TCRP
REPORT 72

TRANSIT
COOPERATIVE
RESEARCH
PROGRAM

Sponsored by
the Federal
Transit Administration

Simulators and Bus Safety: Guidelines for Acquiring and Using Transit Bus Operator Driving Simulators

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 72

Simulators and Bus Safety: Guidelines for Acquiring and Using Transit Bus Operator Driving Simulators

JOHN F. BROCK
CYNTHIA JACOBS
HAROLD VAN COTT
Milestone Group L.L.C.
Arlington, VA

MICHAEL MCCAULEY
Monterey Technologies, Inc.
Monterey, CA

and

DAVID M. NORSTROM
DMN Enterprises
Columbus, OH

SUBJECT AREAS
Public Transit

Research Sponsored by the Federal Transit Administration in Cooperation with the Transit Development Corporation

TRANSPORTATION RESEARCH BOARD — NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. — 2001

TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions*, published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

TCRP REPORT 72

Project A-22 FY'99
ISSN 1073-4872
ISBN 0-309-06711-1
Library of Congress Control Number 2001-135524

Price $25.00

NOTICE

The project that is the subject of this report was a part of the Transit Cooperative Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the project concerned is appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Special Notice

The Transportation Research Board, the National Research Council, the Transit Development Corporation, and the Federal Transit Administration (sponsor of the Transit Cooperative Research Program) do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the clarity and completeness of the project reporting.

Published reports of the

TRANSIT COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

and can be ordered through the Internet at
http://www.national-academies.org/trb/bookstore

Printed in the United States of America

FOREWORD

By Staff
Transportation Research Board

TCRP REPORT 72, "Simulators and Bus Safety: Guidelines for Acquiring and Using Transit Bus Operator Simulators," provides guidance to transit agency managers on whether to purchase a driving simulator and, if so, what kind. Also, this document provides guidance on how to use simulation effectively to improve bus operator training and safety. Information was obtained from a literature search, surveys, and site visits. The guidelines are designed to be used by transit-operations management, human resource management, training instructors, operations, and safety personnel.

Transit agencies are re-emphasizing the requirement for safe and efficient transit bus operations. Numerous advanced technologies are candidates for helping transit agencies meet these various objectives.

One such technology is driving simulation. If student bus operators can be trained more efficiently using simulation, both training costs and operations costs can be reduced. However, only a handful of transit agencies are using driving simulation, and, even among these agencies, different kinds of simulations are being used. Also, because simulation technology is new and ever changing, transit agencies need guidance on not only whether to use simulation, but also on how and when to use it.

Milestone Group, L.L.C prepared this report for TCRP Project A-22. To achieve the project's objective of producing a set of guidelines that may be to used to assess the need and selection of simulators, the researchers visited transit agencies who are using driving simulators to train bus operators. In addition, the researchers conducted surveys of drivers, trainers, and managers who have used simulators. The researchers made site visits to non-transit users of driving simulators, and visits to and inquiries of transit agency training operations that are not using simulators.

The literature review concludes that simulation can work. The site visits and surveys indicate that ground vehicle simulation works. The site visits to and surveys of transit agencies using various simulation systems lead to the conclusion that transit bus operator training can be improved with the selective use of transit bus simulators.

CONTENTS

COOPERATIVE RESEARCH PROGRAMS STAFF

ROBERT J. REILLY, *Director, Cooperative Research Programs*
CHRISTOPHER JENKS, *Manager, Transit Cooperative Research Program*
GWEN CHISHOLM, *Senior Program Officer*
EILEEN P. DELANEY, *Managing Editor*

PROJECT PANEL A-22

KENNETH D. GOLDBERG, *Greater Hartford Transit District, CT* (Chair)
JOHN LUNDELL, *The University of Iowa*
LINDA J. MEADOW, *Linda J. Meadow & Associates, Benicia, CA*
GERARD SYLVAIN MEYER, *Carnegie-Mellon Driver Training & Safety Institute, Uniontown, PA*
PENELOPE J. PAGE, *Yellow Transportation, Baltimore, MD*
STEPHEN A. PETRUCELLI, *Washington Metropolitan Area Transit Authority*
MELISSA A. ROLLE-SCOTT, *Miami-Dade Transit Agency*
RICHARD C. WONG, *Orange County (CA) Transportation Authority*
BRIAN CRONIN, *FTA Liaison Representative*
RICHARD PAIN, *TRB Liaison Representative*

AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under TCRP Project A-22, FY1999, by Milestone Group, Arlington, Virginia. Subcontractors to Milestone Group were Windwalker Corporation, Monterey Technologies, Incorporated, and DMN Enterprises.

John F. Brock, Director of Training and Simulation at Milestone Group, was the principal investigator. The other authors of the report are Dr. Mike McCauley, Monterey Technologies, Inc. (now with Instructional Technology, Inc.); Mr. Shashi B. Gowda, Windwalker Corporation; David Clarke, Monterey Technologies, Inc.; Mr. David Norstrom, DMN Enterprises; and Ms. Cynthia Jacobs, Milestone Group. Dr. Harold Van Cott, former senior human factors engineer for the National Academies, edited the report for technical content.

Many transit agencies made themselves available for the research team and they are mentioned in the body of the report. However, the following persons made significant contributions to this research report:

- Kenneth D. Goldberg, Director of Operations, Greater Hartford Transit District
- Richard G. Wong, Manager, Training and Development, Orange County Transportation Authority
- Thomas M. O'Kane, Director, Operational Training, New Jersey Transit Bus Operations, Inc.
- Stephen A. Petrucelli, Supervisor, Bus Training, Washington Metropolitan Area Transit Authority
- Steve Vidal, Director of Training, New York City Transit
- Dr. Gerard Meyer, President, Carnegie-Mellon Driver Training and Safety Institute

SIMULATORS AND BUS SAFETY

SUMMARY

The transit community, like most private and government organizations, is facing a shortage of well-trained employees, including transit bus operators. At the same time, transit agencies are re-emphasizing the requirement for safe and efficient transit bus operations. Numerous advanced technologies are candidates for helping transit agencies meet these various objectives.

One such technology is driving simulation. If student bus operators can be trained more efficiently and more effectively using simulation, both training costs and operations costs can be reduced. However, only a handful of transit agencies are using driving simulation, and, even among these agencies, different types of simulations are being used. Because simulation technology is new and ever changing, transit agencies need guidelines not only on *whether* to use simulation but also *how* and *when* to use it. It is also possible that different agencies may have different needs for simulation.

TCRP Project A-22, "Evaluation of Simulators as an Effective Tool to Improve Bus Safety and Guidelines for their Applications," was initiated to address these needs. The project was divided into two phases: a data collection and analysis phase (Phase I) and a results phase (Phase II). The second phase led to the development of a set of Guidelines for transit agencies to use to determine if they should procure or use simulators and associated advanced technology training tools. The Guidelines are published herein, following the project final report.

SCOPE OF STUDY

The Phase I tasks included a literature review, a survey of transit agencies using driving simulators, visits to transit agencies and other users of driving simulators, visits and surveys of transit agencies that are not using simulation to compare various indicators with the transit agencies using simulators, development of a methodology for evaluating simulation in transit bus operator training, and an Interim Report. Phase II was primarily involved with developing the Guidelines and this final report.

FINDINGS

There is no evidence that the current models of transit bus operator driving simulators have any negative effects on either training or driving safety. Positive findings were less clear and varied by transit agency. With one exception, users of bus operator simulators reported cost savings from using the devices. Increases in the acquisition and use of driving simulators in transit agency bus operator training can be expected; one goal of this research project is to ensure that transit agencies get maximum effectiveness and efficiency from those simulators.

There are currently three primary types of bus driving simulators/trainers in use in U.S. transit agencies: Open-Loop Video**,** Low-End Simulator, and Mid-Range Simulator. Each has been shown to improve both driver training and safety, although some data are based on a very limited number of users. All three devices have strong proponents and detractors. One finding is that each device trains some sub-set of the skills transit bus operators must have. None trains them all.

Transit agency users of these devices are sophisticated training specialists who understand both the limitations and the strengths of these devices. Users who are also strong proponents of the simulators have better results than users who are either neutral or skeptical about simulators.

Literature Review

The body of scientific and technical literature on simulators and their use for training dates back to at least to the early 1950s. The literature can be broadly characterized as falling into four main domains. These domains are (1) descriptions of simulators or simulator components, their characteristics, and how they are being used; (2) advice on what characteristics are required in a simulator; (3) research results on the effects of simulator characteristics on performance; and (4) research results on the effects of simulator characteristics on training.

The vast amount of this literature is in the context of flight simulators, because aviation has been the predominant use of simulators for the past 60 years. Within this body of literature, the smallest segment has been the findings of research on how certain simulator characteristics affect the rate of learning and proficiency.

Within the research on flight simulators, the smallest portion is on transfer of training (TOT) results, namely, how well someone performs with the actual equipment after having been trained in a simulator. There is insufficient data on how well training simulators actually train. The value of the simulator for training is most often taken on faith or based on expert testimony.

However, over the accumulated history of using simulators for training, there is evidence that training simulators, particularly flight simulators, are effective training devices. That is, time spent in the simulator trades off for some amount of training time using the actual equipment.

The research could not find published studies on TOT for bus operator simulators. A few articles on TOT for truck and automobile simulators were found. However, the majority of the publications addressing TOT results were in the field of military aviation.

Site Visits and Surveys

Research team members who visited transit training facilities were uniformly impressed with both the competence and enthusiasm of all the training staffs. Without exception, the team found carefully planned curricula, training that integrated the var-

ious simulators into the overall training program, and a realistic appraisal of the benefits and limitations of those simulators.

Among the transit agencies visited that are using simulators, the team found differences among the various devices in use. There are three basic devices in current use, which will be described in more detail in the next section of this report:

- Open-Loop Video (Doron L-300) Simulator with multiple-driver stations,
- Low-End Simulator (Doron L-301 VMT [Vehicle Maneuvering Trainer]), and
- Mid-Range Simulator (FAAC MB-2000).

The simulator most frequently used by transit systems is the Doron L-300 in various configurations. The Doron L-301 is a newer design and is located in several agencies; the FAAC MB-2000 is the newest design and is in only one transit training facility as of this writing. All the simulators are used to train new drivers. Many are also used to re-train more experienced drivers. In at least one case, a simulator is used to train drivers other than bus operators.

It was obvious during the research team visits that driving simulators appeals to both current and future users. The researchers did not find staff or trainees who felt the limitations of the various simulator configurations kept the simulators from meeting the instructional objectives of the training; rather all believed that the simulators contributed to the learning process.

It was also observed that a critical feature in the success of these training programs is the competence and enthusiasm of the instructional staff. The simulators provide an opportunity for instructors and students to closely work together in the learning experience. Although not part of the engineering design of a simulator, it is a feature of the simulation experience that cannot be ignored.

Simulator Uses

Every transit agency the team visited uses its simulator(s) to train new drivers. There are some variations among the various agencies on how much time each student spends in the various simulation configurations. This variation is partly the result of the judgment of individual training managers and partly the result of the scheduling problems attached to having training devices that can train only one student at a time.

All agencies with simulators report that new drivers can be taught fundamentals of bus operation in the simulators. Those fundamentals change depending on the simulator being used. Each of the three systems brings strength to the instructional process.

Almost all of the visited agency training personnel reported that the use of simulation has decreased drop-out rates from the training program. The user of the mid-range simulator reported a 50 percent decrease in failures among the students using the simulator compared with students in a conventional course. In one heavy user of other systems, the training manager reported a 95 percent pass rate. This same agency collected data to compare the number of accidents 20 months before and after undergoing the simulator-training program, and it reported a 10 percent reduction in collisions.

Several agencies reported reduced training time by replacing classroom bus training with simulator training. One agency reduced training time from 19 days to 17 days. The operating cost for training a driver in their simulator was $3 per hour, whereas it cost $40 per hour to perform the same maneuvers in a real bus. Another agency, using just the simulator, was able to reduce its training program by 5 full days. Another agency, with the same simulator system, reported no cost savings in the training process at all.

One agency training manager stated that they can send trainees to commercial drivers license (CDL) testing much sooner in a training program that uses a simulator. If the trainees do not pass the testing, management could provide more testing or disqualify the person. Without simulators, more training time/cost was invested before license testing could be imposed.

Two of the agencies that were visited provide training for other transit agency bus operators, thus creating revenue *into* the training organization. One training group within a visited transit agency even provides driver training to emergency and police personnel, as well as to other transit agency bus operators.

Advantages

All but one of the visited transit agencies reported improved effectiveness of training. The training managers believe that the simulators are able to replace some of the time spent in actual buses rather than replacing classroom time. From their point of view, this is a more productive effort than having students ride around in a bus. They liked the one-on-one training opportunities provided by the single-seat systems. Conversely, the multi-station system is seen as freeing up instructors.

One long-time user of bus operator simulation reported that simulation engages the trainees, which then increases their desire to participate in the training. Trainees reported greater confidence and increased awareness of reaction time requirements, and they provide positive testimonials on how realistic the simulation appears.

Disadvantages

Each of the simulators brought unique problems as well as unique benefits to the visited transit agency training programs. Ironically, the two major complaints identify the two fundamental problems with the simulators. In the case of the multi-station system, students and some instructors complained about the lack of interaction between what the student did in his or her learning station and the visual scene. In the case of the other one-station systems, the complaints were that only one student at a time could use the device.

RECOMMENDATIONS

There are two specific recommendations stemming from this research. One is to develop guidance for transit agencies deciding whether to use driving simulation. The second is to develop an approach to curriculum development that exploits the full power of driving simulation. The first recommendation produced the Guidelines published herein; the second recommendation is briefly discussed in this chapter and in more detail in Chapter 4, “Conclusions and Suggested Research.”

Develop Guidelines

There is significant interest in simulation within the transit community. Transit training personnel from around the United States and Canada attended an APTA conference on the topic in April 2000. A working group on driving simulation for transit bus operator training was established at that meeting. However, it is the belief of the research

team that there is still a fair amount of misunderstanding about simulation among transit training personnel and operations managers.

As discussed above, there are three basic types of transit bus operator training simulators. Each is meeting the needs of the using transit agencies, yet each is quite different in design and purpose. Because they are not equivalent, it is important that potential users are provided a vocabulary, needs assessment tools, and decision aids to maximize the payoff of any simulator purchase, lease, or use.

The purpose of the Guidelines is to provide transit agency managers with a tool that can help them decide whether their agency should add driving simulation to its training program and, if so, what kind of simulation should be acquired. In addition, the Guidelines will provide supporting material that can add to the effectiveness of any simulator selected by a particular transit agency. They also provide a brief history and overview of simulation, particularly driving simulation.

The research team believe that when simulation is used correctly student performance improves, cost savings are realized, and safety in the domain being simulated is improved. The Guidelines do not recommend a specific training device or simulator; rather, they provide the user with background, vocabulary, and data in order to reach an informed decision. Section I leads the user through a series of questions that will lead to a narrowing of simulator options. Tables compare the three types of simulators available to train transit bus operators and provide a decision tree to aid transit decision makers in the acquisition of simulators. The Guidelines are designed to help transit agency managers integrate the use of simulation in their agency's training programs in a cost-effective and beneficial way.

Develop Training

To fully exploit the potential of whatever simulation device is being used, a transit agency must adjust its current training program. If a simulator is just dropped into an extant training program, it may conceivably *add* cost to the program, and, if the overall instructional program is not changed, the training effectiveness of the simulator may be decreased.

Users of current models of simulators have done an excellent job of matching each simulator's capability to the training needs of its student operators. The lessons learned from these users have significantly improved both the Guidelines and the curriculum development efforts of new simulator users. Specific steps and remaining questions regarding a simulator-based curriculum are discussed in Chapter 4.

CONCLUSIONS

1. Transit bus operator simulation works. Simulation enhances learning and, in some cases, reduces the cost of training. However, simulation is not a panacea. In site visits and telephone conversations with the various users of transit operator simulators, it was repeatedly stressed that successful implementation of simulation technology required planning, instructional systems integration, and acceptance by the core instructional staff.
2. All three of the transit bus operator simulators the research team studied meet the needs of the using agencies. Both students and trainers expressed satisfaction with the various devices. Specific conclusions regarding each are as follows:
   a. *Open-Loop Video.* This system accommodates multiple users and is the least expensive of the three systems.

b. *Low-End Simulator*. This device replicates the visual, auditory, and vibratory effects of driving a bus in an urban, crowded environment. Students and trainers are convinced that driving this device gets new operators into buses more quickly and that they are safer drivers. Users of this system turn the one-user limitation to their advantage by having an instructor with the student for a one-on-one training experience. The system costs more than the Open-Loop Video, but users claim quick return on that capital expenditure.

c. *Mid-Range Simulator*. This is the newest type of simulator for the transit community and a few are currently in use. The major advantages of this simulator are its realistic visual and audible systems and, most importantly, its use of rear projection so that drivers of the system can adjust their mirrors and still receive full visual replication of the driving experience. The agency using this system is taking advantage of the one-user limitation to conduct intensive, one-on-one training. The manufacturer of this device is pricing it to be the equal of one new transit bus.

3. A Guidebook is needed. Transit agencies lack the tools to optimize their uses of bus operator simulators. Current users, as well as sources beyond the transit community, will be able to contribute to the Guidebook. The Guidebook must be a document to use, not an information text. The Guidebook must be for *transit* agencies and *bus operator training*. This is not to say that transit rail or the trucking industry might not benefit from such a Guidebook. It is only to say that the Guidebook is intended for use by those persons who, on a daily basis, accept the responsibility for training transit bus operators.
4. There is not a generally recognized process for integrating operator simulators into the current transit training programs. Although several agencies have successfully integrated simulation into their programs, a process is still needed.

CHAPTER **1**

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT AND RESEARCH OBJECTIVE

The transit community, like most private and government organizations, is facing a shortage of well-trained employees, including transit bus operators. At the same time, transit agencies are re-emphasizing the requirement for safe and efficient transit bus operations. Numerous advanced technologies are candidates for helping transit agencies meet these various objectives.

One such technology is driving simulation. If student bus operators can be trained more efficiently and more effectively using simulation, both training costs and operations costs can be reduced. However, only a handful of transit agencies are using driving simulation and even among these agencies different kinds of simulations are being used. Because simulation technology is new and ever changing, transit agencies need guidelines not only on *whether* to use simulation but also on *how* and *when* to use it. It is also possible that different agencies may have different needs for simulation.

TCRP Project A-22, "Evaluation of Simulators as an Effective Tool to Improve Bus Safety and Guidelines for their Applications," was initiated to address these needs. The project was divided into two phases: a data collection and analysis phase (Phase I) and a results phase (Phase II). The second phase led to the development of a set of Guidelines for transit agencies to use to determine if they should procure or use simulators and associated advanced technology training tools. This final report describes the overall research effort.

DEFINITIONS

The term "simulation" is used to refer to several entirely different classes of activity. One basic distinction is between analytical simulation and human-in-the-loop simulation. Analytical simulation, often called modeling, is a non-real-time computer analysis of a complex system, such as urban traffic, a nuclear power plant, or the national air space (air traffic control). This process is computationally intensive and internal to the computer. Typically, the outcome of an analytical simulation process is conveyed to the human user only at the end of the session, and the outcome could be as simple as a number (e.g., a flow rate). The time to process one set of initial parameters may range from milliseconds to many hours depending on the system model.

Human-in-the-loop simulation is the real-time simulation of a system in which the human "closes the loop" on a feedback control system, such as an aircraft or ground vehicle. The critical feature of this kind of simulation is that the person is integral to the simulation. These systems are interactive. The actions of the human (driver or pilot) are fed back into the model of the vehicle, and the visual display is updated accordingly. The real-time requirement stems from the need to update a visual display at a high enough rate (on the order of 30 Hz) to make the control task flow smoothly and be normally perceived.

