Feasibility Assessment of the Use of Transit Bus Driving Simulators

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Final Report — October 3, 2012
FHWA-JPO-12-090

U.S. Department of Transportation

Produced by FHWA Office of Operations Support Contract
DTFH61-06-D-00004
ITS Joint Program Office
Research and Innovative Technology Administration
Federal Transit Administration
U.S. Department of Transportation

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-12-090		

4. Title and Subtitle

Feasibility Assessment of the Use of Transit Bus Driving Simulators – Final Report

5. Report Date

August 6, 2012

6. Performing Organization Code

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8. Performing Organization Report No.

9. Performing Organization Name And Address

Science Applications International Corp. (SAIC)
8301 Greensboro Dr.
M/S E-12-02
McLean, VA 22102

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

DTFH61-06-D-00004, Task T-11-026

12. Sponsoring Agency Name and Address

U.S. Department of Transportation
Federal Highway Administration
1200 New Jersey Ave., SE
Washington, DC 20590

13. Type of Report and Period Covered

Final Report

14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

The United States Department of Transportation (U.S. DOT) has initiated a multimodal connected vehicle research initiative (hereafter referred to as the "Initiative") that aims to enable safe, interoperable, networked, wireless communications among vehicles, the infrastructure, and passengers' personal communications devices. The Initiative includes research on technical issues, policy and non-technical issues, safety, mobility, and environmental application areas. This research also assesses technologies and applications to determine their potential benefits and costs.

Developing and testing safety, mobility, and environmental applications for transit vehicles is expensive and time consuming. Once a system is designed, components must be developed and integrated. A field test site must be selected and a test system deployed, data gathered and analyzed, and findings documented. The use of transit bus driving simulators to test and evaluate proposed transit technologies would reduce the time and cost associated with executing a field operational test.

Many transit agencies currently make use of driver training simulators to train drivers. If it can be shown to be feasible to modify these simulators rapidly to emulate the field environment, product design, evaluation, and deployment may be less costly and require less time. In addition, if driver training simulators can be sufficiently adapted, a demonstration of the technology capability could be conducted for stakeholders.

With this goal in mind, this document describes the results of a feasibility study designed to explore the following questions:

- Can current bus driving simulators be used to support Initiative purposes?
- What are the alternatives from among which a solution can be chosen?
- Is there a preferred alternative among these potential solutions?

17. Key Words

transit vehicles, transit bus simulators, multimodal, connected vehicle research, interoperable communications, wireless communications, infrastructure, safety, mobility, environmental applications

18. Distribution Statement

No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	46	N/A

Acknowledgement

The authors would like to acknowledge the guidance and support of Mr. Yehda Gross of the USDOT ITS Joint Program Office, Mr. Jeffery Spencer of the Federal Transit Administration, Mr. Steve Mortensen of the Federal Transit Administration, and Mr. Gwo-Wei of Noblis Corporation for their review and guidance in conducting this study.

We also would like to thank all those individuals who provided invaluable information to the research team including representatives from the bus driving simulator industry community as well as various agency staff who use simulators devices to train their drivers. This work would have not been possible without your cooperation and assistance.

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Chapter 1. Introduction

1.1 Background

The United States Department of Transportation (U.S. DOT) has initiated a multimodal connected vehicle research initiative (hereafter referred to as the "Initiative") that aims to enable safe, interoperable, networked, wireless communications among vehicles, the infrastructure, and passengers' personal communications devices. The Initiative includes research on technical issues, policy and non-technical issues, safety, mobility, and environmental application areas. This research also assesses technologies and applications to determine their potential benefits and costs.

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- What are the alternatives from among which a solution can be chosen?
- Is there a preferred alternative among these potential solutions?

Several dimensions of feasibility are examined, including technological feasibility, economic feasibility, and institutional feasibility:

Technological – What is the feasibility of using current transit bus driving simulators as a tool to assist in transit participation in the research program, including such activities as driver interface testing, application evaluation, human factor analysis, and system interoperability?

