. <u>Display</u>—While it is desirable that cues of surface friction be realistic, the objective involves the vehicle control responses to slippery surfaces rather than the process of identifying them. What is important is that the extremely low surface friction be clearly identified to the student in some manner (e.g., captions, speedometer and tachometer responses, skid sounds, road cues), so that appropriate responses can be applied. Road surface and road delineations are the primary cues required. <u>Response System</u>—Only the primary controls are required. However, brake and steering must have extremely high fidelity with respect to both mechanical feedback and vehicle motion dynamics. Over-application of brakes and/or steering relative to surface friction must result in the visual simulation of a skid.	**Training/Licensing Benefit** 1---2---3---4---5

DRIVING FUNCTION	SKILL OBJECTIVE AND SIMULATOR FUNCTIONAL REQUIREMENTS	RATING 1 = no training benefit 5 = high benefit
3.3.2 Skid Recovery	**Skill Objective** "The student must be able to recover from developing tractor and trailer skids and to bring the rig to a straight-line stop." **Functional Requirements** Attaining this objective requires simulation of tractor skids and trailer skids under conditions in which students can, by detecting the presence of a skid early enough and initiating appropriate steering corrections, recover from the skid. Simulation exercises applied to this objective can be linked to those involved in 3.2.1 to require skid recovery either (1) when students respond incorrectly to a skid control situation, or (2) when simulated surface friction is reduced to a point that a skid is virtually unavoidable. The simulation exercise would be similar to range exercises carried out on skid pads, where instructors initiate skids by deliberately locking up trailer wheels or tractor drive wheels. <u>Display</u>—The display requirements include those described in connection with Objective 3.3.1. In addition, the display must provide cues indicating the presence, nature, and magnitude of a skid including (1) discrepancy between apparent tractor heading and direction of motion, and (2) the apparent motion of the trailer as visible in mirrors. <u>Response System</u>—The response system must involve motion dynamics of sufficient fidelity to both (1) bring about an apparent skid through misapplication of brakes, steering, acceleration; and (2) permit recovery from the skid (i.e., realignment of rig) with appropriate steering and relaxation of acceleration or braking.	**Training/Licensing Benefit** 1---2---3---4---5

FUNCTIONAL REQUIREMENTS FOR A CMV DRIVER TRAINING SIMULATOR

INSTRUCTIONS:

This table provides space for you to comment on the display and response system functional requirements presented in Table 1. Please indicate if you feel that a requirement is not necessary, and provided any additional functional requirements that you believe should be added. Be as specific and detailed as possible when adding requirements.

TABLE 2: COMMENT SHEET

DRIVING FUNCTION	Comments: Display System	Comments: Response System
1.4 Basic Control **1.4.1 Accelerating**	[The remaining pages of this data collection instrument are not shown. These pages list the remaining functional requirements (as shown in the previous table), and provide the same two-column format for the respondent's comments.]	

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2. Stevens, A. & Sypher, G. (October 5, 1992). A study of devices for heavy vehicle driver evaluation and training. Fredericton, NB, Canada: University of New Brunswick. Transport Group.

3. Stevens A., Sypher, G., & Wilson, F. (May 16-18, 1993). APTA/CTRI/UNB truck driver training study. Phase II Report. Fredericton, N.B.: University of New Brunswick. 2ND International Simulation Forum.

4. Tardif, L., Preston-Thomas, J., Stevens, A., Peabody, D., O'Neil, G. & Acton, G. (October 1991). Review of truck driver selection, evaluation and training devices. Canadian Trucking Association.

5. Doron Precision Systems, Inc. Product Brochures and Fact Sheets.

6. Systems Technology, Inc. STISIM. Fact Sheet.

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