In the past, driving simulators were very expensive, primarily because of the computational requirement to update each pixel on a wide field of view display. These simulations are very complex. Because they are both dynamic and representational of the real world, they require a significant number of dynamic world models (e.g., road conditions, tire-inflation pressures, other traffic scenarios, weather conditions, glare, and a complete model of a particular vehicle).

Training Devices and Simulators

Some simulators are training devices; others are R&D tools. Some training devices are simulators, but most are not. This distinction can be made by two examples:

1. All major airlines use flight simulators for pilot training. However, NASA and other research agencies use simulators not for training, but for engineering R&D on future cockpit technology.
2. A wooden airplane on the end of a stick can be an effective training device when used by a good instructor to teach basic flight control. It is a training device but not a human-in-the-loop simulator.

To be considered a true simulation, an instructional activity must be based on the reality of a specific real-world process or situation (Clariana, 1988; Heinich, Molenda and Russell, 1985; Gagne, 1962). Activities such as in-basket and decision-making instructional exercises and role-playing can be classified as simulations if the activity is based on a real

situation or the students are required to apply a process that could be used in a real-life scenario. Note that in these examples, there are no devices. One can have *simulation* without a *simulator device*. However, since the objective of this research was to investigate the application of driving *simulators* to transit bus operator training, this report focuses on simulators that are devices.

Therefore simulation is an instructional method that requires students to interact with specific instructional events based on real-world scenarios. Students must see or experience the consequences of their interaction. All interactions should result in similar real-world outcomes or effects. The primary learning outcome of a simulation should be the demonstration of a real-world process, procedure, or specific behavioral change (Powley, 1999).

What follows is a discussion of various training devices or techniques. Some of these items meet the definition of a simulator and some do not. However, they all can provide superior training given good design and intelligent use.

Open-Loop Video

An open-loop video is the most popular driver training device in use by transit agencies. It consists of several student stations, each with a steering wheel, gas and brake pedals, and rudimentary dashboard. Students watch a video display of traffic or other instructional information. The student's controls are not interactive with the visual display. In other words, a student could turn the steering wheel to the left while a right turn was being shown on the display. In this sense, it is an "open-loop" system. This type of system may have some training value, as discussed elsewhere in this report. But it is a training device, not a simulator.

Low-End Simulator

Arcade video games and desktop PC-driven driving games, controlled by keyboard, joystick, or miniature steering wheel are among the simplest, low end of this category. Beyond the game technology, there are two types of existing simulators that fit in this category:

1. A model-board system in which a miniature camera is installed in a small model of a bus and physically moves about on a small terrain board in an adjoining room. This technology has been used since the early 1960s in flight simulation with some success.
2. A desktop PC-based simulator that is essentially a sophisticated video game with a steering wheel, and gas and brake pedals. It is a real-time closed-loop system, but typically has a narrow field of view, and limited fidelity of visual graphics, vehicle dynamics model, and other features.

Mid-Range Simulator

A larger Field Of View (FOV), on the order of 120 to 80 degrees forward and 60 degrees to the rear, distinguishes the mid-range simulator. Mid-range simulators require more powerful computers than those systems discussed above. A more sophisticated vehicle model is provided, along with more complex environmental effects, such as weather, day-night, and road friction (rain, ice, snow). A mid-range simulator may have a limited motion capability, typically in the higher frequency ranges, to provide "road feel" and vibration. Examples of mid-range simulators for research purposes are at the University of Massachusetts, the University of Washington, the University of Minnesota, the Federal Highway's Turner-Fairbank Highway Safety Research Center, and Monash University (Melbourne, Australia). There is also a mid-range bus training simulator in operation in New York City.

High-End Simulator

The Daimler-Benz research simulator in Berlin, the Iowa Driving Simulator, and the National Advanced Driving Simulator (NADS), both at the University of Iowa, exemplify high-end driving simulators. This level of simulator is characterized by a very sophisticated visual image generation system, vehicle model, and complex motion base. These simulators are prohibitively expensive for training and are most often used for research in the ground vehicle domain. In the aviation domain the best example is NASA's Vertical Motion Simulator, which is used to train astronauts to land the Space Shuttle.

Other Simulator-Related Definitions

Training Effectiveness

Training Effectiveness (TE) is a term used to describe the capability of a training program to teach the intended knowledge, skills, and/or abilities. In the context of simulator-based training programs, the issue of effectiveness arises when determination of the benefits of the simulator component must be quantified. Often, simulator TE is confused with establishing how well the simulation actually reflects reality, commonly called "fidelity." Several studies have confirmed that higher fidelity does not necessarily coincide with TE.

Transfer of Training

The term "Transfer of Training" (TOT) is used to describe the transfer of skills learned in a training device to the operational environment. In this case, the training device is a driving simulator. It is generally assumed that high physical fidelity between simulator and reality is required to increase TOT. This leads to beliefs that providing motion cueing, for

example, increases the fidelity of the simulator and that increased fidelity leads to increased TOT. Unfortunately, very few studies have actually examined TOT between a simulator and the vehicle (Sanders, 1991). Most studies purporting to examine TOT have used a "pseudo-transfer" design, measuring performance in the simulator, or another simulator, as the criterion. Although the goal of simulation is positive transfer (the simulator increases learning), simulators have created negative transfer as well (the simulator actually has a negative effect on learning).

Part Task Simulation/Training

Sometimes, perhaps most often, a device or technique will be designed to teach part of a larger task. For instance, as the research team visited various transit agency training sites, it saw fare collection boxes standing in classrooms and laboratories. These boxes were training a very specific set of procedures that in the workplace must be integrated into the entire bus operation task.

Fidelity

Much research has been undertaken on fidelity of simulation. One of the best discussions of this concept is by Roscoe (1981). Two kinds of fidelity that can be provided by simulators are physical fidelity and psychological fidelity. Physical fidelity is the degree to which the simulator looks like the real thing (driver's view of a bus, cockpit). Psychological fidelity is the degree to which the simulator shapes the student's behavior to be that which will be required in the real world. Physical fidelity alone will not produce psychological fidelity. Psychological fidelity stems from the instructional components of the simulator, not the physical ones. In driving simulators, physical fidelity depends not only on the three dimensional representation of the driver area and the outside world, but also on software that produces the correct vehicle dynamics for particular conditions (e.g., dry highway conditions versus ice or rain), vehicle configurations, and vehicle systems. Psychological fidelity must produce responses and actions in the driver that can transfer to the real vehicle he or she will eventually drive.

SCOPE OF STUDY

Phase I included a literature review, a survey of transit agencies using driving simulators, visits to transit agencies and other users of driving simulators, visits and surveys of transit agencies that are not using simulation to compare various indicators with the transit agencies using simulators, development of a methodology for evaluating simulation in transit bus operator training, and an interim report. The next section of this chapter, Research Approach, describes these tasks in more detail. Phase II was primarily involved with developing the Guidelines and writing this final report

The scope of the entire research program has been limited to driving simulation applications to transit bus operator training. However, in the course of the research, the team collected both research and applied data from driving simulator applications in the trucking and academic domains as well. An unexpected, but fortuitous, occurrence during the conduct of Phase I was the addition of driving simulators by both the Cleveland and the New York City transit systems.

RESEARCH APPROACH

Task 1. Review Literature on Simulators as Training Tools

Much of the current literature on simulation and driving simulation was found in journals and books with a human factors engineering perspective (Brock, 1997; McCauley and Miller, 1997). The research team's search efforts were not limited to the more traditional scientific literature, however, they also looked for documentation of the success and failure of simulation for transit operations as well.

To gain an international scope, the team extensively used the World Wide Web to access libraries around the world, as well as commercial sites that tout driving simulators and training devices. Various search engines were used to search for relevant keywords (see Table 1-1). The North Carolina State University (NCSU) on-line database of periodicals and journals was searched, including Applied Science and Technology Index, PsychInfo, Social Sciences Abstracts, and NTIS. The search focused on articles dated 1990 through 1999.

The team conducted an e-mail survey of known researchers or simulator manufacturers: several e-mails were sent to key contacts identified through the Internet and based on previous project contacts. Each e-mail had a follow-up telephone interview with a key person (see Table 1-2).

The literature review encompassed scientific research on simulation and driving simulators, field studies, and real-world experiences of the users of such systems. Special emphasis was given toward finding links between training with simulators and transit safety data. A review of the instructional technologies that either interact or are expected to interact with more traditional driving simulation was also conducted, using the recent chapter on computer-based instruction for the *Handbook of Human Factors and Ergonomics* (Brock,

TABLE 1-1 Keywords used during review of literature

Bus Driver Training	Simulation Systems
Bus Drivers/Driving	Simulators
Driver Training	Simulator Training
Driving Simulators	Training Effectiveness
Flight Simulators	Transfer of Training
Flight Training	Truck Driving Simulator
Ground Transportation	Virtual Reality

TABLE 1-2 Researchers and others surveyed by e-mail or telephone for data on ground transportation simulator training effectiveness and simulator sickness

Name	*Affiliation*
Casali, John	Virginia Polytechnic Institute and State University (VPI&SU)
Kennedy, R.S.	RSK Enterprises
Hancock, P.	University of Minnesota
Kantowitz, B.K.	University of Michigan Transportation Research Institute
Triggs, T.	Monash University
Allen, Wade	STI
Fisher, D.	University of Massachusetts
Dingus, T.	VPI&SU
Robin, J.	Federal Highway Administration (FHWA)
Carroll, R.	FHWA
Hettinger, L.	AD Little
Watson, G.	University of Iowa
Theodore, A.	Lockheed-Martin
Hein, C.	Hughes Research Lab
Welles, R.	I-SIM
POC	FAAC
Stoffregen, T.	University of Cincinnati
Hansen, M.	Autosim, Norway
Romano, R.	Realtime Tech Inc.
McGehee, D.	University of Iowa
Mollenhauer, M.	Hyperion
Lampton, D.	STRICOM
Swezey, R.	ISAI
Campbell, J.	Battelle TRC

1997) as well as the results of a review for the U.S. Navy (Brock, Faust, and Swezey, 1998) as starting points.

A key feature of simulators in training that is often overlooked is the synergy that can occur between the overall instructional system and the simulator. Too frequently, a simulator is introduced into a training program without any development of new or altered instructional units. In the literature review, the researchers identified approaches to maximize the effectiveness of simulators with instructional (or other) interventions.

The literature review also examined current and anticipated instructional technologies that may impact simulators. For example, the U.S. Department of Defense links ground, ship, and airplane simulators for multi-force simulations across continents. The researchers investigated whether some small version of this kind of distance learning might be feasible and productive for one or, perhaps, several transit training facilities. Several key issues in driving simulation were addressed in the review:

- Training effectiveness (does the training produce better drivers);
- Training efficiency (does the simulator reduce the overall cost of training);
- Types of training (skill acquisition, advanced training, procedures training, emergency training);
- Other uses for simulators (performance assessment, evaluation of new procedures or policies); and
- Simulator sickness, interaction of simulators with different student populations (inexperienced drivers, older drivers).

Additionally, the team devoted a specific research inquiry into the issue of a simulator's contribution to safety.

Task 2. Develop and Conduct Survey

The research team developed and conducted a survey of transit agencies and related industries currently using simulators for training. The survey was designed to gather information about the application of simulation technology for training transit personnel. It broadly encompassed the issues of training effectiveness, changes in training practices, and perceived benefits of simulator introduction. The key information sought in the survey was evidence of simulator effectiveness, costs, and benefits. The survey participants were operations and training personnel knowledgeable about the effectiveness of training methods before and after the introduction of simulators.

A mail survey was used as it was determined to be the most cost-effective method of delivery. First, telephone contact was established with each transit agency to be included in the survey (i.e., agencies using driving simulators) to identify the specific personnel most appropriate to respond to the questionnaire. This telephone communication was also used to encourage preliminary "buy-in" to the process before receipt of the survey. The survey was distributed to the following agencies: Greater Hartford Transit Agency, Delaware Transit Corporation, Greater Cleveland Regional Transit Authority, New Jersey Transit, Orange County Transportation Authority, Southeastern Pennsylvania Transportation Authority, Tidewater Regional Transit, Broward County, Florida Transit, and MTA- New York City Transit. The survey was designed to require about 1 hour to complete.

Survey Format

The survey used a combination of closed-end formats (such as multiple choice), rating scales, and open-ended questions. These formats were chosen for their amenability to quantification, statistical analysis, and graphical depiction of results.

Survey Content

Three questionnaires were used in determining whether driving simulators are effective tools to improve bus driver and safety training:

1. Simulator Effectiveness Survey—Transit Agency Director Form focused on the agency's background and the

cost/benefits of transit bus simulator training. The questionnaire was to be completed via an in-person or telephone interview.

2. Trainer Survey on Simulator Effectiveness—targeted at gathering information from the trainer's perspective on simulator effectiveness. The questionnaire addressed the effectiveness of training for new and experienced drivers, skill development, and the role of the simulator in bus driver training.
3. Driver Survey on Simulator Effectiveness—addressed the driver's demographics and the usefulness of, effectiveness of, and barriers to simulator training.

Training effectiveness, costs, benefits, and technology implementation issues were the focus of the survey content. Some measures of effectiveness were explicitly specified, such as reductions in collision rate and reductions in maintenance or operations costs. Secondary indices of effectiveness, such as improved on-time performance or increased customer satisfaction were also assessed. The survey's short-answer format also solicited any other measures used by the transit agency to determine simulator-based training effectiveness.

Costs and cost-benefit issues were addressed in terms of total dollars and as ratios or percentages of operating budgets, or measures such as cost per passenger mile. Trainee throughput was also addressed to determine whether the simulator is a chokepoint in the training pipeline. The specific cost and benefit measures were developed as a result of the team's review and analysis of recent methodology and models for cost-benefit evaluation in the transportation industry.

Introduction and implementation issues can be important considerations for the introduction of new simulators. Experience in this area indicates that considerable costs and delays can be associated with the initial deployment of simulators. An accurate assessment of the costs and benefits that accrue from simulators must take into account these implementation issues. Consequently, the survey also captured information on implementation and operations issues connected with simulator introduction, such as:

- Curriculum changes,
- New knowledge and skills required of the instructional staff,
- Simulator downtime due to software and hardware "bugs,"
- Changes in trainee performance measurement techniques,
- Changes in trainee record-keeping procedures,
- Unwanted side effects (e.g., "simulator sickness"),
- Scheduling challenges for integrating the simulator sessions with traditional media, and
- Personnel requirements for simulator maintenance and operations.

Survey participants were asked to provide background information on the generic type of simulator in use by their agency. Information on specific simulator models was avoided; however, information was sought on the relationship between major simulator features and training effectiveness. The survey responses were anonymous; no participant signed his or her answer sheet, and the questionnaires were randomly distributed at the individual transit agencies. Demographic data were obtained from the participants to allow post-hoc determination of relationships between those data and the questionnaire results. For example, one could examine whether there was a relationship between years of experience and ratings of simulator effectiveness.

The data collection strategy was a mail survey supported by a Scantron 2000 Optical Mark Reader (OMR). The survey questionnaires were developed using Pulse Survey II software. The Scantron 2000 OMR survey questionnaires were distributed to the following populations:

- Drivers,
- Trainers, and
- Directors.

Survey packages were mailed to eight transit agencies using bus simulators to train drivers. Transit agencies administered the questionnaires locally and returned the completed forms for analysis.

Additional Survey Data

In addition to the transit agency surveys described above, the team contacted by telephone and e-mail various universities and private agencies currently conducting research using driving simulators. These less formal surveys were used to locate specific studies or experimental data that would either support or not support the idea of using driving simulators to train drivers. By contacting these research facilities, the researchers were able to gain access to the latest findings in simulator research prior to their reaching the published literature.

Task 3. Conduct Site Visits

Site visits were conducted to agencies that use simulators for bus operator training. Visits were made to the following agencies:

- Greater Hartford Transit,
- Southeastern Pennsylvania Transportation Authority (SEPTA) in Philadelphia,
- Orange County (California) Transportation Authority,
- Greater Cleveland Regional Transit Authority (GCRTA),
- Delaware Transit Corporation (Wilmington),
- New Jersey Transit, and
- MTA-New York City Transit.

During site visits, data were gathered that was supplemental to the information gathered in Task 2, as well as information that could only be obtained while on-site (e.g., observation and participation in a simulator training exercise). The researchers conducted on-site interviews with instructors. Training directors, operations directors, financial managers, and facilities managers were interviewed to gain information on costs, resource requirements, management support, and other factors.

The research team collected information on how training was conducted before the simulator was used and how it was conducted after the simulator had been in use awhile. This information included perceptions of both the strengths and weaknesses of simulation. Data on resource requirements for supporting the simulator, the decision process that led to the purchase of the simulator, and the capital costs of the simulator were also captured.

Data on truck driving simulators were included as many of these simulators are similar to those primarily used by transit agencies. Users of these systems were visited to identify any information that could help transit agencies (e.g., particularly effective or ineffective uses). The researchers contacted the following sites by either a site visit, telephone interaction, or through the mail:

- North American Van Lines Training Center, Ft. Wayne, Indiana;
- Werner Trucking Training Center (simulator currently in Orlando, Florida);
- I-SIM, Carnegie-Mellon University; and
- Digitrans, Carnegie-Mellon University Driver and Training Safety Institute.

Task 4. Peer Group Data and Comparison

For decades, transit agencies have used peer group comparisons to measure operating performance across systems. While widely used, such comparisons can often generate controversy because transit operators will argue that each location is sufficiently unique to have no peer. Nevertheless, peer group comparisons were employed as part of the team's data collection efforts. Common factors used in identifying peers included number of vehicles, size of operating area, population served, climate, modes operated, and area of the country. To control costs, the team used three different approaches to obtaining peer agency data: (1) visits to transit agencies with no simulator, (2) visits to agencies that have only recently obtained simulators and who could provide pre-simulator data, and (3) mail inquiries to transit agencies who expressed interest in simulation but to date are not using simulation in bus operator training.

For each chosen peer system, the researchers gathered information on methods used to train instructors and operators. They also collected whatever safety data were available.

Task 5. Develop and Execute a Methodology to Analyze the Effectiveness of Bus Simulator Training

The data and information from literature review, survey, observation, and interview were collated and analyzed to gain insight into the effectiveness of simulator training for bus operators. There were no straightforward statistical analyses appropriate for application because of the wealth of information types from different transit agencies. The collected information required careful analysis and judgment on the part of the investigators because of the potentially large number of uncontrolled variables. The introduction of a simulator may coincide with other changes in instructional personnel, new bus equipment, computer-based training, new hiring criteria, new routes, and so on. Changes in accident rates, or any other outcome variable, cannot logically be attributed solely to the introduction of the simulator. There is no quantitative methodology to control for these and other influences on the data. The best tactic was to capture and display the data in a form that is as systematic as possible, and then search for trends and patterns in the data.

Task 6. Evaluate Results of Simulator Use

Table 1-3 provides a summary of various simulator and instructional media options. Each of the transit training simulators and support systems found was compared with the various criteria identified in the table. The table rates each option in terms of cost, maturity of technology, installed base, instructional power, and availability.

Cost is rated in terms of low (below $50 per unit); medium (over $50 but normally under $1,000 per unit); high (between $1,000 and $10,000); very high (between $10,000 and $100,000); and extremely high (over $100,000). Cost *per student* may be a fairer comparison figure and is provided based on an annual (and arbitrary) student throughput of 300. In this case, low is below $50 per student; medium is between $50 and $499 per student; high is between $500 and $999 per student; and very high is anything exceeding $1,000 per student.

Mature technology is a way to express the risk involved in buying into a particular technology. "Yes" in the column means that the medium or device has high reliability and maintenance and repair would be readily available. "Moderate" means that there may be problems of device reliability, needed spare parts, or required technical support. If the column entry is "no," this indicates technology that is either on the leading edge of instructional technique or is in little enough use that special technical support and devices are needed.