Economic – Is the use of a bus driving simulator cost effective? What resources (time and expertise) are required?

Institutional – What are the relative pros and cons of using transit bus driving simulators from various stakeholder perspectives such as transit drivers, transit agencies, and application developers?

1.2 Purpose

In order to focus efforts, the feasibility assessment examined the use of currently available bus driving simulators for two application areas: Pedestrian Warning Application for Transit Vehicles and Right Turn in Front of Transit Vehicle Application**.**

Pedestrian Warning Application for Transit Vehicles - This application is intended to mitigate the problem of transit vehicles hitting pedestrians when the transit vehicle is making either a right or left hand turn at a signalized intersection. This problem occurs when transit vehicles, turning either right or left at a signalized intersection, cannot see pedestrians for a variety of reasons. For example, during evening hours or inclement weather, pedestrians may be difficult for transit drivers to see, especially when the pedestrians are wearing dark clothing. Another risky situation is when pedestrians are crossing the street at a speed in conjunction with the turning speed of the transit vehicle. This creates a situation where the pedestrian can remain obscured from the driver's view for a period of time by the column in the transit vehicle that supports the windshield.

Two options for the Pedestrian Warning Application are provided below.

Option 1 includes a transit vehicle's onboard equipment issuing a warning message when the transit vehicle is on its fixed route and turning either left or right at a signalized intersection where the left or right crosswalk signal is activated by a pedestrian pushing the button.

Option 2 is similar to Option 1; however, the left and right crosswalks are equipped with a pedestrian detection system that distinguishes the physical presence of a pedestrian in the crosswalk. The pedestrian detection system may include video detection, acoustic sensors, Light Detection and Ranging (LIDAR) technology, or some other means for determining if a pedestrian is physically in the crosswalk.

To realistically replicate this application, a bus driving simulator would have to present the driver with a visual depiction of the intersection environment, including the display of pedestrians crossing the street at crosswalks. In addition, modifications might be required within the vehicle cab that represented the visual and audio collision alert capability. Software processes would interconnect the simulated actions of pedestrians with the pedestrian detection systems and the alert device as well as capture driver responses to alert warnings and pedestrian behavior.

Right Turn in Front of Transit Vehicle Application - This vehicle-to-vehicle (V2V) application is intended to mitigate the problem of crashes between transit vehicles and light vehicles that occur when a light vehicle turns right in front of a transit vehicle as it leaves a bus stop. This situation occurs when a bus stop is located prior to an intersection and the transit vehicle is stopped in the right lane. The driver of a light vehicle traveling behind the transit vehicle—and planning to turn right at the intersection—is unsure or impatient of the transit vehicle's dwell time and opts to pass around it on the left. After passing the transit vehicle, the light vehicle immediately makes a right hand turn in front of the transit vehicle. If the transit vehicle is pulling away from the bus stop at the same time the light vehicle is turning right at the intersection, there is potential for a collision.

The Right Turn in Front of Transit Vehicle Application only issues a warning message when a light vehicle turns right at the intersection in front of the transit vehicle when the transit vehicle is stopped at a bus stop and the transit vehicle begins pulling away from the bus stop. Similar to the first application area, two options are considered. In Option 1, a warning is issued to the driver of the transit vehicle. In Option 2, a warning message is issued to the driver of the light vehicle.

In order to replicate this application, a bus driving simulator would have to present the driver with a visual depiction of the intersection environment, including the display of vehicles overtaking the bus. In addition, modifications might be required within the vehicle cab that represented the visual and audio collision alert capability. Software processes would interconnect the actions of overtaking vehicles, the vehicle detection systems, and the alert device as well as capture driver responses to alert warnings and overtaking vehicle behavior.

In examining these two applications, the study team identified three alternative approaches to identifying a potential solution from among the bus driving simulators that are currently available. The first approach is to use a low-cost, low-fidelity simulator to solicit driver opinion data. Depending on the design of the experiment, simulator modifications may be required. The second approach is to modify a moderate-cost, medium-fidelity simulator and install scenarios that will enable experimental research. Finally, the third approach is to use a high-fidelity simulator to gather vehicle and driver performance data. A high-fidelity simulator, however, entails high initial and ongoing cost and may provide more capability than required for some applications.

1.3 Organization of the Report

The remaining sections of this report include a summary of literature describing how simulators have been used to support training and research, including information about available simulators and their current use by transit agencies; an analysis of the technical, economic, and institutional feasibility of using simulators; and a summary and recommendations resulting from the feasibility assessment.

Chapter 2. Review of Literature and Summary of State of the Practice of Bus Driver Simulators

2.1 Literature Search Methodology

For purposes of this project, the search was primarily limited to the past 3 years and concentrated on the following:

- Literature on technological advances related to transit bus and other relevant (such as light vehicle and truck[1]) driving simulators;
- Literature on recent deployment and/or procurement of transit bus driving simulators; and
- Literature associated with inter-agency (i.e., shared) and/or innovative usage of transit bus driving simulators.

The research team searched a broad array of publication databases, including the Institute of Electrical and Electronics Engineers (IEEE), Elsevier's Science Direct, Science.gov, Scitopia.org, and Scitation. Searches were generally limited to the years 2009-2012 (pre-print available), and the team used key words such as:

- Bus
- Simulator
- Driving
- Driver
- Transit
- Collision
- Pedestrian

In addition to conducting a search of the literature, the research team also contacted driver training simulator manufacturers and transit agencies to discuss the latest technological developments, relevant research applications, and current uses.

2.2 Literature and Available Product Review Results

The results of the review include both a summary of the research and training applications of bus driving simulators described in the literature, or revealed through discussions with members of

[1] Although some sources located in the course of this literature search included or referenced other mode simulators, such as passenger or light truck, sufficient information on bus simulators was found that it was not deemed useful to include extensive citations of other modes.

the industry, a discussion of several of the most popular bus driver training simulator systems, and the results of direct engagement with various transit agency representatives regarding their use of bus driving simulator devices. As an introduction to all of these topics, a short summary of the state of the technology in bus driving simulators is first included.

2.2.1 State of the Technology in Bus Driving Simulators

The overall level of capability in the vehicle simulation industry (sometimes known as “virtual simulation”) has risen dramatically over the past two decades. This has been made possible to a degree by the investments by the defense sector, but also in passenger and truck simulators. Bus driving simulator technology has kept pace with the overall vehicle simulation industry. This is likely the case because bus driver simulation is a logical and natural extension of vehicle simulation product lines. Bus simulators benefit from advances in the basic simulation platforms as those platforms go through technology refresh. Bus simulators can be obtained with low, mid, or high fidelity and have a range of capabilities that include modern visual systems, audio systems, motion platforms, data collection, and varied scenarios. However, the overall community of practice (COP) of developers, integrators, and bus simulator users is much more limited than other types of vehicle simulation COPs.

Table 2-1 describes some common vehicle simulator characteristics and the state of the practice for each.

As training devices, it can be important, depending on the particular task being trained, for bus driving simulators to replicate to as great a degree possible the physical look and feel of the actual driving experience in order to assess a driver’s behavior under field driving conditions. Simulator manufacturers have incorporated a range of physical features and software capabilities to portray the actual experience of operating a transit bus closely. These features include emulating the physical cab, vehicle controls, and display panels; simulating the visual flow of driving the vehicle in response to driver input for a range of environments and conditions; and recording driver behaviors for use in training and evaluation scenarios.

Table 2-1. Vehicle Simulator Technology Characteristics in the Current State of the Practice

Vehicle Simulation Characteristic	Current Range in the State of the Practice
Motion and Degrees of Freedom (DOF)	Motion cues vary widely from zero DOF to 9 or more. It is typical for a military ground vehicle simulator to have 6 DOF. Bus driver trainers range from 0 to 3 or more DOF. High end commercial passenger vehicle simulators can have more than 9 DOF accounting for rotation, translation,* and acceleration.
Visuals and Field of View (FOV)	Visual resolution is defined by a number of factors including image generator (IG) and/or projector characteristics, video format (e.g., interlace, progressive scan) and IG window to FOV mapping. It is not uncommon to see 3 to 5 screens (windows) with 180 or more degrees of FOV. Some commercial bus simulators have 280 deg (Doron) and 315 deg (FAAC).