Installed base is an attempt to describe the technology in terms of how unique it really is. "Yes" means that there is a base of devices and materials already in the transit-training world. A "medium" classification means that the base is small

TABLE 1-3 Simulation and instructional media characteristics

	COST	COST/ STUDENT	MATURE TECH.	INSTALLED BASE	INSTRU. POWER	AVAIL-ABILITY
Written Materials	LOW	LOW	YES	YES	MEDIUM	OTS
Audiotapes	LOW	LOW	YES	YES	LOW	OTS
Videotapes	LOW	LOW	YES	YES	HIGH	OTS
IVD	HIGH	LOW	YES	MEDIUM	HIGH	OTS/MTO
CAI	MEDIUM	LOW	MODERATE	MEDIUM	HIGH	OTS/MTO
CD-ROM	HIGH	MEDIUM	NO	MEDIUM	MEDIUM/ HIGH	MTO
CDI	LOW	LOW	NO	NO	HIGH	OTS/MTO
Group Simulation	MEDIUM	LOW	YES	NO	MEDIUM	OTS/MTO
Interactive Simulation (No motion)	HIGH	HIGH	NO	NO	HIGH	MTO
Interactive Simulation (Motion)	HIGH	HIGH	NO	NO	HIGH	MTO

but growing. A "no" means there is no installed base—at least in the transit training community.

Instructional power describes the potential each of the media has for providing student individualization, task practice, real-time performance measurement, and student engagement.

Availability refers to the number of options a buyer of the material will have in terms of course content and competitive vendors. A rating of "OTS" refers to Off the Shelf—multiple content and multiple vendors readily available. A rating of "MTO" means that the device or materials will be produced "Made to Order"—it meets a company's unique needs, but it is unlikely that there will be multiple vendors or content packages.

As the research team assessed the simulators and mediated instructional programs in use in the transit agencies, they began to lay the groundwork for the guidelines that were developed in Phase II of this research project. The researchers compared the simulators and instructional systems to one another and to more traditional instructional techniques. Two characteristics that were specifically examined were the fidelity of the simulators and any evidence of transfer of training from simulator to the actual driving task.

Cost, Productivity, and Safety. The ultimate goal of any transit training program is increased safety and productivity. If neither of these benefits can be identified in ongoing simulator-based training programs, then significant cost savings must be identified to justify use of simulators (less expensive training that produces drivers who are as competent as those trained in the more expensive system would be attractive to any transit agency). Cost comparisons included both procurement costs and life-cycle costs, including any additional staff or staff training to operate and maintain a particular simulator. Productivity was measured in terms of the instructional process (more students, fewer training hours, more efficient use of student's time) and on-the-job productivity (fewer hours lost to maintenance, better schedule discipline). Safety data were collected from the participating transit agencies in Tasks 3 and 4.

Task 7. Produce an Interim Report

An interim report was prepared. The A-22 panel reviewed the report, and, at a meeting between the panel and the principle investigator, the report was accepted and authorization to move to Phase II of the program was granted.

Task 8. Draft Guidelines for the Effective Use of Simulator Technologies

The draft Guidelines were submitted and reviewed by the project panel. The panel was generally receptive of the Guidelines and requested only several changes.

Task 9. Finalize Guidelines for the Effective Use of Simulator Technologies

Most of what is contained in the Guidelines is discussed and supported by the research documented in this final report. The major conclusions of the Guidelines were that any transit agency responsible for training its bus operators should seriously consider using driving simulation as one tool for such training. The Guidelines provide specific criteria for selecting one or more simulators. The data supporting the value of driving simulators, when training is designed and managed with the simulator in mind, are unambiguously positive. Figure 1-1, which is reproduced from the Guidelines, provides an aid for deciding what kind of simulator to acquire.

The Guidelines also offer options for smaller transit agencies to gain access to simulator technologies. Simulators are expensive. For transit agencies with few students it would be difficult to see how they could recover the costs associated with acquiring a Level 2 or Level 3 simulator. However, the benefits of such a simulator remain no matter how small the student throughput.

Because the payoff from using a driving simulator can be so big in terms of both safety and instructional efficiency, some method for exposing more students to the simulator experience should be found. One idea that has merit is the concept of a regional transit training center.

Such a center would be able to serve numerous small- and mid-sized transit agencies. It could be managed and funded by a consortium of these agencies. Another approach would have a major transit agency providing the simulation facility as part of its overall scheduling of simulator use. In either case, all non-simulator training would be accomplished at the student's normal transit training site. When the simulator was scheduled for a particular transit agency, the students would have to be transported to the simulator location for that phase of the training only. It is also possible that simulators can be installed in trailers and taken to each agency in the consortium on a set (and manageable) schedule.

The key to the success of such a center is to have every student ready for the simulator at the time he or she is sched-

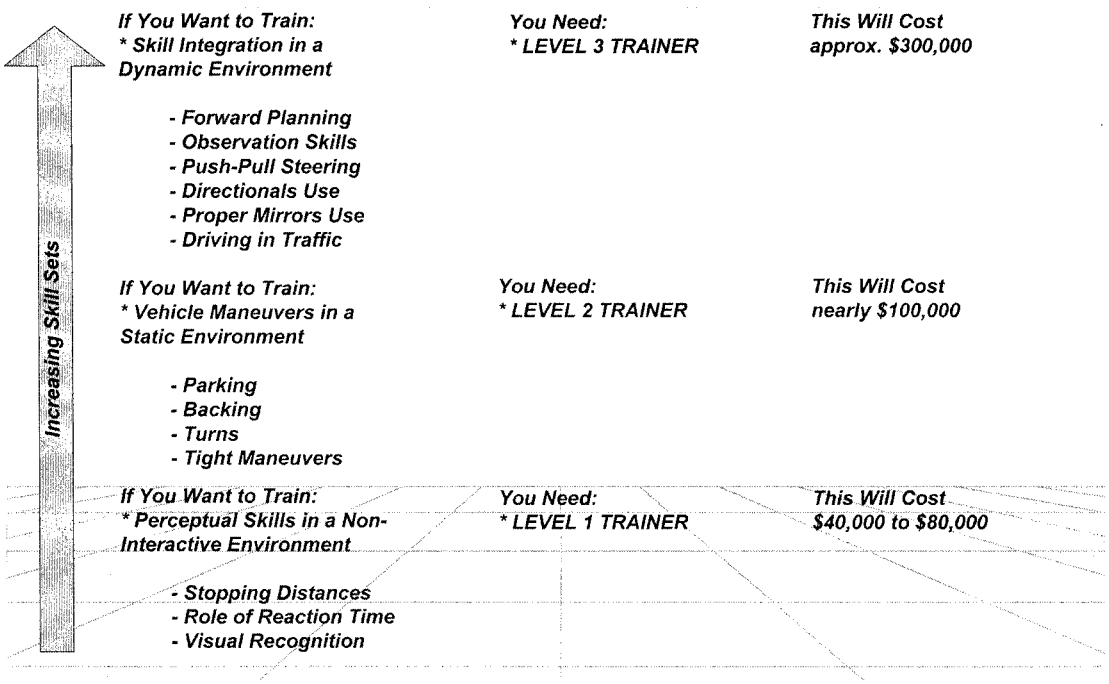

Figure 1-1. Which simulator?

uled to drive. This would be accomplished by providing off-simulator training over a computer network using the Internet. Each participating transit agency would be responsible for preparing the students for the simulator sessions.

Obviously, the cost for such an activity would have to be spread across all the participating transit agencies. Although no single agency would have absolute use of the simulator, at least no single agency would have to bear the entire cost of the simulator.

Task 10. Produce Final Report

The final task of the project produced this final report documenting the research effort.

CHAPTER 2

FINDINGS

SUMMARY OF FINDINGS

The first rule of instructional change is the same as the first rule of medicine: Do no harm. There is no evidence that current models of transit bus operator driving simulators have any negative effects on either training or driving safety. Positive findings were less clear and variable by transit agency. With one exception, users of bus operator simulators reported cost savings from using the devices. Therefore, driving simulators in transit agency bus operator training are inevitable; one goal of this research project is to ensure that transit agencies get maximum effectiveness and efficiency from those simulators.

There are currently three primary types of bus driving simulators/trainers in use in U.S. transit agencies: Open-Loop Video, Low-End Simulator, and Mid-Range Simulator. Each has been shown to improve both driver training and safety, although some data are based on a very limited number of users. All three devices have strong proponents and detractors. One finding is that each device trains some subset of the skills transit bus operators must have. None trains them all.

Transit agency users of these devices are sophisticated training specialists who understand both the limitations and the strengths of these devices. Users who are also strong proponents of the simulators have better results than users who are either neutral or skeptical about simulators.

LITERATURE REVIEW

General Findings from the Literature Review

There is a long and rich body of scientific and technical literature on simulators and their use for training that dates back to the early 1950s. The literature can be broadly characterized as falling into four main domains. These domains are: (1) descriptions of simulators, or simulator components, their characteristics, and how they are being used; (2) advice on what characteristics are required in a simulator; (3) results of research on the effects of simulator characteristics on performance; and (4) results of research on the effects of simulator characteristics on training.

The vast amount of this literature is in the context of flight simulators, because aviation has been the predominant use of simulators for the past 60 years. Within this body of literature, the smallest segment has been the findings of research on how certain simulator characteristics affect the rate of learning and proficiency.

Within the research on flight simulators, the smallest portion is on transfer of training (TOT) results, that is, how well someone performs with the actual equipment after having been trained in a simulator. However, over the accumulated history of using simulators for training, there is evidence that training simulators, particularly flight simulators are effective training devices. That is, time spent in the simulator trades off for some amount of training time using the actual equipment.

No published studies on TOT for bus operator simulators were found. However, a few articles on TOT for truck and automobile simulators were found. The majority of the publications addressing TOT results were in the field of military aviation.

With the advantages of simulators and the changing cost of these devices in mind, it is easy to see why aviation training has been the dominant application of simulators. The cost of a full-flight simulator for a military aircraft is tens of millions of dollars. When the aircraft has a value equal to or greater than the simulator but has a much higher operating cost, the use of a simulator for training is attractive. It is even more attractive when loss of the aircraft during training is a real possibility. Likewise, an expensive aircraft dedicated to training is not available for revenue-producing operations.

Until the 1990s, the cost of a fully functional ground vehicle simulator would also be in the multi-million dollar range. Most of the cost is attributable to expense of the visual image generation system and the motion system. Spending millions of dollars to simulate a vehicle that costs, at most, tens of thousands of dollars, has not been an attractive proposition. Moreover, except for training police pursuit and emergency response by fire trucks, the safety concerns for basic training in ground vehicles has been less than for aircraft. Consequently, there have not been many simulators built for ground vehicles. The demand has been low because of the costs relative to the anticipated benefits.

In the past 5 years or so, the cost of a comprehensive and realistic vehicle simulator has dropped from over a million dollars to a few hundred thousand dollars or less. The previously most expensive element, the visual image generation system, has dropped in price from approximately 6 to 8

million dollars in the 1980s to hundreds of thousands of dollars in the early 1990s to a few tens of thousands of dollars currently. The most expensive element at present, if it is included, is the motion system. Descriptions of the current state-of-the-art driving simulators are provided in the "Definitions" section of Chapter 1.

The U.S. military has typically been in the forefront of simulation technology, so it is not a surprise that the military is a leader in procurement of realistic truck simulators for training purposes. Recently, trucking companies have purchased training simulators of more modest capability and cost for some elements of driver training. There are a number of recent developments in ground transportation simulation outside of the training area, namely for purposes of engineering research and development. The National Highway Traffic Safety Administration (NHTSA) is underwriting the development of the National Advanced Driving Simulator (NADS) at the University of Iowa. Because of the demanding requirement to produce lengthy periods of accelerative forces, the NADS will cost over 50 million dollars.

Simulator Sickness

Introduction

The following discussion is intended to be an overview of the problem of persons becoming sick in simulators. Because any use of a bus operator simulator will involve a cross-section of persons—older and younger drivers, men and women—it is appropriate to include this discussion in this report.

Motion sickness has been the bane of ocean travelers for thousands of years (Money, 1970; Reason and Brand, 1975). Currently, advanced technology makes it possible to experience the same basic phenomenon in simulators, laboratories, and virtual environments, where the motion is virtual rather than actual. The common term for this syndrome is "simulator sickness," consistent with sea sickness, air sickness, car sickness, space sickness, and related terms (Casali, 1986; McCauley, 1984).

Simulator sickness is an unwanted side effect of simulation. It is a form of motion sickness thought to arise from the visual-vestibular conflict induced by apparent motion in a simulator. The false sensation of motion, which is elicited in a wide FOV scene, is called "vection." Vection is two-edged sword—it contributes to the perceived realism of being in a moving vehicle, but simultaneously establishes the basis for sensory conflict. The visually perceived motion is not corroborated by the vestibular system (the otoliths and semicircular canals in the inner ear), which acts like linear and angular accelerometers. Your eyes tell you that you are moving through the scene. Your vestibular system tells you that you are stationary.

Cases of simulator sickness have been reported in flight simulation for over 40 years (Havron & Butler, 1957; Miller & Goodson, 1958). Because there are far more flight simulators than driving simulators, most of the reports of simulator sickness have been associated with aviation. It has been reported in simulators of a wide variety of aircraft types and missions. The one constant has been a visual display of the outside scene that implies acceleration and self-motion through the environment. The same outcomes have been found in virtual reality or virtual environment applications with head-mounted displays.

Driving Simulator Sickness

One of the earliest reports of simulator sickness in a ground transportation simulator was by Reason and Diaz (1971) in a simple point-light-source projection for an automobile simulator. Subsequent reports and analysis of this phenomenon in automobile simulation have come from the laboratory at Virginia Tech (Casali and Wierwille, 1980) and the Iowa Driving Simulator (Watson, 1995; 1998a; 1998b).

The incidence and severity of simulator sickness varies greatly. It can range from a minor annoyance to a severe problem in rare individual cases. Major contributors to this wide range of occurrence are the susceptibility of the participants, the driving task, the duration of the exposure, the simulator engineering and design features, and the introduction and use of the simulator. In general, a typical driving simulator is likely to have a relatively low incidence, on the order of 5 to 10 percent of the first-time users reporting mild symptoms such as "stomach awareness" and mild nausea after an exposure on the order of less than 10 min duration. Simulator sickness is a manageable problem except in applications that require, for example, older subjects, longer exposures, high-intensity maneuvering, and no opportunity for the adaptation that occurs with repeated sessions.

Hein (1993) reported that in the Hughes driving simulator, young male drivers were predominately insensitive to simulator sickness, while older female drivers were considerably more susceptible. Further, she reported that the age and gender results tended to be true, that is, female drivers of all ages were more susceptible than males and older drivers of either gender were more susceptible than younger drivers.

As part of an older commercial driver research project, Swezey, Llaneras, and Rogers (1995) analyzed the incidence of simulator sickness in the North American Van Lines TT150 Truck Driving Simulator. The results of the study indicated that overall, 20 percent of the drivers experienced moderate to severe symptoms of simulator sickness ("extreme disorientation and dizziness, which in most cases resulted in vomiting"). Further, the authors reported that age was an important factor. Drivers under the age of 50 were less likely than older drivers to experience symptoms. While only 5 percent of the drivers under age 50 had simulator sickness symptoms, more than 30 percent of the drivers over 50 experienced symptoms. The authors reported, ". . . for the 43 drivers above age 55, 17 (or 39.5%) became physically sick"

(Swezey et al., 1995, p.9). This is a high incidence of simulator sickness, but the age trend is consistent with the findings of Hein (1993) described above. Assuming a linear relationship between age and driving experience, the results also are consistent with the findings in flight simulation indicating that experienced aviators tend to be more susceptible to simulator sickness.

An extensive series of investigations of simulator sickness was conducted recently by G.S. Watson at the University of Iowa (Watson, 1995; 1998a; 1998b). These studies were performed using the University of Iowa Driving Simulator (see Khul, Evans, Papelis, Romano, and Watson [1995] for a description of that device). Watson reported a number of interesting findings, including the following:

- More experienced drivers were more susceptible than novices,
- Females were more susceptible than males,
- Wider FOV did not exacerbate the problem,
- Motion base on or off did not affect simulator sickness,
- A short (5-min) session promoted some degree of adaptation in 17-min sessions 24 to 72 hours later,
- Adaptation significantly reduces sickness by the third simulator session,
- A graduated increase in maneuvering intensity is effective in minimizing symptoms, and
- A Motion Sickness History Questionnaire was a significant predictor of simulator sickness.

Approaches to Mitigation of Simulator Sickness

Engineering Design. Engineering solutions to the problem of simulator sickness are unlikely. Although poor engineering and calibration (transport delay, asynchronies, distortions, etc.) may contribute to the problem, a theoretically perfect system still will produce sensory conflict because the simulator does not move the same as the vehicle. In other words, good engineering may reduce simulator sickness, but it will not prevent it.

Procedures. Driving scenarios can be more benign by emphasizing the following:

- Short sessions (less than 10 min),
- Mild and infrequent acceleration and braking,
- Gentle and infrequent turns, and
- Rural rather than urban setting (to reduce the visual flow of scene content).

Establishing benign scenarios in accordance with these guidelines is recommended, especially for the first few sessions to minimize the incidence of simulator sickness. As the participant develops adaptation to the visual-vestibular rearrangement experienced in the simulator, the scenarios can include increased session durations and increased maneuvering.

Exposure time is one of the most important, and easily managed, factors in the development of simulator sickness symptoms. Short exposure times, on the order of 5 to 10 min are highly recommended for initial familiarization. Subsequent sessions can be incrementally longer, with breaks as necessary to accommodate individual differences in the rate of adaptation. Traditional instructional time periods, like the 50-minute classroom session, are not appropriate for initial exposures to vehicle simulation

The amount of vehicle maneuvering also contributes to simulator sickness. Constant velocities, like holding a speed on a straight road, will not produce sickness. Acceleration, braking and turning will contribute to the problem. An example of a worst-case scenario would be a long (e.g., 1-hour) exposure with frequent starting, stopping, and turns. Researchers using the Swedish driving simulator, VTI, stated that the most important factor influencing motion sickness in their simulator is “a driving task containing many sharp bends and requiring many fast and large manoeuvres” (Nilsson, 1993, p. 614).

Simulator operators should be given instruction in the proper use of instructional features such as “freeze” and “restart.” For example, it is poor procedure to invoke the freeze feature while the simulated vehicle is in motion, bringing the driver to an immediate and complete stop. The deceleration implied by this maneuver is large and totally unsubstantiated by the dynamics sensed by the driver and/or passengers in the simulator vehicle cab. Similarly, features such as “fast forward” should never be used unless the visual scene is blanked. In summary, the visual scene should convey the appropriate motion of the vehicle only as controlled by the driver. The design and use of simulator instructional features is important for both avoiding simulator sickness and for achieving training effectiveness.

Following are other recommended procedures for simulator use:

- Simulator operators and instructors should receive instruction on how to manage simulator sickness;
- Room temperature should be kept cool; provide good ventilation;
- Tasks should not require frequent or extensive head movement;
- Susceptible individuals should be given a series of brief “adaptation” exposures prior to full training sessions; and
- Drivers who exhibit symptoms should be allowed time for recovery and should not be allowed to drive an actual vehicle until they are fully recovered.

Adaptation. Humans adapt to rearranged sensory input. New eyeglasses, binoculars, or experimental manipulations (inverted lenses or prisms) are examples of conditions that rearrange the visual world, and, in some people, these will be accompanied by the beginning symptoms of motion sickness. Upon constant or repeated exposure, people will adapt

to the rearranged sensory input and begin to perceive and perform adequately and the associated symptoms disappear.

Scheduling simulator sessions is important for reducing simulator sickness. More sessions of short duration are preferred. As stated above, initial familiarization sessions of 5 to 10 min are recommended. Drivers will adapt over repeated simulator sessions and nearly all of those who experienced symptoms in the initial session will be symptom-free after approximately three sessions. Flexibility in the training program is essential to accommodate highly susceptible individuals. They should be removed from the simulator whenever symptoms reach the moderate level. The effectiveness of the training may be compromised by attempts to ignore symptoms and bravely press on with the training scenario. Table 2-1 summarizes these approaches to mitigating the negative physiological effects of driving simulators.