Vehicle Simulation Characteristic	Current Range in the State of the Practice
Vehicle model (dynamics)	Vehicle model dynamics are well understood and can be achieved to a high degree of both resolution and fidelity. Vehicle physics models are sometimes validated by the vehicle manufacturer (or can be validated by the manufacturer).
Traffic (and environment) models	Since this simulator characteristic depends on modeling human behavior as well as modeling traffic rules. Environmental effects (rain, light levels, etc.) are increasingly present in modern simulator systems, but their effects are not as always completely integrated with other model (e.g., traffic) behavior. A distinction must be made between visual modeling and behavioral modeling. Both are important, but while visual modeling advances have been led by the gaming industry, behavioral modeling has been advanced by various computer-generated forces (CGF) through military entity modeling.
Audio	Environment noises are sometimes represented in bus simulators. Intercom systems are also used.
Scenarios and Instructions	The number and complexity of available scenarios is typically driven by the training requirements. A good scenario system will allow the user/trainer to make modifications to the scenario. Most systems allow this, but some training is often required to be able to make the modifications.

*Translational motion refers to motion that changes the position of an object without rotation; i.e., moving left or right, forward or back, and up or down along lines referred to as vectors. Translational motion is also referred to as linear motion.

2.2.2 Applications of Bus Driving Simulators for both Research and Training

A review of the literature resulted in the identification of several research-related applications of commercially available bus driving simulators including systems manufactured by Systems Technology, Incorporated (STISIM) and FAAC (MB-2000). Dorn and Stannard (2006) compared the simulator driving performance of experienced and novice bus drivers using the Arriva Bus Simulator. The Arriva simulator is a fixed-base, wide field-of-view simulator that was built using a STISIM PC-based driving simulator. A cab sits in the middle of a 180 degree curved screen, 6 m in diameter and 2.75 m high, from which the participant drives the simulator. Driving performance was measured around three locations: a parallel bus stop, a lay-by bus stop, and an intersection. Several measures of performance were gathered: lane position, speed, steering, acceleration, braking, and overall acceleration. The researchers concluded that experienced drivers exhibited safer strategies in negotiating the three locations than novice drivers. They describe two practical reasons why a simulator may be useful for novice bus driver training: first, a simulator enables the sensitive measurement of performance to identify the weaknesses of a novice driver, and second, a simulator allows benchmarking of acceptable driving performance.

Deits et al. (2011) used a bus driving simulator to examine the driving performance of drug-impaired drivers in work zones. A high-fidelity driving simulator built by FAAC, Incorporated and owned by the Paducah Area Transit System (PATS) was leased for this study. The simulator was built on a Gillig Bus front end and had a 360 degree display through seven video-channels (three front video projectors, two side displays, and two rear displays) and a complete set of bus controls. The research consisted of comparing the performance of a test group and a control group. Triazolam (Halcion) was administered in a placebo-controlled, double-blind, randomized crossover design. Drivers were presented with a scenario that required them to safely negotiate a work zone layout that purposely blocked the driver's lane of travel, requiring them to drive around a set of safety barrels. Two dependent measures were collected, including total driving distance of the driver's path around the barrels and steering entropy, a measure of increased mental workload. The study found differences in driver behavior between experiment groups.

Reinach and Everson (2005) examined bus operator performance and attitudes toward a collision warning systems using a high-fidelity training simulator developed for New York City Transit (NYCT) by FAAC, Incorporated. The simulator consisted of a real New Flyer bus cab, a fixed base, a steering wheel with torque feedback, normal pedal controls, normal rear view mirrors, typical bus switches and controls, and a 360 degree field of view. Operators were presented with a driver-vehicle interface display that provided them with a visual and auditory warning regarding the imminence of a collision with a vehicle traveling in front of the bus. The goal was to provide a bus driver with a warning to assist in maintaining a safe traveling distance from a vehicle traveling ahead of the bus. The operator performance-related measures that were collected included whether or not operators crashed, operator response time to the lead vehicle braking, and other measures such as vehicle velocity, response time, and time-to-collision values. Simulator results indicated that the collision warning device appeared neither to improve nor to worsen driver performance. Also as part of this study, subjects were asked to rate the performance of the collision warning system subjectively on a seven-point Likert-type scale. Overall, operators gave a positive assessment of device usefulness and did not find the device annoying or distracting.

The literature search uncovered a number of bus simulator crash avoidance studies conducted using a driving simulator developed by researchers in Taiwan. These included papers describing the use of a simulator to examine bus rear-end collision warning thresholds, bus-pedestrian collision warning systems (CWS), and variable speed limit signs on freeways. Each of these studies, including Chen, Lin, and Hwang (2008) as well as those authored by Chang, et al. (2008-2010), applied a bus driving simulator (CHU-DS) developed by the Department of Transportation Technology and Logistics Management at Chung Hua University. The CHU-DS is a fixed-base driving simulator consisting of four systems: the cabin system, the visual projection system, the driving simulator system, and the data acquisition system. A three-projector screen creates a 135 degree field of view. The results demonstrate the applicability of bus driving simulators to test advanced technology concepts. The work of the researchers at Chung Hua also provides a useful analytic framework for the study of CWS with simulators.

Bus driving simulators have also been used to train drivers in the application of new technology. For example, the University of Minnesota (2011) recently conducted an investigation of a driver assistive system (DAS) to help drivers operate safely in bus-only shoulder lanes. The research team developed a driving simulation that creates a DAS-equipped bus cab and is used to train drivers on the use of the system on bus-only shoulder driving lanes in all types of weather conditions. This simulator has been in place and in use since 2009. Its principal function is to support driver training on the routes from suburban areas into the Twin Cities. Since the majority of these routes are bus-only, they are inherently lower in crash rate than strictly urban routes. While no metrics are available on safety or cost (saving lives or costing less), discussions with the director of the Intelligent Vehicles Laboratory at the ITS Institute at the University of Minnesota indicate that the program is successful and provides good training effectiveness.

Mobile driving simulators have also been developed.

A modern, mobile, high-fidelity simulator manufactured by FAAC, Inc., is used by the Paducah Area Transit System (PATS) to train drivers throughout Kentucky. The system is also used in Tennessee; Missouri; Georgia; Ohio; Illinois, and Florida (Miami). Each year, the PATS simulator travels to between 30 and 50 destinations. After using the driving simulator in 2006, PATS saw the agency's insurance claims fall and the number of accidents decline.

2.2.3 Currently Available Bus Driver Training Simulator Systems and Inventory of Selected Transit Bus Driving Simulators

Table 2-2 summarizes fidelity characteristics for driving simulators contained in a report prepared by Brown, Richard and Campbell (2010). These values are not meant to be absolutes and simulators may contain a mix of features. The fidelity, or realism, provided by a driving simulator is enabled by a number of visual, auditory, motion, tactile, and sound features. Generally speaking, a low-fidelity simulator mimics fewer driving features than a high-fidelity simulator. Therefore there is a general relationship between the cost of the simulator and the level of fidelity it provides.

The review of the literature identified only a single bus driving simulator developed exclusively for research purposes: the CHU-DS developed by the Department of Transportation Technology and Logistics Management at Chung Hua University in Taiwan. This system provides a moderate to high level of fidelity, and has proven to be useful in conducting research. However, its location in Taiwan makes it impractical as an option to support the current research program.