Ground Vehicle Simulators

Although there are only a few ground vehicle simulators being used to train transit bus operators, the number of such simulators being used for research or the training of other vehicle operators is significant. Simulators have proven to be a valuable device to study human driving performance under controlled conditions. Additionally, vehicle manufacturers and university engineering laboratories use simulators to study various vehicle design and engineering options. Table 2-2 lists most if not all ground vehicle simulators in the world.

SITE VISITS

General Impressions

The research team members who visited Transit Training facilities were uniformly impressed with both the competence and enthusiasm of all the training staffs. Without exception, the team found carefully planned curricula, training that integrated the various simulators into the overall training program, and a realistic appraisal of the benefits and limitations of those simulators.

Although most transit agencies visited had simulators, the team found differences among the various devices in use. There are three basic devices in current use, which will be described in more detail in the next section of this report:

- Doron L-300 simulator with multiple driver stations,
- Doron L-301 VMT (Vehicle Maneuvering Trainer), and
- FAAC MB-2000.

The simulator most frequently used is the Doron L-300 in various configurations. The Doron L-301 is a newer design and is located in several agencies; the FAAC MB-2000 is the newest design; four simulators are currently in one transit training facility but at least four others are being installed in the United States and Mexico. All the simulators are used to train new drivers. Many are also used to re-train more experienced drivers. In at least one case, a simulator is used to train drivers other than bus operators.

It was obvious during the research team visits that driving simulators appeal to both current and future users. The researchers did not find staff or trainees who believed that the limitations of the various simulator configurations kept the simulators from meeting the instructional objectives of the training; rather all felt that the simulators contributed to the learning process.

It was also observed that a critical feature in the success of these training programs is the competence and enthusiasm of the instructional staff. The simulators provide an opportunity for instructors and students to closely work together in the learning experience. Although not part of the engineering design of a simulator, it is a feature of the simulation experience that cannot be ignored.

TABLE 2-1 Simulator sickness prevention strategies

Before	During	After
Know the symptoms and Screen for them	Avoid overuse of complex driving scenarios (turns, grade changes, curves, etc.)	Look for symptoms that may occur during the debrief session
Identify vulnerable trainees	Minimize substantial changes in orientation, especially when the visual scene is on	Do not allow a trainee who is displaying symptoms to leave until he or she has recovered
	Minimize the use of high speeds	
	Incorporate breaks and time-outs	
	Report symptoms immediately	
	Remove an affected trainee from the simulator immediately upon displaying symptoms	
	Allow for adaptation to occur	
	Limit the maximum duration of the session to 50 minutes	

TABLE 2-2 Listing of current simulators in ground transportation domain

SIMULATOR NAME & TYPE	BRIEF DESCRIPTION
RESEARCH DRIVING SIMULATORS	
CERI simulator for winter conditions	Japanese Civil Engineering Research Institute.
COV Driving Simulator	Centre for Environmental and Traffic Psychology (COV) in Groningen (The Netherlands)
DRASIM	A Japanese driving simulator with 3 DDL motion system in Tokyo University.
DriS project	A driving simulator project in Portugal.
Hamburg University Simulator	The Driving Simulator with lateral motion and coupled with tire test bed. University of the German Armed Forces in Hamburg (in German).
HFRL simulators	Fixed base driving simulators at University of Minnesota - Minneapolis.
HITLAB	A mobile mid-range driving simulator at the University of Washington.
HYSIM II	FHWA Highway Research Center driving simulator, currently being upgraded.
Iowa Driving Simulator (IDS)	Driving simulator with a hexapod motion base at the University of Iowa.
Iowa State University of Science and Technology	A doctoral student presents a real-time driving simulator.
ISF simulators	Driving simulator used in University of the German Armed Forces in Munich (in German).
JARI simulator	A short citation and a picture - Japan Automotive Research Institute.
Kookmin University (South Korea)	Driving simulators. One with small synergistic platform. Many pictures.
Leeds University Driving Simulator	A fixed base simulator in psychology department.
University of Massachusetts	A mid-level driving simulator for research.
Monash University	Australian mid-range driving simulator at the Monash University Accident Research Centre.
Montreal University Driving Simulator	Canadian fixed base driving simulator.
National Advanced Driving Simulator (NADS)	World's most sophisticated driving simulator, under construction at the University of Iowa.
Northeastern University Simulator	Virtual Environments Laboratory in NU Boston (with head mounted display).
NTNU/SINTEF simulator	Driving simulator from the Norwegian National Laboratory for Behavioral Science.
Oak Ridge National Laboratory	In-Vehicle Information System Driving Platform.
PAVCAS simulator	A driving simulator to study driver vigilance in France – Strasbourg University.
PTI Truck simulator (updated link)	Pennsylvania Transportation Institute Research Driving Simulator.
Rochester University	Fixed base driving simulator. Site in construction. A driving simulator for autonomous driving program.
SEAT	Driver's Simulation Environment for Arm Therapy in Palo Alto Center.
SIRCA Project	A research driving simulator for road safety applications. SIRCA is a project carried out by ARTEC, LISITT, Institute of Robotics and Road Safety Research.
Southampton University	Driving Simulator in Department of Psychology.
TAC Research Center	Monash University (Australia).
TNO-HFRI, Driving Simulator	General presentation of TNO Institute simulator in The Netherlands.
TRL driving simulator	General presentation from Transport Research Laboratory simulator in Great Britain.
UMTRI	Driver Interface Research driving simulators at the University of Michigan.

TABLE 2-2 ***(Continued)***

SIMULATOR NAME & TYPE	BRIEF DESCRIPTION
UM-VRL	Virtual Reality Laboratory at the University of Michigan: applications for automotive industry.
Virginia Tech Simulators	Vehicle analysis and simulation Laboratory from Virginia Polytechnic Institute.
University of Washington	Human Interface Lab mid-range, mobile driving simulator (formerly at Battelle).
VTI simulator	The driving simulator from Swedish National Road and Transport Research Institute with a unique moving base and a proprietary graphics engine.
CORPORATE DRIVING SIMULATORS	
BMW	BMW with VAPS software by Virtual Prototypes.
CISI simulation center	Driving simulator designed by Renault.
Daimler-Benz driving simulator	One of the most advanced simulators in the world is on the Net.
Dynamic Research Inc.	Dynamic Research Inc. simulator with hexapod motion system.
FIAT mobility Center	Rehabilitation for handicapped people with driving simulator.
JS (X)	Driving simulators developed for a U.S. DOT and University of Alabama.
Nissan Cambridge Basic Research	A fixed base driving simulator with a Nissan 240SX cab.
TRAINING DRIVING SIMULATORS	
Digitran	Various vehicle simulation systems.
Doron Precision ***	Provides training and entertainment simulators.
First Ann Arbor Corp (FAAC) ***	Driver Training Simulator (DTS).
Hyperion	Training and research desktop simulation technology.
I*SIM	Driving simulators and trainer: a compact, high-performance driving simulator for the law enforcement and government marketplace.
Lockheed-Martin	LMIS truck driving simulator with motion base in Orlando, Florida.
Lulea University	A tractor simulator with motion base in Sweden, Lulea University.
Simusa	Training simulator in Israel.
SoftLab simulator	A training driving simulator by a company in Novosibirsk (Russia).
STN-ATLAS	Training simulators.
Stora Holm	A truck simulator (TRaCS) in a Swedish training center.
Systems Technology, Inc.	Low cost driving simulators.
TraCS	A truck driving simulator. Designed in an European project, this simulator is in operation in a French training institute (AFT-IFTIM).
TRUST	Same driving simulator sold by Thomson Training & Simulation.

Transit Operator Training Simulators

As indicated earlier, there were three simulators observed at the transit agencies surveyed for this project. Each is described below. *Note: This material represents the best information available to the research team at the time the report was written. Other suppliers might exist, and any omissions were inadvertent. Discussions of each in no way implies their endorsement.*

Doron L-300 (Open-Loop Video)

Doron's L-300 Bus multi-place systems are designed to simulate key elements of the driving environment of a typical transit bus. The system features what the manufacturers call, "training stations," that simulate driving controls, instruments, and the seating of the vehicle of choice (bus, car, truck). Students see wide-screen views of various driving situations while sitting in the training stations. The student's

actions on the controls do not change the visual scene, so this is not a true, interactive simulation. However, each station allows an instructor to monitor individual trainee responses from an instructor console. The L-300 is used to train and test very specific bus operator activities (e.g., reaction time, visual recognition).

Computers track student reaction times and other actions as the students react to the various scenarios projected on the screen. In addition, instructors receive feedback at the end of each driving session, allowing them to evaluate the performance of each trainee.

An instructor console with full color monitors provides touch screen displays for selecting functions and activities at each training station. The computer is the command center of the system; it collects, interprets, and provides immediate feedback to the instructor about each driver's actions as the scenario unfolds.

Each training station features a microprocessor for fast scoring and is equipped with functional gauges, headphones, comfortable bucket seats, and retractable safety restraints. The company provides an array of training scenarios for the training facilities.

The L-300 system can be configured specifically for transit bus operations; the training stations are equipped with large bus steering wheels, emergency brake controls, and general dimensions of a typical bus operator workspace. However, the research team also found instances of general-purpose training stations being effectively used to train transit bus operators.

Doron L-301 VMT (Low-End Simulator)

This device places the trainee in a mock-up of a driving console resembling a transit bus. The system is composed of two parts: the driver console, located in the student area, and a $^1/_{16}$-scale model of an urban driving course, which is located in an adjacent room (called the diorama room). The driving course offers a network of streets and buildings designed to replicate a real-world driving environment. Using a system of computer software and video cameras attached to a $^1/_{16}$-scale model bus, images of the course are projected on the windows of the student driver's console. As the student "drives" his or her simulated bus, the miniature bus reacts; thus, the scene changes in response to the student's action. The VMT provides an electrical-mechanical system for human-in-the-loop simulation. There is no attempt to simulate physical motion in the simulator except for specific seat-based feedback (e.g., a bump).

The device is specifically designed to train student operators to maneuver a transit bus in relatively tight and unforgiving situations. If a student turns too hard, the bus jumps just as if it had gone over a curb. One member of the visiting team, who had never driven any large vehicle, learned to back and park the simulated bus in less than 20 min.

FAAC MB-2000 (Mid-Range Simulator)

From the driver's seat of the MB-2000™ simulator, it looks and feels almost identical to an actual transit bus. Each cabin has an entire complement of instruments and gauges, all appropriate safety items, and typical steering, pedal, and gear shift equipment. The sights and sounds created by the computer generation and digital audio systems are designed so that drivers react to situations as if they are actually on the road.

The computer-generated virtual world provides simulated bus kneeling, interlock, stale green signal awareness and reaction to random door openings on parked cars in the visual scene. The student can drive in a 50-sq-mi virtual world. Malfunctions (e.g., tire blow out, drop in brake pressure) can be inserted into the scenario while the student is driving. The system is also capable of regulating other traffic flow through the control of the instructor.

Other Visited Ground Vehicle Simulators

A history of ground vehicle simulators is detailed in the Literature Review discussion above and in Appendix A, Bibliography. The research team visited and drove four current state-of-the-art driving simulators designed for truck simulation. These visits were a requirement of the contract to ensure that the transit community would have a complete representation of the state-of-the art in ground simulation.

North American Van Lines

The North American Van Lines truck-driving simulator has been used for both driver training and as a platform for research studies. The research team, in fact, has used it in a study of older professional driver performance. Since the simulator is located in a large trailer, it can be taken to wherever it is needed. It is manufactured by FAAC, builder of the MB-2000 bus simulator described above. The simulator features a 170-deg screen with high-resolution graphics, a variety of scenarios to draw from, and a stereo sound system that reproduces engine, transmission, and road noise.

I-SIM Truck Simulator, Carnegie-Mellon University

The I-SIM driving simulator provides an open seat driving station in a high fidelity, driving environment that is suitable for training and research applications. It includes an Operator Console that provides interactive, real-time control of the driving environment. The Driving Simulator incorporates I-SIM's proprietary vehicle dynamics, traffic scenario, and road surface software that provide accurate stimuli to the simulator driver. It is available in a car, bus, or truck configuration. The scene the user views is 170 deg and the imagery

is graphically generated. The I-SIM system has a sophisticated performance measurement system.

Digitrans Truck Simulator, Carnegie-Mellon Driver Training and Safety Institute

The Digitrans simulator at the Driver Training and Safety Institute is over 5 years old. However, it used a graphics-based visual system and realistic sounds and displays. It simulates the visual environment and cab instruments, but its performance measurement capability was somewhat limited. The Digitrans simulator is no longer at the CMDTSI.

Thales Training & Simulation's TRUST Simulator, Carnegie-Mellon Driver Training and Safety Institute

TRUST features an electric motion system, a full-sized replica cab, and a 180-deg FOV visual system with both front and rear views. It is the commercial version of TraCS, a truck driving simulator developed in 1997 by a consortium of European companies.

Lockheed Martin Truck Simulator

Lockheed Martin has built a large number of ground vehicle simulators for the U.S. and other armed forces. They have also built a prototype commercial truck simulator for one (as of this writing) trucking company. Members of the research team drove this simulator in Orlando, Florida. Besides the wide screen and state-of-the-art graphics, the large truck cab has a motion base. At the present time, the manufacturer is not going to pursue a bus equivalent of the truck driver simulator.

Simulator Uses

New Driver Training

Every transit agency visited uses its simulator(s) to train new drivers. There are some variations among the various agencies on how much time each student spends in the various simulation configurations. This is partly the result of the judgment of individual training managers and partly the result of the scheduling problems attached to having training devices that can only train one student at a time.

All agencies with simulators report that new drivers can be taught fundamentals of bus operation in the simulators. Those fundamentals will change depending upon the simulator being use. Each of the three systems brings strength to the instructional process.

Doron L-300. Stopping distances, road conditions, relationship of speed to both, role of reaction time: all of these can be shown and then practiced in the L-300. Because the instructor station for the system measures performance in each learning station, the instructors can monitor and identify students who are not correctly responding as the scenarios play out.

Doron L-301VMT. This system teaches such skills as approaching a bus stop, parking, tight turns, and backing to a single student without risk of damage to either an actual bus or to platforms, other vehicles, or pedestrians.

FAAC MB-2000. In this device, the mirrors in the simulated cab are actual mirrors; they can be physically manipulated to reflect imagery that is projected behind the simulator cab. The visual imagery for this system was developed for the specific driving environment of the transit buses for which the operators are being trained. The device provides high-fidelity simulation of the actual driving the operator trainees will be facing on graduation from the training program.

Refresher Training

In every transit training group visited, the simulators are also used for training the current driving staff, usually on some aspect of defensive driving. Some agencies try to cycle all bus operators through the simulator on a catch as catch can basis. Others identify operators with specific performance problems and use the simulator to both diagnose the problem and train the problem away.

Reported Results

It is difficult to generalize results from the site visits because the research team visited varying configurations of simulation systems. The survey data, reported below, all come from similarly configured systems. However, what follows is a discussion of very specific finds at various transit bus operator training sites. The value of this information is that it comes from the daily users of these systems. The warning is that generalizations from this information must be made with extreme care.

Performance

One simulator has a program that is specifically designed to reduce reaction time of a bus operator. One user of this device found that reaction time decreased by 23 percent. This same agency reported that fleet supervisors were convinced that the simulator-trained operators were better prepared for adverse weather conditions. Another simulator has only been in use for less than a year at one location. However, early results indicated that operators who have used the simulator

are having 36 percent fewer accidents than their counterparts who have not been trained using the simulator.

Almost all of the visited agency training personnel reported that the use of simulation has decreased drop-out rates from the training program. The user of one simulator reported a 50 percent decrease in failures among the students using the simulator compared with students in a conventional course. In one heavy user of simulators, the training manager reported a 95 percent pass rate. This same agency collected data to compare the number of accidents 20 months before and after undergoing the simulator-training program, and reported a 10 percent reduction in collisions.

Cost Savings

Several agencies reported reduced training time by replacing bus training with simulator training. One agency reduced training time from 19 days to 17 days. The operating cost for training a driver in their simulator was $3 per hour, whereas it cost $40 per hour to perform the same maneuvers in a real bus. Another agency, using just a simulator, was able to reduce its training program by 5 full days. Another agency, with the same simulator system, reported no cost savings in the training process at all.

One agency training manager stated that they can send trainees to commercial drivers license (CDL) testing much sooner in the training program that uses a simulator. If the trainees do not pass the testing, management could provide more testing or disqualify the person. Without simulators, more training time/cost was invested before license testing could be imposed.

At least two of the agencies that were visited provide training for other transit agency bus operators, thus creating revenue *into* the training organization. One training group within a visited transit agency even provides driver training to emergency and police personnel, as well as to other transit agency bus operators.

Advantages

All but one of the visited transit agencies reported improved effectiveness of training. The training managers view the simulators as able to replace some of the time spent in actual buses rather than replacing classroom time. From their point of view, this is a more productive effort than having students ride around in a bus.

One long-time user of bus operator simulation reported that simulation engages the trainees, which then increases their desire to participate in the training. Trainees reported greater confidence and increased awareness of reaction time requirements, and provided positive testimonials on how real the simulation appears.

Disadvantages

Each of the simulators brought unique problems as well as unique benefits to the visited transit agency training programs. Ironically, the two major complaints identify the two fundamental problems with the simulators. In the case of one multi-station system, students and some instructors complained about the lack of interaction between what the student did in his or her learning station and the visual scene. In the case of the other systems, the complaints were that only one student at a time could use the device.

Curriculum Implications

All transit agency training sites that were visited had gone to some trouble to integrate the simulator-based training into the overall bus operator curriculum. The research team was consistently impressed with the insight the various training managers and instructors had into the needs of the students and the impact of the simulators on meeting those needs.

Individualization

The single-user simulator presents a difficult problem to the manager of a bus operator-training program that in most other respects is keyed to a lockstep curriculum with all students in a classroom or distributed across a number of buses. In simplistic terms, what does one do with the other students while the one student is in the simulator?

One solution would be to individualize a major part of the entire curriculum. One could construct a curriculum that would allow each student to progress at his or her own pace and follow an individualized optimal path. Such a curriculum would require major changes to current transit training programs. Before such an activity is undertaken, a thorough analysis of bus operator training needs would have to be made.

Performance Measurement

A major advantage of simulation is the ability to measure operator performance without endangering either equipment or people. The effects of adverse weather can be simulated, and operators learn how the dynamics of driving change with rain, snow, and ice. A strong point of one system is its capacity to measure various behaviors in the learning station. Another system provides realistic visual representations, various traffic conditions, and both clear and inclement weather conditions; the instructor station allows student performance to be measured under these various conditions. Another system provides an opportunity to measure a student's ability to maneuver in tight spaces, back up, and pull into passenger pick-up areas without, again, putting property or people at risk.

Most systems provide automatic performance measurement abilities. One is set up so that the instructor can evalu-

ate the student from either observing the student or watching the miniature bus navigate in the miniature urban space. This allows the instructional staff to provide meaningful feedback and scores to the student, as well as to screen the students for readiness to drive a bus.

SURVEY RESULTS

This section will highlight key findings from the project surveys. Of the 245 questionnaires distributed, 69 (28 percent) of completed questionnaires were returned for analysis. The three surveys yielded the following response rates:

- Of the 47 Trainer questionnaires, 17 (36 percent) of completed surveys were returned for analysis.
- Of the 190 Driver questionnaires, 51 (27 percent) of completed surveys were returned for analysis.

Trainer Results

The Trainer Survey on Simulator Effectiveness questionnaire gathered information from the trainer's perspective on simulator effectiveness. The questionnaire addressed training effectiveness for new and experienced drivers, skill development, and the role of the simulator in bus driver training.