Table 2-2. Driving Simulator Characteristics

Characteristic	Low Fidelity	Medium Fidelity	High Fidelity
Vehicle Cab	Desktop	Quarter of Half Vehicle	Half or Full Vehicle
Driving Controls	Desktop steering wheel and separate foot controls	Actual vehicle controls (partial set)	Actual vehicle controls (full set)
Screen	Desktop monitor	Flat screen	Spherical/cylindrical screen
Physical size of each display screen	< 32" x 24"	32" x 24" to < 93" x 90"	> 93" x 90"
Continuity between projected images	Gaps between screens	No gaps between images	Seamless image using edge blending
Field of view	< 140 degrees	140 degrees to 240 degrees	> 240 degrees
Rear view imagery	None	Rear imagery emulated using images on forward screen	Rear imagery using passive mirror with rear screen or active panels in mirror fixtures
Audio	No localization	Generally localized	Highly localized

Characteristic	Low Fidelity	Medium Fidelity	High Fidelity
Motion base	None	Motion seat	Motion based
Degrees of freedom	None	1 to 2	3 or more
Vibration	None	Shaker vibration (in seat/steering wheel)	Shaker vibration in seat column, steering wheel, and foot pedals
Tactile feedback	Passive feedback in steering, brake, and accelerator controls	Active feedback in steering control Passive feedback in brake and accelerator controls	Active feedback in steering brake, and accelerator controls
Image quality	Simple	Moderate detail	Near photo- realistic

Source: Brown, J., Richard, C. and Campbell, J., "Making Simulators More Useful for Behavioral Research Task 3 – Simulator Characteristics Survey Final Report." October 1, 2010.

A search of commercially available bus driving training simulators indicated that the two principal bus training simulator manufacturers in the United States, as measured by estimated market penetration, are Doron Precision Systems, Inc., and FAAC, Inc. Three other domestic manufacturers of bus driving simulators were identified including: L-3/D.P. Associates, Inc.; Simulator Systems International, Inc.; and Technologies International, LLC. Among these five manufacturers, FAAC and Doron produce a bus simulator training product line. Others concentrate on military and commercial vehicle product lines.

The FAAC and Doron systems are classified as mid- to high-range simulators as they include a high degree of physical fidelity. As a result, they are relatively expensive. In order to consider possible lower cost options, a third system, manufactured by Systems Technologies, Inc. has been added to the assessment. The Systems Technologies, Inc. product, STSIM, is a software system that can be installed on a number of hardware platforms and, therefore, requires the integration of the physical components of a simulator system.

Table 2-3 summarizes the General Services Administration (GSA) schedule cost of systems available from Doron (460Bus and 400Bus), FAAC (MB-2000), and Systems Technology, Inc. (STSIM M100W).

The FAAC MB-2000 and the Doron 460Bus are high-fidelity simulators while the Doron 400Bus and the STSIM are lower in fidelity. The Doron 400Bus consist of a driving station where drivers observe scenarios projected on a screen.

The STSIM M100W products are desktop systems that include steering and braking controls. The cost for the STSIM Drive M100W software product includes only a software system that must be loaded onto a hardware system. The prices displayed in this table do not include any required modifications to support the research program purposes nor do they include facility and maintenance costs.

Driver training simulators have been designed to support driver instruction and are not a replacement for field training using a full-sized vehicle in actual driving conditions. Typically, a driver training simulator is used under the close guidance of a trainer who observes trainee driving behaviors and reinforces learning objectives. Training is very much an interactive process between trainer and trainee. Therefore these products require modification to support the range of research program areas. As described below, these modifications include changes to software and hardware configurations to represent the driving environments, including driver cab configuration.