This survey had five sections:

1. Demographics: Six closed-ended questions that describe age, gender, length of bus driving instructor experience, and length of involvement in simulator training.
2. Site-specific focus questions: 24 open-ended questions that ask respondents to describe bus simulator hardware, software, implementation issues, and costs and benefits.
3. Bus simulator training effectiveness: Ten closed-ended and four open-ended questions that measure training usefulness, skills development, and bus drivers' overall satisfaction with the learning experience.
4. Bus simulator training barriers: Nine closed-ended questions and one open-ended question that measure the challenges to bus simulator training.
5. Bus simulator training effectiveness questions: Four open-ended questions that ask respondents to describe the effectiveness of bus simulator training based on their knowledge of prior course evaluation data and diagnostics/test measures.

The typical trainer responding to this survey was a male in his 40s located in the Eastern United States with 6 or more years in bus driving experience. Most have more than 6 years of experience as a trainer and 1 to 3 years experience training with a bus simulator.

When asked if they were satisfied with the training simulator, 92 percent of respondents from all locations reported a high level of satisfaction with the training simulator. However, one respondent expressed concern with the sickness as a result of using the training simulator.

Trainers rated bus simulator training high in the areas of effectiveness in training first-time drivers and utility in the overall training curriculum. However, trainers from one system were less enthusiastic about simulation than the other trainers in the survey. When asked if the simulator is more effective than traditional training for teaching certain types of knowledge, skills, or attitudes, 58 percent of respondents reported that the simulator is more effective than traditional training methods.

When asked what role simulator training plays in the overall bus operator curriculum, respondents in all locations reported that bus simulators reinforce the concepts taught in the classroom. Most trainers feel that simulator training validates defensive driving techniques taught in the classroom. All respondents believe that the simulator training provides an excellent opportunity to experience a hazardous situation without actually being in a hazardous situation. The system is used to reinforce proper driving habits and defensive driving principles and allows instructors to scientifically check reaction time, eye-hand coordination, and driving skills.

When asked about the disadvantages of bus simulator training, respondents believe there are two main disadvantages of bus simulator training: (1) the trainees do not feel that simulator is realistic enough (one respondent expressed concern that the training simulator does not represent the actual "feeling" of driving a bus) and (2) motion sickness and nausea. Respondents reported a significant amount of motion sickness due to perceived or actual movement.

When asked about the advantages of bus simulator training, a consistent response across all locations was that bus simulator training reproduces a lifelike driving experience without the risks or cost of training in an actual bus. Most respondents reported that trainees with little or no experience are better prepared for their initial driving assignment.

Respondents were asked to respond to four open-ended questions that describe the effectiveness of bus simulator training based on their knowledge of prior course evaluation data and diagnostics/test measures.

When asked about test score data supporting the effectiveness of the simulator, 23 percent knew about test score data supporting the effectiveness of the simulator. While one group of respondents had no knowledge of test score data, another group of respondents stated that they were unsure or uncertain about test score data.

When asked about course evaluation data supporting the effectiveness of the simulator, only one respondent reported the existence of course evaluation data that supported the effectiveness of the simulator. Two sets of respondents reported that they were unsure or that they were not aware of course evaluation data.

When asked about any cost reduction-over-time data supporting the effectiveness of the simulator, most respondents

claim that they did not know or that they were unsure about cost reduction data supporting the effectiveness of the simulator. One respondent reported that there was a reduction in training time and accidents.

When asked about any diagnostics/test measures data supporting the effectiveness of the simulator, one respondent reported the existence of that diagnostics/test measures data supported the effectiveness of the simulator.

Driver Results

The Driver Survey on Simulator Effectiveness addresses the driver's demographics and the usefulness of, effectiveness of, and barriers to simulator training. This survey has four sections:

1. Demographics: Six closed-ended questions that describe age, gender, length of bus driving instructor experience, and length of involvement in simulator training.
2. Bus simulator training effectiveness: 10 closed-ended and four open-ended questions that measure training usefulness, skills development, and bus drivers' overall satisfaction with the learning experience.
3. Bus simulator training barriers: Nine closed-ended questions and one open-ended question that measure the challenges to bus simulator training.
4. Bus simulator training satisfaction questions: Three open-ended questions that ask respondents to describe their satisfaction and dissatisfaction with bus simulator training.

The typical driver responding to this survey was a male in his 30s located in the Eastern United States with less than 1 year of driving experience. 82 percent of the respondents had been employed with their transit company less than a year following simulator training when they answered this survey.

When asked what they like best about bus simulator training, most indicated that bus simulator training helped them prepare for their jobs. In addition, the training experience made them more effective as drivers. Nearly 75 percent of all respondents reported that bus simulator training did enhance their learning experience. When asked what they disliked about bus simulator training, six respondents reported motion sickness, dizziness, and disorientation after bus simulator training.

PEER GROUP COMPARISONS

The research team visited several transit agencies that either do not have simulation or have only recently begun using a simulator. In addition, they surveyed via e-mail the attendees at an APTA conference on bus operator simulation that do not have simulation but are interested in the technology for future applications.

They looked for any trends in transit data that might account for changes being reported by agencies using simulation (e.g., decreased cost of training, reduction in bus crashes). No such trends were found. The most interesting information to come from these inquiries was the general view that new students are less ready for learning bus operations than the students of 3 to 5 years ago.

CHAPTER 3

INTERPRETATIONS, APPRAISAL, AND APPLICATIONS

The literature review concludes that simulation can work. The site visits and surveys indicate that ground vehicle simulation works. The site visits to and surveys of current transit agencies using various simulation systems lead to the conclusion that transit bus operator training can be improved with the selective use of transit bus simulators.

As noted above, one key reason simulation is working for the visited transit agencies is the competence and enthusiasm of the instructional staffs. If simulation is to be integrated into a transit agency's bus operator training program, the early and intensive involvement of current staff is critical.

GENERAL RECOMMENDATIONS

There were two specific recommendations stemming from the first phase of this research. One was to pursue the second phase of the TCRP A-22 project to develop Guidelines for transit agencies deciding whether to use driving simulation. The second was to develop an approach to curriculum development that exploits the full power of driving simulation. The first recommendation is discussed in detail in this chapter. The second recommendation, described in this chapter, is discussed in more detail in Chapter 4, under "Suggested Research."

Develop Guidelines

It is obvious that there is significant interest in simulation within the transit community. Recently, transit training personnel from around the United States and Canada attended an APTA conference on the topic. One result of that meeting was a working group on driving simulation for transit bus operator training. However, it is the belief of the research team that there is still a fair amount of misunderstanding about simulation among transit training personnel and operations managers.

As discussed above, there are three basic types of transit bus operator training simulators. While each is meeting the needs of the using transit agencies, each is quite different in design and purpose. It is important that potential users are provided vocabulary, needs assessment tools, and decision aids to maximize the payoff of any simulator purchase, lease, or use.

Develop Training

To fully exploit the potential of whatever simulation device is being used, a transit agency must adjust its current training program. If a simulator is just dropped into an extant training program, it may conceivably *add* cost to the program, and, if the overall instructional program is not changed, the training effectiveness of the simulator may be decreased.

Fortunately, users of current models of simulators have done an excellent job of matching each simulator's capability to the training needs of its student operators. The lessons learned from these users will significantly improve both the Guidelines and the curriculum development efforts of new simulator users. Specific steps and remaining questions regarding a simulator-based curriculum are discussed in Chapter 4.

GUIDELINES

There are two general questions a transit manager will need to answer about driving simulation: (1) should I acquire one, and (2) if so, what should I acquire. The Guidelines attempt to answer both questions.

Guidelines for Acquisition

As in any acquisition, the first question can be answered by a cost/benefit analysis. Not only will the Guidelines lead a manager to a yes/no answer, but they should also provide him or her with guidance on purchasing, leasing, and renting time. The Guidelines will match such variables as student loading, geographic size of the transit area, proximity to other simulator facilities, and physical plant of the training activity. The Guidelines will also provide worksheets so that the individual transit manager can factor in such variables as: average student load, operator turnover, potential surges in either trainees or operators, and current staffing capacities.

The Guidelines must provide sufficient information about the various simulator options that a training or operations manager will be able to match a particular set of training objective to a simulator system. The Guidelines will not recommend nor reject a particular device. Rather they will describe the various options in terms of operational capabilities. For instance, if a

training manager determines that student flow dictates a multi-station device to handle an entire class of students at one setting, he or she would be led to that kind of OTS device and presented with the advantages and disadvantages of that device. The Guidebook also will try to outline the tradeoffs involved in the decisions.

The Guidelines will also provide a set of options for the training manager once he or she decides that bus operator simulation is a reasonable choice. One option, of course, is to buy one or more simulators. The Guidelines will contain the equations for estimating the costs and benefits of such an undertaking. Smaller agencies will find guidance on how to share the costs of simulation across several organizations. The idea of regional bus operator simulators serving several transit agencies is one reasonable solution to reducing costs for smaller transit agencies.

Therefore, the Guidelines will also provide a set of primers on hypothetical structures for providing bus operator simulation to small-, medium-, and large-sized transit agencies. For instance, one option would be for each of several transit agencies to have a distance learning network (see below) and, perhaps, a multiple seat driver training system. At particular times in each agency's instructional program, students could travel to a single-use simulator for specific kinds of simulator-based training. The distance-learning network could be used to coordinate all this.

Guidelines for Use

The above discussion about site visits pointed out that the successful use of bus operator simulators depended every bit as much on curriculum integration and instruction competence and enthusiasm as it did on any particular technology. A critical feature of the Guidelines, then, will be to support the training manager and his or her staff as they build an instructional program that will use their simulator to meet their training objectives.

The Guidelines for use must emphasize the specific skills a particular simulator is to be teaching. The transit bus operator curriculum must ensure that each student that is using the simulator has received the prerequisite instruction and has demonstrated key competencies before using the device. The Guidelines will (1) identify what those competencies would be for all the simulator options and (2) describe how to measure those competencies.

Any simulator user agency would have to introduce a "train the trainer" program. The manufacturers of the three current simulators assist in such a program. This program must include not only simulator-specific guidance, but also include the curriculum changes and implications generated by the simulator use. The Guidelines will describe such a train the trainer program and provide specific guidance on its design and implementation.

DISTANCE LEARNING

Distance learning is much in the news and technical literature. The term relates, generally, to any system that provides instruction to one or more people at remote locations. Television has been used for such purposes almost from its beginning. One could also make the case that traditional correspondence courses were a low-tech form of distance learning.

The current meaning of the term is usually in the context of the Internet. The underlying idea is that society is getting connected and one reason for this connectivity is to bring the learning experience to wherever a person happens to be. Learners can experience just-in-time instruction when they need it and where they need it. The Internet can also function as a pipeline for interactive, multimedia instruction that, presumably, makes the learning experience more interesting and effective.

This same pipeline could also serve as a backbone for transit agencies that want to share instructional resources. One way transit-training managers could use simulation is to share one or more devices in a particular region. Bus operator students could receive their normal training curriculum either directly over the Internet or more conventionally but with schedule management over the Internet. The simulator could serve several agencies.

CHAPTER **4**

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

1. Transit bus operator simulation works. Simulation enhances learning, and, in some cases, reduces the cost of training. However, simulation is not a panacea. In site visits and telephone conversations of the various users of transit operator simulators, it was repeatedly stressed that successful implementation of simulation technology required planning, instructional systems integration, and acceptance by the core instructional staff.
2. The transit bus operator simulators the research team studied meet the needs of the using agencies. Both students and trainers expressed satisfaction with the various devices. Specific conclusions regarding each are as follows:
   a. *Open-Loop Video*. This system accommodates multiple users and is the least expensive of the three systems.
   b. *Low-End Simulator*. This device replicates the visual, auditory, and vibratory effects of driving a bus in an urban, crowded environment. Students and trainers are convinced that driving this device gets new operators into buses more quickly and that they are safer drivers. Users of this system turn the one-user limitation to their advantage by having an instructor with the student for a one-on-one training experience. The system costs more than the open-loop video, but users claim quick return on that capital expenditure.
   c. *Mid-Range Simulator*. This is the newest simulator for the transit community. The major advantages of this type are its realistic visual and audible systems and, most importantly, its use of rear projection so that drivers of the system can adjust their mirrors and still receive full visual replication of the driving experience. The agency using this system is taking advantage of one-user limitation to conduct intensive, one-on-one training.
3. A Guidebook is needed. Transit agencies lack the tools to optimize their uses of bus operator simulators. Current users, as well as sources beyond the transit community, will be able to contribute to the Guidebook. The Guidebook must be useful for *transit* agencies and *bus operator training*. This is not to say that transit rail or the trucking industry might not benefit from such a Guidebook. It is only to say that the Guidebook is for use by those persons who, on a daily basis, accept the responsibility for training transit bus operators.
4. There is not a generally recognized process for integrating operator simulators into the current transit training programs. Although several agencies have successfully integrated simulators, a process is still needed.

SUGGESTED RESEARCH

Simulation Research

The transit community can base much of its simulator decisions on the research reported above. The defense, aerospace, academic, and commercial driving research, development, and documentation provide solid support for using driving simulators. There is also a solid collection of lessons learned from other domains that can aid transit-training personnel to effectively use the simulators they have.

But some research is still needed. Fortunately, transit agencies can proceed in their simulation planning, procurement, and use. Early users, in fact, can provide the laboratories for the research to be done. One of the research programs should make good training programs even better; another must study the persistent problem of simulator sickness.

The research team believes that the current engineering research and development being conducted by various simulator manufacturers will lead to better products. Companies have shown an enthusiasm for listening and meeting the needs of their customers. As more transit agencies express interest in simulation, one can expect manufacturers to respond to those interests with advanced engineering solutions.

In terms of research beyond engineering development, the researchers believe that a systematic data collection effort should be established as more transit agencies become simulator users. Most of the data reported in this report have been serendipitous. After all, the primary mission of a transit agency training group is to train, not to collect data for some future research project. Therefore, it is recommend that a systematic program be developed to collect data in transit agencies before, during, and after simulator implementation.

The second research program should address simulator sickness. The transit bus operator population more closely reflects the community they serve than other populations

participating in simulator research studies (e.g., truck drivers are over 90 percent male, military pilots are overwhelmingly male, and college graduates). The recommended research program should look at both incidence of simulator sickness among transit bus operators in simulators and examples where such sickness has been ameliorated.

Instructional Design and Technology

The researchers also recommend a program of research to establish the optimum curriculum design for simulator use. Unique instructional pathways and media for each student are now possible. Research is needed to determine if that level of individualization is needed. Part of that study should determine how the simulator should fit with actual bus operation, classroom activities, practical exercises, and performance measurement.

Part of this research should focus on advanced technologies other than driving simulators that can support the simulator curriculum. This research should also produce a set of performance standards for bus operators. If the research is comprehensive, it should also produce a set of objectives and techniques for refresher training, train the trainer training, and performance diagnostics for drivers with poor driving records.

APPENDIX A

BIBLIOGRAPHY

Brock, J.F. (1997). Computer-Based Instruction. In G. Salvendy (Ed.), *Handbook of Human Factors and Ergonomics, 2nd. Edition.* New York: John Wylie and Sons, 578–593.

Brock, J.F., Faust, D.G., and Swezey, R.W. (1998). *Development of Instructional Technology Options for LPD 17 Training.* Orlando, FL: Naval Air Warfare Center Training Systems Division, February.

Casali, J.G. (1986). *Vehicular simulation induced sickness. Volume I: An Overview*. (NTSC TR 86-010). Orlando, FL: Naval Training Systems Center.

Casali, J.G. and Wierwille, W.W. (1980). The effects of various design alternatives on moving-base driving simulator discomfort. *Human Factors*, 22(6), 741–756.

Clariana, R.B. (1988). Computer Simulations of Laboratory Experiences. *Journal of Computers in Mathematics and Science Teaching*, 8(2), 14–19.

Havron, M.D. and Butler, L.F. (1957*). Evaluation of Training Effectiveness of the 2FH2 Helicopter Flight Trainer Research Tool.* Technical Report NAVTRADEBCEN 1915-00-1. Port Washington, NY: Naval Training Device Center.

Hein, C. (1993). Driving Simulators: Six years of hands-on experience at Hughes Aircraft Company. Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting, 607–611.

Heinich, R., Molenda, M. and Russell, J.D. (1985). *Instructional Media and the New Technologies of Instruction*. Second Edition. New York: Macmillan Publishing Company.

Gagne, R.M. (1962). *Psychological Principles in System Development.* New York: Holt, Rinehart & Winston.

Kuhl, J.G., Evans, D., Papelis, Y.E., Romano, R.A, and Watson, G.S. (1995). The Iowa Driving Simulator: An immersive environment for driving-related research and development. *IEEE Computer*, 28(7), 35–41.

McCauley, M.E. (Ed.) (1984). Research Issues in Simulator Sickness: Proceedings of a Workshop. Washington, DC: National Academy Press.

McCauley, M.E. and Miller, J.C. (1997). Issues Pertaining to the Driver's Role in Automated Highway Systems (AHS): Vigilance, Supervisory Control, and Workload Transition. Final Report under Contract DTFH-94-C-00067 for the Intelligent Transportation Systems Joint Program Office, Federal Highway Administration, Washington, DC.

Miller, J.W. and Goodson, J.E. (1958). A note concerning "motion sickness" in the 2-FH-2 Hover Trainer. Pensacola, FL: Naval School of Aviation Medicine.

Money, K.E. (1970). Motion Sickness. *Physiological Review*, 50, 1–39.

Nilsson, L. (1993). Behavioural Research in an Advanced Driving Simulator—Experiences of the VTI System. *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*, 612–616.

Powley, R. (1999). Simulation and gaming: A proposed taxonomy and process selection model. Personal correspondence.

Reason, J.T. and Brand, J.J. (1975). *Motion Sickness*. New York: Academic Press.

Reason, J.T. and Diaz, E. (1971). Simulator sickness in passive observers. Report FPRC1310. London: Flying Personnel Research Committee, Ministry of Defense.

Roscoe, S.N. (1981). *Aviation psychology*. Iowa City: University of Iowa Press.

Sanders, A. (1991). Simulation as a tool in the measurement of human performance. *Ergonomics*, 34(8), 995–1025.

Swezey, R.S., Llaneras, R. E., and Rogers, W. (1995). Incidences of simulator sickness in a commercial driving simulator. Personal correspondence.

Watson, G.S. (1998a). Simulator Sickness Adaptation in a High-Fidelity Driving Simulator as a Function of Scenario Intensity and Motion Cueing. Doctoral Thesis Abstract, The University of Iowa, Iowa City, IA.

Watson, G.S. (1998b). The Effectiveness of a Simulator Screening Session to Facilitate Simulator Sickness Adaptation for High-Intensity Driving Scenarios. Presented at the 1998 IMAGE Conference, Scottsdale, AZ.

Watson, G.S. (1995). Simulator Effects in a High Fidelity Driving Simulator as a Function of Visuals and Motion. Paper presented at the Driving Simulation Conference, Sophia Antipois, France.

Guidelines for Acquiring and Using Transit Bus Operator Driving Simulators

Cynthia Jacobs and John F. Brock
Milestone Group
Arlington, VA

GUIDELINES CONTENTS

GUIDELINES FOR ACQUIRING AND USING TRANSIT BUS OPERATOR DRIVING SIMULATORS

SUMMARY

The purpose of these Guidelines is to provide transit agency managers with a tool to help them (1) decide whether their agency should add driving simulation to its training program and (2), if so, what kind of simulation it should acquire. In addition, these Guidelines will provide supporting material that can add to the effectiveness of any simulation selected by a particular transit agency. They also provide a brief history and overview of simulation, particularly driving simulation. The Guidelines are accompanied by a report reviewing the entire research program leading up to this document.

MAJOR FINDINGS

There are currently three primary types of bus driving simulators/trainers in use in U.S. transit agencies: (1) Open-Loop Video, (2) Low-End Simulator, and (3) Mid-Range Simulator. Each has been shown to improve both driver training and safety although some data are based on a very limited number of users. All three devices have strong proponents and detractors. One finding is that each device trains some subset of the skills transit bus operators must have. None trains them all. All three are discussed in detail in the body of the Guidelines.

Transit bus operator simulation works. Simulation enhances learning and often reduces the cost of training. However, simulation is not a panacea. In the site visits and telephone conversations with the various users of transit operator simulators, it was repeatedly stressed that successful implementation of simulation technology required planning, instructional systems integration, and acceptance by the core instructional staff.

The only agency currently using a Level 3 bus operator driving simulator reports significant safety benefits from using the simulator to train beginning drivers. One quarter of all the new drivers were trained using the simulator; 75 percent of the new drivers were trained without the simulator. The accident rate for the simulator trained-drivers over the 90 days after completing the training was 18 percent (i.e., slightly less than one in five had an accident). The accident rate for the drivers conventionally trained was almost 32 percent.

Perhaps more significantly, the tasks specifically trained by the simulator resulted in 17 accidents for the simulator students and 154 for the non-simulator group. These were

tasks related to overtaking and being overtaken by vehicles on the left and right sides of the bus. Another transit agency collected data to compare the number of accidents 20 months before and after undergoing the Level 1 and Level 2 combined simulator training programs. That program was reported to effect a 10 percent reduction in collisions.

CONCLUSIONS AND RECOMMENDATIONS

Any transit agency responsible for training its bus operators should seriously consider using driving simulation as one tool for such training. The Guidelines published herein provide specific criteria for selecting one or more simulators. The data supporting the value of driving simulators, when training is designed and managed with the simulator in mind, are unambiguously positive.

The Guidelines also offer options for smaller transit agencies to gain access to simulator technologies. A short discussion of and argument for regional transit training centers follows the general Guidelines document.

A. INTRODUCTION

1. Purpose

The purpose of these Guidelines is to provide transit agency managers with a tool that can help them decide whether their agency should add driving simulation to its training program and, if so, what kind of simulation should be acquired. In addition, this handbook will provide some supporting material that can add to the effectiveness of any simulator selected by a particular transit agency. It also provides a brief history and overview of simulation, particularly driving simulation.

The research team believes that when simulation is used correctly student performance improves, cost savings are realized, and safety in the domain being simulated is improved. This handbook does not recommend a specific training device or simulator. Rather, it provides readers with background, vocabulary, and data in order to reach an informed decision. Section I of this handbook leads the reader through a series of questions that will lead to a narrowing of simulator options. Table 1 compares the three kinds of simulators available to training transit bus operators. Figure 1 provides a decision aid to assist transit decision makers in the acquisition of simulators.

2. Program Review

In 1999, Milestone Group was awarded a contract to perform TCRP Project A-22, "Evaluation of Simulators as an Effective Tool to Improve Bus Safety and Guidelines for Their Applications." The project was divided into two phases: a data collection and analysis phase (Phase I) and a results phase (Phase II). From this second phase, it was anticipated that a set of Guidelines would develop that would assist transit agency officials in determining if they should procure or use simulators and associated advanced technology training tools. This document provides those Guidelines. The project also produced a Final Report describing the overall effort.

3. Literature Review

The body of scientific and technical literature on simulators and their use for training dates back to at least the early 1950s. The literature can be broadly characterized as falling into four main areas: (1) descriptions of simulators, or simulator components, their characteristics, and how they are being used; (2) advice on what characteristics are required in a simulator; (3) results of research on the effects of simulator characteristics on performance; and (4) results of research on the effects of simulator characteristics on training.

The vast amount of this literature is in the context of flight simulators, because aviation has been the predominant use of simulators for the past 60 years. Within this body of literature, the smallest segment has been research on how certain simulator characteristics affect the rate of learning and proficiency. However, over an accumulated history of the study of these devices, there is evidence that training simulators, particularly flight simulators, are effective training tools. Specifically, it is believed that time spent in the simulator trades off for some amount of training time using actual equipment.

4. Site Visits and Surveys

There are currently three primary types of bus driving simulators/trainers in use in U.S. transit agencies: (1) Open-Loop Video, (2) Low-End Simulator, and (3) Mid-Range Simulator. Each has been shown to improve both driver training and safety although some data are based on a very limited number of users. All three devices have strong proponents and detractors. Nevertheless, although each device trains some subset of the skills transit bus operators must have, none trains them all.

The research team members who visited transit agency training facilities were uniformly impressed with both the competence and enthusiasm of all the training staffs. Transit agency users of the devices listed above are sophisticated training specialists who understand both the limitations and the strengths of these devices. Without exception, the team found carefully planned curricula, training that integrated the various simulators into the overall training program, and a realistic appraisal of the benefits and limitations of those simulators.

It was obvious during the research team visits that driving simulators appeal to both current and future users. Therefore, it is the authors' belief that driving simulators in transit agency bus operator training are inevitable. One goal of this research project is to ensure that transit agencies get maximum effectiveness and efficiency from the acquisition and use of those simulators.

The team did not find staff or trainees who felt that the limitations of the various simulator configurations kept the simulators from meeting the instructional objectives of the training; rather all felt that the simulators contributed to the learning process. With one exception, trainers who used the simulators reported cost savings from using the devices.

Finally, it was also observed that a critical feature in the success of these training programs is the competence and enthusiasm of the instructional staff. The simulators provide an opportunity for instructors and students to work closely together in the learning experience. Although not part of the engineering design of a simulator, it is a feature of the simulation experience that cannot be ignored.

5. Simulator Uses

The research team visited most transit agencies with simulators and found differences among the various devices in their use. Specifically, although all the simulators are used to

TABLE 1 Operational capabilities matrix

	Open Loop	Low-End Simulation	Mid-Range Simulation
Throughput/Session	8	1	1
Simulated Vehicle Environment	✓	✓	✓
Interactivity		✓	✓
High Task Fidelity			✓
Model Terrain Board		✓	
Realistic Audio/Visual Systems			✓
Instructor Console	✓		✓
Realistic Gauges and Instruments	✓	✓	✓
Performance Measurement Tools	✓	✓	✓
Full Visual Replication of Driving Scene			✓
Fully Functional Traffic Signals			✓
Virtual driving world encompassing 50 square miles			✓
Intelligent Traffic			✓
Real Mirrors			✓
Skill-based Training	✓	✓	✓
Rule-based Training		✓	✓
Knowledge-based Training			✓

train new drivers, many are also used to re-train more experienced drivers. In at least one case, a simulator is used to train drivers other than bus operators.

As stated above, every transit agency the team visited uses its simulator(s) to train new drivers. There are some variations among the various agencies on how much time each student spends inside the simulator configurations. This is partly the result of the judgment of individual training managers and partly the result of the scheduling problems attached to having training devices that can only train one student at a time. All agencies with simulators report that new drivers can be taught the fundamentals of bus operation in the simulators. Those fundamentals will change depending upon the simulator being used.

Almost all of the visited agency training personnel reported that the use of simulation has decreased drop-out rates from

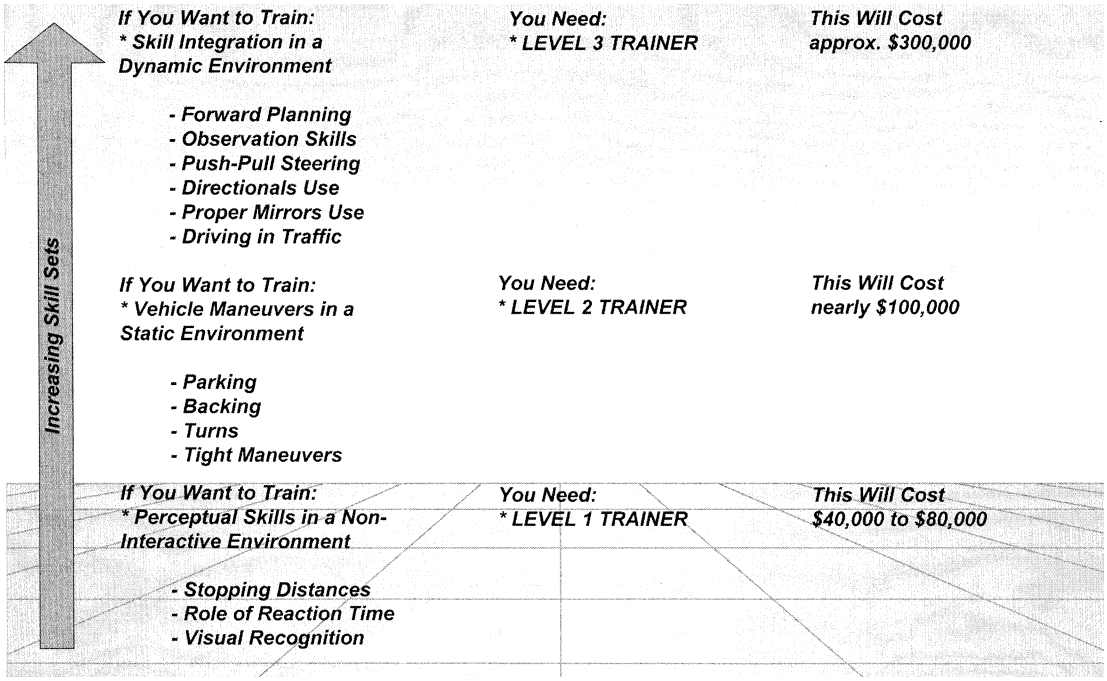

Figure 1. Which simulator?

the training program. Specific data supporting the use of bus operator driving simulators will be presented when each type of simulator is discussed below. One agency training manager stated that they can send trainees to commercial drivers license (CDL) testing much sooner in a training program that uses a simulator. If the trainees do not pass the testing, management could provide more testing or disqualify the person. Without simulators, more training time/cost is invested before license testing could be imposed.

At least two of the agencies that were visited provide training for other transit agency bus operators, thus creating revenue *into* the training organization. One training group within a visited transit agency even provides driver training to emergency and police personnel, as well as to other transit agency bus operators.

Advantages

All but one of the visited transit agencies reported improved effectiveness of training. The training managers believed that the simulators are able to replace some of the time spent in actual buses rather than replacing classroom time. From their point of view, this is a more productive effort than having students ride around in a bus. They liked the one-on-one training opportunities provided by the single-seat systems. Conversely, the multi-station system is seen as freeing up instructors.

One long-time user of bus operator simulation reported that simulation engages the trainees, which then increases their desire to participate in the training. Trainees reported greater confidence and increased awareness of reaction time requirements; they also provided positive testimonials on how real the simulation appears.

Disadvantages

Each of the simulators brought unique problems as well as unique benefits to the visited transit agency training programs. Ironically, the two major complaints identify the two fundamental problems that are associated with the simulators. In the case of the multi-station system, students and some instructors complained about the lack of interaction between what the student did in his or her learning station and what occurred in the visual scene. Regarding the single-seat systems, the complaints were that only one student at a time could use the device.

6. Recommendations of the Research Study

There were two specific recommendations stemming from this research. One was to develop guidelines for transit agencies deciding whether to use driving simulation. The second was to develop an approach to curriculum development that exploits the full power of driving simulation. These Guidelines are the direct result of these recommendations.

7. Conclusions of the Research Study

1. Transit bus operator simulation works. Simulation enhances learning and often reduces the cost of training. However, it is not a panacea. In the site visits and telephone conversations with the various users of transit operator simulators, it was repeatedly stressed that successful implementation of simulation technology required planning, instructional systems integration, and acceptance by the core instructional staff.
2. All three of the transit bus operator simulators the research team studied meet the needs of the using agencies. Both students and trainers expressed satisfaction with the various devices. Specific conclusions regarding each are as follows:
   a. *Open-Loop Video.* The obvious advantage of this system is that it can accommodate multiple users. It is also the least expensive of the three systems. Its primary disadvantage is that it is not a human-in-the-loop simulation. Students cannot effect changes in the visual scene. This presents a risk of negative transfer to operating an actual bus, although there are no data to suggest that this is happening.
   b. *Low-End Simulator.* This device replicates the visual, auditory, and vibratory effects of driving a bus in an urban, crowded environment. Students and trainers are convinced that driving this device gets new operators into buses more quickly and that they are safer drivers. Two disadvantages to this device are that only one student at a time can use it and it is limited to a small, albeit visually rich, driving environment. Users of this system turn the one-user limitation to their advantage by pairing an instructor with the student for a one-on-one training experience.
   c. *Mid-Range Simulator.* This is the newest type of simulator for the transit community and only one is currently in use. The major advantages of this simulator are its realistic visual and audio systems and, most importantly, its use of rear projection so that the driver of the system can adjust his or her mirrors and still receive full visual replication of the driving experience. It has the same disadvantage as any single-seat system: only one person at a time can drive it. Once again, the agency using this system is taking advantage of that limitation to conduct intensive, one-on-one training.
3. A Guidebook is needed. Transit agencies lack the tools to optimize their uses of bus operator simulators. Current users will be able to contribute to the Guidebook, but sources beyond the transit community will also have input. The Guidebook is for use by those persons who,

on a daily basis, accept the responsibility for training transit bus operators.

4. Although there is not a generally recognized process for integrating operator simulators into the current transit training programs, several agencies have done this successfully through unique dedication and hard work. Such a process is needed.

B. KEY TERMS AND ASSUMPTIONS

1. Overview

Simulators are devices that replicate, either functionally and/or physically, real-world systems that are operated by one or more people. Some simulators represent only a limited range of functions (part-task), while others are a comprehensive representation of an entire system (whole-task). Simulators of aircraft, ships, ground vehicles, command centers, and power plants are common. Such simulators are used principally in engineering design, test and evaluation, and training applications (Jones et al., 1985). Training is by far the most frequent application as simulators are widely used in instances where real-world errors would be too costly or dangerous.

The origin of simulators goes back to at least the nineteenth century when a streetcar simulator was used to teach young women the proper way to board and alight from the car. Additionally, crude, wooden simulators were used sporadically during WW I for aviation training. WW II, however, heralded the introduction of the famous "Blue Box" instrument flight trainer developed by Edwin A. Link. This ground-based flight trainer made it possible to train large numbers of pilots safely and efficiently. From that period onward, aviation training (both civilian and military) has remained the preeminent use of simulators. There are two main reasons for the historical dominance of aviation simulation. First, the cost of operating a flight simulator is far less than that of an actual aircraft (especially for large, commercial aircraft). Second, hazardous procedures and maneuvers can be practiced safely in a simulator. For example, engine failure on take-off cannot be practiced safely in a real aircraft.

2. Simulators as Training Devices

In addition to cost and safety, there are other reasons why simulators are attractive for training. The real world, for example is not the most efficient training environment, whereas simulated training environments can be completely controlled to be appropriate for the tasks being taught. Location, time of day, weather, and the behavior of other agents in the environment can all be controlled to achieve training objectives. Additionally, a simulator can include augmentations to facilitate learning that are not possible in reality such as highlighting salient objects or marking a path. As compared to real-world times, returning to an initial condition to repeat a task in a simulation is far more expeditious. In fact, re-setting to a desired start condition is nearly instantaneous in a simulator. Lastly, training can be accomplished for a system that is not available for training—training astronauts to land the Space Shuttle is an example.

C. BUS SIMULATION TRAINING DEVICES—HIGH-LEVEL CATEGORIZATION

All simulators are not created equal. They vary in a number of characteristics ranging from fidelity (the level at which the system task replicates the real-world task) to interactivity (the level at which the system reacts/responds to user inputs) to throughput (the number of users that may access the system at any given time). Table 2 describes the high-level categorization of ground simulation training devices. This level of categorization reflects the technology that is available regardless of modality and without regard to whether or not the technology is actually being used in the transit industry.

Although all these device categories are available for transit training purposes, only three categories (3, 5, and 6) in particular appear to be used with any frequency. Figure 2 shows both the High-Level Simulator Categories and the point where current transit simulators fit on that continuum. A detailed discussion of these device categories follows in the next section.

D. BUS SIMULATION TRAINING DEVICES—LOW-LEVEL CATEGORIZATION

There are currently three methods for bus driving simulation/training delivery in use in U.S. transit agencies. These delivery systems are categorized below. These levels of categorization reflect technologies that are currently in use by the transit agencies. These simulators differ in terms of their technologies and also in terms of the various operator tasks they are designed to train.

Level 1: Open-Loop Video

The most popular method of driver training delivery in use in transit agencies is a device that uses Open-Loop Video to display traffic and other instructional information. It consists of several student stations, each with a steering wheel, gas and brake pedals, and a rudimentary dashboard. This device is characterized as an "open-loop" system because it is non-interactive. Although each station is equipped with a steering wheel, gas pedal, and brake pedal, the student's engagement of any of these controls will not produce any appreciable effect on the video display.

The system, as designed, trains and tests very specific bus operator activities (e.g., reaction time and visual recognition). Stopping distances, road conditions, the relationship of speed to both, and the role of reaction time can be shown and

TABLE 2 High-level simulator categories

Category 1 - Desktop. Refers to driving scenarios presented on standard personal computer. The user interacts with the program with his or her mouse or keyboard and the program responds accordingly.

Category 2 - Video game with driving interface. These programs run on personal computers, game systems, or special-purpose, low-cost computer systems. The display is either a desktop monitor or a television set. The user interacts with the program by using a steering wheel and/or pedals.

Category 3 - Group presentation. Several students sit in mock-ups of the vehicle being trained and view a movie or videotape of an out-of-windshield driving scene. Nothing the student does can have any influence over the presented scene. However, his or her reactions with the steering wheel, accelerator, and brake can be recorded for later review.

Category 4 - Graphics based. This system presents a wide-screen display to a single-student sitting in a replication of the vehicle being simulated. As the student turns, brakes, or accelerates, the scene changes in reaction. Some realistic feedback will be in the steering wheel and the clutch, accelerator, and brake. Most of these systems also provide realistic sound effects.

Category 5 - Terrain modeling board. This system is used for training driving in restricted areas (urban streets, tight corners, backing). The student sits in a replica of a particular vehicle and views a scene that is generated by a 1/16th-scale model bus and model board that is slaved to the student's device. As he or she turns, the miniature bus actually turns on the model board and transmits a picture from a small camera mounted on the front of the model to the projector displaying the view to the student. Because the model board is static, pedestrians and other traffic cannot be presented to the student.

Category 6 - Advanced graphics based. Essentially an improved version of Category 4, these systems have graphics that can replicate numerous weather, road, and traffic conditions. Side mirror images are fully replicated and, if the vehicle being simulated has inside rear view mirrors, it will be simulated with realistic images as well.

Category 7 - Motion based. These represent the most advanced driving simulators currently available. They have all the traits of the Category 6 systems plus a full motion base that can replicate road characteristics, vehicle dynamics, tire tread, and general handling characteristics of numerous vehicles.

then practiced. Because the instructor station for the system measures performance in each learning station, the instructors can monitor and identify students who are not correctly responding as the scenarios play out. The system effectively demonstrates the way a large transit bus behaves under varying conditions as well as how the student should operate such a large vehicle. This system corresponds to Category 3 in the High-Level Categorization.

Level 2: Low-End Simulator

The second method of driver training delivery is a model-board system. In this Low-End Simulation, a miniature camera is installed in a small model of a bus that physically moves about on a small terrain board in an adjoining room. This system replicates the visual, auditory, and vibratory effects of driving a bus in an urban, crowded environment in order to train student operators to maneuver a transit bus in relatively tight and unforgiving situations. The system demonstrates basic maneuvering of transit buses in typical urban areas. Skills such as approaching a bus stop, parking, tight turns, and backing can be taught to a single student without risk of damage to an actual bus or to platforms, other vehicles, or pedestrians. This system corresponds to Category 5 in the High-Level Categorization.

Level 3: Mid-Range Simulator

The third driver training delivery method is a Mid-Range Simulator that uses realistic audio and video; including rear projection, to deliver a fuller replication of the driving experience. A larger field-of-view (FOV), on the order of 180 deg forward, a vertical FOV of at least 45 deg and 60 deg to the rear, distinguishes this simulator from the Low-End Simulator described above. Additionally, a more sophisticated vehicle model is provided, along with more complex environmental effects (weather, day-night, and road friction), and motion cues to replicate the look and feel of the outside world as seen by a driver looking out of the windows of a bus cabin.

One of the very strong features of this device is the fact that the mirrors in the simulated cab are actual mirrors; they can be physically manipulated to reflect the imagery that is projected behind the simulator cab. The visual imagery for this system was developed for the specific driving environment of the transit buses for which the operators are being trained. Therefore, the device provides high fidelity simulation of actual driving situations that trainees are likely to encounter

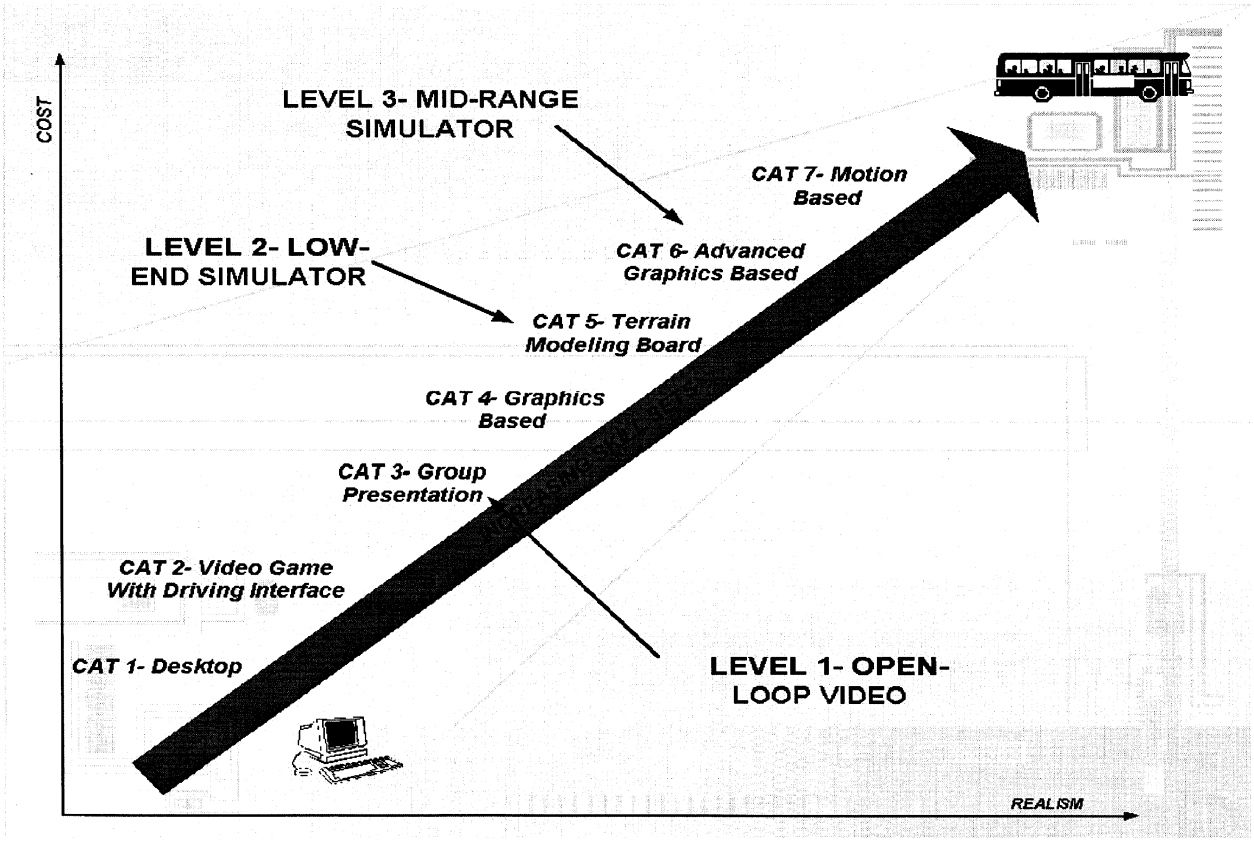

Figure 2. High-level simulator categorization.

upon completion of the training program. This system corresponds to Category 6 in the High-Level Categorization.

Although all three devices discussed above train some subset of the skills transit bus operators must have, none trains them all. The Agency Training Specialist who is responsible for selecting among these devices should understand both the limitations and strengths of the devices. This guidebook is designed to highlight the operational capabilities of each device as well as point out the tradeoffs that are associated with a particular device's selection.

E. DRIVING AS DECISION MAKING

It would be difficult and perhaps inappropriate to make direct comparisons among the three delivery systems as they all offer different features and operate on radically different platforms. However, it would be appropriate to compare them in terms of how they approach the specific behavior that they are trying to shape; namely, decision making while driving. The following discussion lays the groundwork for viewing driving as a decision-making task. A detailed discussion of how each of the three delivery systems approaches the decision-making task will then follow.

The traditional decision-making task involves a decision maker selecting among a number of choices or courses of action. The selection is based on information or cues that are presented in an environment that is filled with uncertainty. Additionally, the selection usually occurs after a relatively long period of consideration—on the order of a second or more. For example, the selection and purchase of a new bus driver training delivery system qualifies as a decision-making task. Purchasing a new bus driver training delivery system is a task that is representative of knowledge-based behavior as defined by Rasmussen (1986) in his model of decision making. According to this model, knowledge-based behavior is distinguished from rule-based and skill-based behaviors, all of which fall on some point along a decision-making continuum.

Knowledge-based decision making is complex decision-making. It often requires the use of algorithms and other methods to facilitate the selection. Again, the purchase and selection of a new bus driver training delivery system qualifies as a knowledge-based decision-making task as a number of variables such as cost/per student, throughput, and availability will be used in the determination along with heuristics (shortcuts) such as "only trainers that cost A." Rule-based decision making falls somewhere in the middle and is characterized as decision making wherein the decision maker uses existing rules and matches them to current conditions to make a selection. Rule-based behavior tends to employ the following logic: "If X, then Y." A good example of rule-based behavior would be a bus driver pulling up to a curb;

specific procedures must be followed in that instance, separate and different from the procedures that would be required while backing, for instance. Finally, skill-based behaviors are well learned, almost reactive responses to conditions in the environment. To illustrate this, think of the bus driver who slams on the brakes when another vehicle unexpectedly enters the drive path.

From the above, it becomes easy to view driving as a decision-making task that may, depending on the specific subtask (trip planning and route selection, driving in bad weather, and collision avoidance) represent knowledge-, rule-, and skill-based behaviors.

F. PART TASK SIMULATION/TRAINING

Sometimes, perhaps most often, a device or technique will be designed to teach part of a larger task. Driving is a complex task that may be decomposed into several subtasks (i.e., trip planning and route selection, driving in bad weather, visual search as in finding street names while reading directions, navigation, steering, and collision avoidance). Training all aspects of the driving task may be an unrealistic goal for any one training device or technique, especially if the device or technique involves simulation. Simulators, as a rule, increase in cost as they increase in fidelity (level of realism to the task). As an alternative, simulators may opt to simulate part of the task instead of the whole task, as whole-task simulators tend to be extremely costly to develop.

As stated earlier, all three delivery systems are part-task trainers, as each only trains a subset of the skills that transit bus operators must have. In the case of the Level 1 system, basic, perceptual, and reaction skills are trained. The Level 2 system builds upon the Level 1 skill set to include interactive training of vehicle maneuvers. Finally, the Level 3 system provides training in more advanced skills such as emergency maneuvers and maneuvering in bad weather in addition to basic, perceptual, and reaction skills.

G. TRAINING APPROACHES DEFINED

Following is a discussion of how each of the three delivery systems attempts to shape driving behavior. It must be noted that, while all the systems described herein contain many capabilities and features, only those capabilities and features that are actually being used in transit training curriculums across the country will be included in this discussion.

1. Level 1 Training Approach

The Level 1 Trainer is used primarily to train the more skill-based aspects of the driving task. It focuses specifically on the enhancement of the sensory and perceptual skills of the trainee. The system uses wide-screen video to depict a rich, although static, replication of various driving scenes. The trainee, stationed at a mock-up of a traditional bus cab environment, views the driving scenes and reacts to elements within those scenes. An instructor, seated at a separate instructor console, monitor's the trainee's performance with the use of computerized performance tracking equipment.

The trainee's reaction times are measured and recorded through an automated performance-tracking system that is monitored by the instructor, allowing for immediate performance feedback. Through repeated interactions with the system and across the various scenarios, the trainee is drilled and, therefore, gains practice using his or her sensory and perceptual skills to locate and respond to potential hazards in the driving scene. As driving is a highly visual task, as well an unpredictable and potentially dangerous one, finely honed sensory and perceptual skills are invaluable to the driver.

2. Level 2 Training Approach

The Level 2 Trainer is used most often to train the rule-based aspects of the driving task. It focuses on training the specific vehicle maneuvers that would be necessary to qualify for the commercial driver's license and certification. With this system, a trainee sits in a mock-up of a bus cab. In another room, a miniature camera is installed in a $^{1}/_{16}$-scale model of a bus that moves about on a terrain board. As the trainee steers the steering wheel in the mock up, the bus model responds by moving about on the terrain board.

With this system, the trainee is able to gain practice in basic maneuvers such as stops, turns, backing, and pulling to and away from a curb. This system's approach is regarded as rule-based because the maneuvers that are learned require specific procedures, or rules, in order to be properly executed. For example, the steps or rules involved in backing are different than those involved in turning a vehicle. Although primarily a rule-based trainer, skill-based learning does occur as the trainee is drilled and obtains practice in the basic maneuvers. In this case, the improvement in decision-making performance comes from the acquisition of well-learned rules and procedures that the trainee can execute whenever the appropriate circumstances arise. The more rules a trainee acquires during the training session, the better his or her performance is expected to be on the job.

3. Level 3 Training Approach

The Level 3 Trainer is truly an all-purpose trainer. It provides training experiences in all aspects of the driving task. As a fully interactive, high-fidelity simulator, the Level 3 Trainer can be used to hone sensory and perceptual skills, teach procedures for vehicle steering/maneuvering, and improve the forward planning ability of the trainee. The system combines realistic audio and video (including rear projection) to deliver a rich replication of the driving experience. The trainee sits in a simulated bus cab and interacts with the

driving scenes that are projected onto a panoramic screen. Additionally, intelligent traffic within the driving scenes allows for spontaneous interactions with the trainee's vehicle.

The rich visual display, along with the dynamic characteristics (i.e., intelligent traffic and complex environmental/conditional factors such as extreme weather and tire blowouts) of the driving task itself, continually shape the perceptual and sensory skills of the trainee. The content-rich nature of the virtual driving world forces the trainee to engage in visual search much as in the real world. In order to facilitate visual search, trainees are instructed on the proper set-up and use of mirrors. The system is ideally equipped for this kind of training as the mirrors in the simulator provide dynamic information that changes depending upon how the trainee's head is positioned in the cab. Improvements in performance are essentially skill-based as they are achieved through practice. The more practice the trainee has with searching the environment, the better he or she becomes at locating and responding to potential hazards. Better visual search results in a decrease in reaction times.

Rule-based learning is acquired during training opportunities wherein the trainee is required to steer or maneuver the vehicle in some way. Specifically, the system can be used to teach the trainee how to pull up to a bus stop, make left and right turns, and load and unload passengers, along with a host of other skills. All these skills require the execution of specific procedures, or rules, in order to be carried out successfully. As with the Level 2 Trainer, performance improvement comes from the acquisition of well-learned rules and procedures that the trainee can execute whenever the appropriate circumstances arise. The more rules a trainee acquires during the training session, the better his or her performance is expected to be on the job.

Finally, knowledge-based learning is obtained through the instructional emphasis that is placed on forward planning and observational skills. As the trainee is encouraged and trained in the use of mirrors, he or she becomes more efficient at visual search. The trainee experiences this efficiency as an improvement in his or her ability to scan the scene and not only locate and respond to potential hazards, but to avoid them altogether. By being able to "read the road" the trainee is able to be proactive and plan his or her drive path well in advance, staying clear of obstacles and other hazards. With repeated practice, the trainee's observation skills are further developed. Performance improvement, in this case, comes from the knowledge of knowing when and where to look.

4. Summary of the Approaches

Although each of the three trainers described above are categorized according to one of the aspects of Rasmussen's decision-making continuum, it is important to note that, as a continuum, these aspects are not mutually exclusive. There is some overlap, for example, with the skills trained in the Level 1 and Level 2 trainers. Specifically, both skill- and rule-based may occur in the Level 2 Trainer. Similarly, the Level 3 Trainer incorporates all the training opportunities found in the other two trainers. Additionally, it should be noted that the purchase of one trainer, does not preclude the purchase of the others. They can be used in conjunction as part of a comprehensive training program. Figure 3 describes the overlapping nature of the training opportunities associated with each of the three delivery systems. The range of costs for each kind of system is also included.

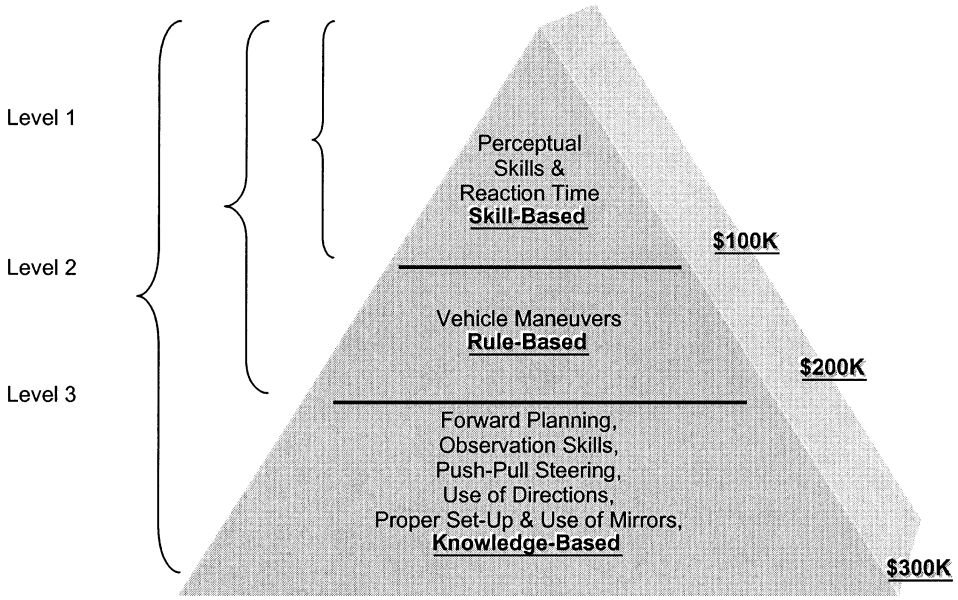

Figure 3. Levels 1 through 3 training opportunities.

H. TAXONOMY OF OPERATIONAL CAPABILITIES

Below is a brief summary of the operational capabilities and features associated with each of the trainers.

Level 1 Operational Capabilities

- Multiple training stations to accommodate up to eight trainees simultaneously
- Simulated vehicle environment (bus controls, instruments, and seating)
- Wide-screen views of various driving scenarios
- Instructor monitoring of individual student responses from an instructor console
- Data management to record student reaction times and other data as students react to the various driving scenarios
- Feedback loop to the instructor at the end of each driving session, allowing the instructor to evaluate each student's performance
- Touch screen displays for selecting functions and activities at each training station
- Microprocessors in each station for fast scoring of student performance
- Functional gauges, headphones, comfortable bucket seats, and retractable safety restraints
- An array of available training scenarios
- Acquisition costs area functions of the number of student driving stations

Level 2 Operational Capabilities

- A mockup of a driving console resembling a flexible bus
- Replicated real-world driving environment through the use of a $^1/_{16}$-scale model of an urban driving course (network of streets and buildings)
- Images communicated to the window of the student's driving console through the use of computer software and video cameras attached to a $^1/_{16}$-scale model bus
- Interactive environment (i.e., the miniature bus reacts and the scene changes in response to the student's activities in the simulated bus)
- Seat-based feedback in the specific instance of maneuvering over a bump

Level 3 Operational Capabilities

- High-fidelity transit bus vehicle simulation
- An entire complement of instruments and gauges, all the appropriate safety items, as well as typical steering, pedal, and gearshift equipment
- State-of-the-art audio and visual elements to deliver a rich replication of the driving experience
- Roads, highways, markings, and traffic control devices designed in accordance with state and federal guidelines
- Fully functional traffic signals
- Simulated bus kneeling, interlock, stale green signal awareness, and reaction to random door openings on parked cars in the visual scene
- A virtual world encompassing 50 sq mi through which a student can drive
- Off-road and geographically specific driving areas through the use of the CGI-based scenarios
- Complex environmental effects such as weather, day/night, or road friction
- Situational factors such as tire blowouts, drops in brake pressure, and other malfunctions
- Intelligence to allow spontaneous interactions with the trainee's vehicle
- Instructor regulation of other traffic flow

Table 1 also provides a matrix summarizing the capabilities and features described above.

I. IS SIMULATION FOR YOUR TRANSIT AGENCY?

1. Transit Agency Training Program

Bus operator driving simulators are used to train specific kinds of tasks, as previously described. If a transit agency does not train its own drivers, it is highly unlikely that it would see benefits from acquiring a driving simulator. However, if an agency does provide training for its bus operators, there are a series of questions that it must answer to determine if a simulator is in its future.

There are two primary questions that each transit agency must answer for itself : (1) What do we want to train with our simulator? and (2) Can we afford a simulator? The previous discussions and tables provide descriptions of driver performance tasks that can be trained by each of the simulators. Training designers for each transit agency must determine, in advance, which tasks the potential simulator should train.

As part of the research study, instructors and training managers of all agencies currently using bus operator simulators were asked if they were satisfied with the training simulator; 92 percent of respondents from all locations reported a high level of satisfaction with their training simulator. Only one respondent expressed concern regarding the sickness associated with the use of the training simulator.

Trainers positively rated bus simulator training in the areas of effectiveness in training first-time drivers and utility in the overall training curriculum. When asked if the simulator is more effective than traditional training for teaching certain types of knowledge, skills, or attitudes, 58 percent of respondents reported that the simulator is more effective than traditional training methods.

When asked what role simulator training plays in the overall bus operator curriculum, respondents in all locations reported that bus simulators reinforce the concepts taught in the classroom. Most trainers feel that simulator training validates defensive driving techniques taught in the classroom. All respondents believe that the simulator training provides an excellent opportunity to experience a hazardous situation without actually being in a hazardous situation.

When asked about the disadvantages of bus simulator training, respondents believed that there are two main disadvantages of bus simulator training: (1) trainees do not feel that the simulator is realistic enough (one respondent expressed concern that the training simulator does not represent the actual "feeling" of driving a bus) and (2) simulator sickness.

When asked about the advantages of bus simulator training, a consistent response across all locations was that bus simulator training reproduces a life-like driving experience without the risks or cost of training in an actual bus. Most respondents reported that trainees with little or no experience are better prepared for their initial driving assignment after completion of simulation training.

Drivers who had used simulators during their training were asked what they liked best about bus simulator training. Most indicated that bus simulator training helped them prepare for their jobs. In addition, they indicated that the training experience made them more effective as drivers. Nearly 75 percent of all drivers reported that bus simulator training did enhance their learning experience. When asked what they disliked about bus simulator training, six respondents reported motion sickness, dizziness, and disorientation after bus simulator training.

Simulator sickness is a potential side effect to driving simulation that arises from a visual-vestibular conflict induced by the apparent motion in the simulator. The Final Report has a detailed discussion of simulator sickness and approaches to ameliorating its effects. Table 3 provides an overview of approaches that may be implemented to combat simulator sickness in trainees. The point is that although simulator sickness can be a problem, users of driving simulators can dampen its effect on learning.

2. Cost of Simulators

Acquisition Cost

The cost to purchase the simulators discussed herein range from $50,000 to $300,000. The increase in cost tracks directly with the increase in technology and capability. Each agency must compute its own cost per student. Obviously, an agency training 600 drivers a year has a lower cost per student than an agency training 100 students. The next section of the Guidelines describes the benefits associated with the simulators and each agency will have to do its own cost/benefit analysis. The possibility of cost sharing among multiple agencies is also discussed.

Acquisition cost may also include any tailoring the vendor does for the purchasing agency. Off-the-shelf (OTS) systems will be less expensive but may also lack key ingredients for a particular transit agency's driving environment (e.g., Los Angeles and New York transit buses operate in significantly different kinds of street conditions and building sizes). The

TABLE 3 Simulator sickness prevention strategies

Before	During	After
Know the symptoms and screen for them	Avoid overuse of complex driving scenarios (turns, grade changes, curves, etc.)	Look for symptoms that may occur during the debrief session
Identify vulnerable trainees	Minimize substantial changes in orientation, especially when the visual scene is on	Do not allow a trainee who is displaying symptoms to leave until he or she has recovered
	Minimize the use of high speeds	
	Incorporate breaks and time-outs	
	Report symptoms immediately	
	Remove an affected trainee from the simulator immediately upon displaying symptoms	
	Allow for adaptation to occur	
	Limit the maximum duration of the session to 50 min	

reason the first step in any simulator procurement is to determine what is to be trained is to ensure that the simulator meets the specific needs of the procuring agency.

Another consideration in any simulator acquisition is the number of units that will be needed. For a multi-station device, an agency can have as few as six student stations or as many as 20 stations. Obviously, the cost will increase with the number of student stations. The purchase of more than one simulator of any kind is always an option. Individual transit agencies will need to evaluate how many devices are needed. One large agency has acquired four mid-level simulators to meet its training needs.

Facility Costs

All of the simulators evaluated for this study require significant facility space for their installations. These costs are not trivial; space is expensive. Before the acquisition is completed, the acquiring agency must ensure that all power requirements of the devices can be met, that access to the simulator and its control station will be unimpeded, and that adequate cooling and heating systems are in place. Buyers should be prepared for facility costs that may approach the cost of the simulator itself. All three current transit simulators occupy significant real estate. A typical classroom for 12 or 15 students would *not* accommodate any of the three systems. This is a recurring cost that any procurement process must anticipate.

Life-Cycle Costs

There are personnel, maintenance, and real estate costs associated with simulator support. Vendors will offer various support packages that must be negotiated. But as the research study found, an in-house instructor advocate who kept the system running, the students enthusiastic, and management pleased, can go a long way toward ensuring a successful simulation program. The training of these personnel is a cost ignored at an agency's risk. The agency acquiring a simulator must also negotiate with the vendor for maintenance, spare parts, and software upgrades.

Instructional Design Costs

The least effective use of any simulator is to just insert it into a current training program. Therefore, current training programs will have to be redesigned to exploit the instructional power of the simulators. The key to the success of this design effort is to ensure that as each student enters the simulator he or she has had all the training necessary to take full advantage of the simulator experience. Concerns have been raised about the use of simulators. The best way to maximize use of any of the three simulators is to integrate them fully into a program designed around the simulation capability.

Note: As of the writing of these guidelines, there are no obsolete transit bus operator simulators currently installed at transit agency training facilities. That is to say, all three simulators represent state-of-the-art, OTS technologies. They differ in two respects: the kind of technology each uses and the set of driving tasks they train. However, there is no suggestion in our findings that a transit agency should discard a current system if it were to acquire a newer, different system. In fact, because the various simulators train different driving skill sets, they could all be used in an integrated transit bus operator training curriculum.

3. Cost Savings from Using Simulators

Almost all of the training personnel at the visited agencies reported that the use of simulation has decreased drop out rates from the training program. The user of the most advanced simulator reported a 35 percent reduction in attrition rate compared to students in a conventional course. In one heavy user of both the Level 1 and Level 2 systems, the training manager reported a 95 percent pass rate.

Several agencies reported reduced training time by replacing bus training with simulator-based training. One agency reduced training time from 19 days to 17 days. Another agency, using just the Level 1 system, was able to reduce its training program by five full days. Another agency, with the same simulator system, reported no cost savings in the training process at all.

One agency training manager stated that trainees could be sent to CDL testing much sooner in a training program that uses a simulator. If the trainees do not pass the testing, management could provide more testing or disqualify the person. Without simulators, more training time/cost is invested before license testing could be imposed.

At least two of the agencies visited provide training for other transit agency bus operators, thus creating revenue *into* the training organization. One training group within a visited transit agency even provides driver training to emergency and police personnel, as well as to other transit agency bus operators.

4. Safety Benefits from Using Simulators

The only agency currently using a Level 3 bus operator driving simulator reports significant safety benefits from using the simulator to train beginning drivers. One-quarter of all the new drivers were trained using the simulator; 75 percent of the new drivers were trained without the simulator. The accident rate for the simulator-trained drivers over the 90 days after completing the training was 18 percent (i.e., slightly less than one in five had an accident). The accident rate for the drivers conventionally trained was almost 32 percent.

Perhaps more significantly, the tasks specifically trained by the simulator resulted in 17 accidents for the simulator students and 154 for the non-simulator group. These were tasks related to overtaking and being overtaken by vehicles on the left and right sides of the bus. Another transit agency collected data to compare the number of accidents 20 months before and after undergoing the Level 1 and Level 2 combined simulator training programs. That program was reported to effect a 10 percent reduction in collisions.

5. Side-By-Side Comparisons

Table 4 provides a summary of the advantages and disadvantages of the three, bus operator, driving simulators. (See Figure 1 for a decision aid for transit managers who need to determine which simulator to acquire.) Sections 6 and 7 of these Guidelines will provide a model of how an agency might use these simulators.

6. A Hypothetical Model Transit Training Program Using All Available Technologies

In a perfect (and resource-rich) world, a transit agency's training program could use all three of the simulators described above. Certainly, the use of any one of the three does not preclude the use of either of the other two. One could use the multi-station Level 1 simulator to evaluate the reaction and steering capabilities of each student. The Level 2

TABLE 4 Comparisons of the three bus operator simulators

TYPE OF SIMULATOR	ADVANTAGES	DISADVANTAGES
Level 1	Accommodates Multiple Users Per Session	Open-Loop System (non-interactive)
	Inexpensive To Acquire	Does Not Provide Opportunity to Simulate Student Performance
	Frees Up Instructors	Canned Scenarios
	Potential To Reduce Driver Reaction Times	Students Have Different Views of the Screen (Parallax Problem)
	Potential To Decrease Student Drop Out Rates	Requires Special Training For Agency Instructor
	Provides Automatic Performance Measurement Tools	
	Reduces Training Time	
Level 2	Potential For Quick Return On Capital Expenditure	Accommodates A Single User Per Session
	Provides For A One-On-One Training Experience	More Costly to Acquire than The Level 1 System
	Interactive Simulation	Performance Measurement Is Not Automated
	Potential To Reduce Training Time	No Dynamic Traffic or Pedestrians
	Potential To Decrease Student Drop Out Rates	
	Potential To Reduce Collision Rates	
Level 3	Realistic Audio And Visual Systems	Accommodates A Single User Per Session
	Provides Full Visual Replication Through The Use Of Rear Projection	Most Expensive To Acquire
	Provides For A One-On-One Training Experience	Some Students Have Problems With Simulator Sickness
	Potential To Reduce Student Drop Out Rates	Agency Instructors Must Be Trained to Use
	Potential To Reduce Collision Rates	
	Provides Automatic Performance Measurement Tools	
	Data Supports Accident Reduction Capability	

simulator could be used for parking, backing, and tight maneuvering training. Finally, the Level 3 simulator would serve as the most challenging simulation drive before the student would drive an actual bus.

The advantage of such a system would be the automatic performance measurement in the Level 1 and Level 3 devices, the elimination of accidents in the Level 2 and 3 learning experiences, and the ability to shape the driving performance of each student under tight control in Level 2 and 3 devices. The disadvantage of such a system would be the management of a group of students leaving a multi-seat training environment (both the Level 1 device and the classroom) and entering a single-seat simulator.

The point to make is that the three simulators are not mutually exclusive. Each, as shown in Table 4, has its strong and weak points. Each trains or measures some specific aspects of driving performance. An agency acquiring a simulator must first decide what that simulator is to do. Only then can an effective program be developed and the right simulator be acquired.

7. How to Maximize Simulator Use

As with any advanced technology, a simulator represents a significant investment of resources. It is therefore incumbent upon the acquirer of a simulator to use is as effectively and efficiently as possible. There are three ways to do this: instructional design, expanding the student base, and providing simulator services to other transit agencies. These few paragraphs will describe how each of those can be accomplished.

Instructional Design

As previously discussed, the first step to successful implementation of a simulator-based instructional program for transit bus operators is the overall design of the instructional program. If a simulator is only an “add on” to an extant program, it is not likely to receive full utilization nor approach maximum effectiveness. Instead, a training program must be systematically designed so that the simulator is folded into the overall training process.

Each type of simulator is designed to train specific bus operator tasks. The course designed must identify the tasks to be trained in the simulator, identify any prerequisite tasks that must be trained before the student first drives the simulator, identify what post-simulator activities the student must have, and then lay out a program of instruction that reflects those analyses. What should result from this process is a curriculum outline showing the sequence of learning objectives to be met in the course.

The instructional designer will find that there is a critical path to learning to drive a transit bus and that the simulator sits on that path. The designer will also see that there are learning objectives that are not on that particular path; that is, they are necessary learning objectives for a transit bus operator to meet but they are not part of the *driving* learning objectives. It is these non-driving learning objectives that provide the opportunity to take full advantage of the driving simulator. As each student cycles through the various simulator experiences, it is these non-driving learning objectives that provide instructional activities for those students not using the simulator.

If simulators are not factored into instructional design, then it is unlikely that they will be used effectively or efficiently. Students may be put into the simulator before they are ready to efficiently learn from it. Student may mill about with only one student using the device. Or conversely, in a lock-step instructional program the simulator may stand empty because no students can be freed up to use it without losing out on the instruction being provided to the entire class. A carefully designed instructional program can avoid all of these situations.

Expanding the Student Base

There is no reason why simulators should be limited to training beginning drivers. Transit bus operators who have been out of the workforce for awhile (illness, staff assignment) could re-train on the simulator before driving an actual bus. Simulators can play a role in accident re-creation, at least to the extent of having a driver who has been in an accident drive a scenario similar to the one being driven when the accident occurred. In the same vein, drivers who are having an inordinate number of near misses, traffic complaints, or minor accidents could drive the simulator for both performance diagnosis and correction. It is possible that individual drivers may want to drive the simulator for additional practice on to self-correct some small performance problem. All of these opportunities are present to use the simulator as much as possible.

Providing Simulator Services to Other Transit Agencies

The next section discusses a model for how smaller transit agencies can gain access to driving simulators. One way for a larger agency to get maximum use out of its simulator is to provide driving simulator services to transit agencies that cannot afford their own simulators. Although 24/7 operations are probably not realistic, there is no reason that evenings and Saturdays could not be available for simulator clients. Not only would this increase usage of the simulator or simulators, but it could result in a positive revenue stream for the supplying agency.

8. Model for a Simulator-Based Transit Bus Operator Training Center

Simulators are expensive. For transit agencies with few students, it would be difficult to see how they could recover

the costs associated with acquiring a Level 2 or Level 3 simulator. However, the benefits of such a simulator remain no matter how small the student throughput.

Because the payoff from using a driving simulator can be substantial in terms of both safety and instructional efficiency, a method for exposing more students to the simulator experience should be found. One idea that has merit is the concept of a regional transit training center.

Such a center would be able to serve numerous small- and mid-sized transit agencies. It could be managed and funded by a consortium of these agencies. Another approach would have a major transit agency providing the simulation facility as part of its overall scheduling of simulator use. In either case, all non-simulator training would be accomplished at the student's normal transit training site. When the simulator was scheduled for a particular transit agency, the students would have to be transported to the simulator location for that phase of the training only.

It is also possible that simulators can be installed in trailers and taken to each agency in the consortium on a set (and manageable) schedule.

The key to the success of such a center is to have every student ready for the simulator at the time he or she is scheduled to drive. This approach would be accomplished by providing off-simulator training over a computer network using the Internet as a backbone. Each participating transit agency would be responsible for preparing the students for the simulator sessions.

Obviously, the cost for such an activity would have to be shared among all the participating transit agencies. Although no single agency would have absolute use of the simulator, at least no single agency would have to bear the entire cost of the simulator.

REFERENCES

Jones, E.R., Hennessy, R.T., and Deutsch, S. (Eds.). (1985). *Human Factors Aspects of Simulation.* Washington, DC: National Academy Press.

Rasmussen, J., *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering.* (1986). New York, NY: North Holland.

GLOSSARY OF TERMS

Active Learning
Learning in which the student actively participates (e.g., driving a simulator versus watching a televised picture of a bus). Active learning, which involves multiple sensory modes, has been shown to be a potent instructional tool.

Automated Instruction
Instruction that is provided to a student, through a computer or simulator, without the intervention of a human instructor.

Breakdown Database
Provides the simulator the ability to recreate various vehicular malfunctions (e.g., flat tire, brake failure, engine failure).

Competence
An ability to perform the activities and tasks associated with a particular occupation or function in accordance with some specified standard.

Competency
An area of personal capability (knowledge, skill, and/or ability) that assists in successful on-the-job performance.

Competency-Based Instruction
Instruction that is designed around a set of learning objectives based on the knowledge, skills, and abilities required to perform a particular task. Competent performance of the task by the learner is used as an indicator of learning.

Computer Generated Imagery (CGI)
Animated graphics produced by a computer.

Computer-Based Training (CBT)
Interactive training between a computer and a learner in which the computer, taking the place of an instructor, provides stimuli such as conceptual content and questions based on that content to the learner. Feedback is provided to the learner based on the learner's responses, resulting in progress toward increased skills or knowledge. An all-encompassing term used to describe any computer-delivered training including CD-ROM and the World Wide Web.

Continuous Learning
A program of instruction that continues throughout the learner's career. In transit bus operations, such a program could include periodic re-visits to the training center, distance learning modules, and specific performance deficiency corrections on the job.

Courseware
Any instructional content that is used in CBT applications.

Cost/Benefit Analysis
An approach to solving problems of choice in which the positive and negative effects of selecting an alternative are weighed against each other. The ultimate goal is to select the alternative that yields the greatest benefit for a given cost or produces an acceptable level of benefits for the lowest cost.

Criterion
A task or learning objective against which performance is measured.

Criterion-Referenced Instruction
Instruction that uses performance on tasks and learning objectives as indicators of the learner's mastery of the instructional material.

Curriculum
A plan of instruction that details the learning objectives, method of delivery of instructional content, and the context in which the instruction shall occur.

Distance Learning
An individualized form of study in which the instruction is delivered electronically to a learner. The learner may be at a location that is remote from the location where the learning resources are distributed, allowing for off-site access to the resources. Contacts between instructors and learners are usually by telephone or mail, including e-mail.

Evaluation Module
A simulator should record and display the performance of each operator in the simulator. This module infers human performance from the various inputs to the simulator during a particular session.

Feedback
Information that is provided to learners about the outcome of an action or response and its relation to some performance criterion.

Field of View (FOV)
The angle, in degrees, of the visual field that can be seen when looking at a target head on.

Ground Database
Simulator software that represents the geographic world in which the student will drive the simulator. Should include the area where the simulated vehicle will maneuver, any populated area, roads, and other salient driving cues.

Instruction Vehicle
The vehicle being simulated. The instruction vehicle can be generic or can represent a very specific vehicle's interior and dynamics.

Instructional Control
Features of a simulator that direct the desired learning on the part of the student.

Instructional Designer
An individual who designs courseware for interactive training delivery applications.

Instructional Technology
Any technology (computer, compact disc, interactive media, modem, satellite, teleconferencing, etc.) that is used to support learning.

Interactive Training
Any learning scenario that employs two-way communications between the instructional system and the user.

Knowledge of Results
Providing feedback (immediate or delayed) to a student on his or her performance.

Learner-Centered Instruction
Instruction in which the content is developed according to the learner's needs and abilities.

Learner Enhancement
Features of a simulator that are not relevant to task or job replication, but are designed to direct the student to learn specific performance characteristics.

Motion Parallax
A depth cue that allows the eyes to judge distance. As the observer moves, close objects will move farther across the field of view than more distant objects.

Multimedia Training
Any form of interactive training that incorporates a mix of media (audio, animation, graphics, video, and text) to deliver the instructional content to the learner. The instruction is most often delivered on CD-ROM.

Needs Analysis
A method used to identify the training needs of an individual by reviewing work tasks, identifying performance factors and objectives, defining training objectives, and employing other diagnostic assessments.

Off-the-Shelf (OTS) Software
A commercially available software program produced and marketed by a company for use by other organizations.

Performance Analysis
Measurement, storage, and analysis of student performance in a simulator.

Part-Task Training
Instruction that permits selected aspects of a task to be practiced independently of other elements of the task.

Platform
Individual or shared virtual reality displays that are built into physical mockups of vehicles.

Practice
The repeated performance of a task or activity to gain proficiency using the skills acquired in the training phase.

Refresh Rate
The frequency with which an image is regenerated/updated on a computer display.

Refresher Training
Training that is used to reinforce previous training and/or sustain/regain previously acquired skills and knowledge.

Reinforcement
A form of feedback that affects the learner's tendency to make a specific response again. It is either positive, resulting in a response increase, or negative, resulting in a decrease of the response.

Replay
To show a student or students the performance just completed in a simulator. Replay can either be in the simulator or projected onto a large screen.

Resolution
The number of pixels in a computer display.

Scenario
All the events associated with a particular driving program. A scenario could be designed to teach the student to make safe right hand and left hand turns. Another could include a mechanical failure that the student had to compensate for.

Shaping
The process of gradually modifying a learner's behavior until it conforms to a desired behavior.

Simulator
A device that replicates, functionally and/or physically, a real-world system operated by one or more people.

Simulator Sickness
A form of motion sickness thought to arise from the visual-vestibular conflict induced by apparent motion in a simulator.

Stimulus
Any event, situation, condition, signal, or cue to which a response must be made.

Synthetic System
Although having many characteristics of an operation system, it exists only to meet some goal other than operational (e.g., training, design).

System Dynamics
Data storage and processing that allows a simulator to reflect the operational characteristics of the system being simulated. In vehicle simulation this would include acceleration curves, braking characteristics under varying road surface states, turning radius, and suspension feel.

Task
The smallest unit of work. It has an identifiable start and end point and results in a measurable accomplishment or product.

Task Analysis
The process of decomposing jobs and tasks into their constituent parts. It facilitates instructional design by providing a description of the fundamental elements (e.g., procedural steps, task conditions, standards, and other information) of a job.

Task Fidelity
The degree to which a task in a training environment corresponds to its real-world counterpart.

Touch-Screen Display
Hardware that allows a user to make inputs to the computer by touching a display screen.

Traffic Database
Represents the traffic conditions and characteristics to be simulated. A complete database will include not only a number of different vehicles but also will simulate various kinds of drivers (cautious, reckless, normal) and driving conditions.

Training Simulation
An instructional strategy that immerses learners in situations resembling reality. This type of instruction is especially important in situations where real-world errors would be too dangerous or too expensive.

Virtual Reality/World
A computer-generated artificial world in which the user has the experience of navigating through the world and manipulating objects therein.

Weather Database
Provides the means to simulate rain, snow, fog, daylight, and night.

Whole Task Support
Complete replication of a complex task setting. Would include not only the physical properties and dynamics of the system being simulated but should simulate in the student such things as workload, stress, and fatigue.

The **Transportation Research Board** is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation by stimulating and conducting research, facilitating the dissemination of information, and encouraging the implementation of research results. The Board's varied activities annually draw on approximately 4,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council