Table 2-3. Bus Driving Simulator Systems

System	Manufacturer and Description	Costs per GSA Schedule	Image
	Doron Precision Systems, Incorporated		
460 Bus Driving Simulator	Includes one (1) place 460BUS Driving Simulation System with instructor work station with Windows operating system, dispatch radio for instructor work station and simulator station(s), training scenarios, site set-up and check out, operation, and instructor console.	$191,090	
400 Bus Driving Simulator	Includes one (1) place 400Bus driving simulation system with riser, driver analyzer, tilt steering, upright instructor console, DVD player, pull-down screen, LCD video projector, audio amplifier, two speakers, main computer, 19" color monitor, printer, mouse, keyboard DVD barcode system. System includes installation and three days of instructor training.	$48,064	
	FAAC, Incorporated		
MB-2000 Bus Driving Simulator	Includes bus driving Simulator with three high resolution displays, generic enclosed bus cab, generic bus dynamics model and standard warranty. Three rear projection displays for forward view. Extended warranty options are available on this product.	$235,000	
	Systems Technology, Incorporated		
STSIMDRIVE-M100W	Includes one (1) Model 100, Wide FOV System	$38,490	

Source: GSA *Advantage!* Web page: FAAC product: https://www.gsaadvantage.gov/advantage/s/search.do?q=0:0bus+driving+simulators&db=0&searchType=0 ; Doron Precision Systems products: https://www.gsaadvantage.gov/advantage/s/search.do?q=0:0doron&db=0&searchType=0; Systems Technology product: https://www.gsaadvantage.gov/advantage/s/search.do?q=0:0gs02f0043l&q=0:0STISIMDRIVE&s=17&searchType=1&db=0

2.2.4 Current Practice in Transit Bus Simulator Use

The primary users of transit bus simulators at the present time are transit agencies. In order to assess the degree to which simulators have been or are being used for the categories described in the SOW,[2] agency representatives were engaged to provide information and opinions on the usefulness and requirements of simulator use.

2.2.4.1 Approach to Gathering Information on Transit Agency Use

Transit bus agency departments of training were contacted and asked to participate in brief discussions about their simulator use. An effort was made to contact both larger and smaller agencies in different geographic locations in order to account for a diversity of experiences and opinions. The following agencies provided information used in this assessment:

- Delaware Transit (Wilmington, DE)
- LA Metro (Los Angeles, CA)
- MTA (Flint, MI)
- Nashville MTA (Nashville, TN)
- OCTA (Orange County, CA)
- Paducah Transit (Paducah, KY)
- Palm Tran (Palm beach FL)
- WMATA (Washington, D.C.)

Each conversation lasted between 30 and 60 minutes. In addition, the assessment team also made use of online resources describing simulators and reviewing materials shared by the agency. The assessment team also had the opportunity to tour one agency's simulator training facility.

The goal of this information-gathering stage was to understand how and why simulators are being used by agencies; the resources required to purchase and operate the simulators; and the institutional and policy issues related to operation. Discussions focused on the following topics.

- Simulator manufacturer and model
- Use of or familiarity with other simulator and rationale for purchase decision
- Age of simulator/years of experience
- Characteristics of simulator (e.g., cab layout, mirror design, motion capabilities, screen properties, "rabbit" or instructor controls)
- Portability of simulator
- Any modifications made or additional resources obtained
- Purpose of use (e.g., training/retraining, equipment testing)
- Commonly used scenarios
- Scenario design process and required resources

[2] These categories are: Driver Vehicle Interface (DVI) and human factor assessment, driver acceptance, application development and testing, application evaluation, driver training, and stakeholder engagement. These categories are further discussed in Section 3 Feasibility Assessment below.

- Data analysis tools
- Opinions of image quality and overall realism
- Experience with simulator sickness
- Perceptions of novice and expert driver experience
- Union concerns and liability issues
- Experience with sharing/loaning simulator to other agencies
- Other lessons learned

Different agencies were able to provide a varying level of detail in their responses for each of these topics. These responses are synthesized in the following sections.

2.2.4.2 Findings Regarding Agency Use of Simulators

Of the eight agencies contacted, one agency had abandoned use of a simulator with no reason given. The remaining 7 agencies had used one or more simulators for periods of time between several months and approximately 9 years. A mix of simulators was in use and included:

- Doron 460Bus™(full cab with motion)
- FAAC MB-2000™ (full cab with motion)

2.2.4.3 Reasons for Simulator Use

As anticipated, all of the agencies contacted used their simulators for training drivers. At the majority of agencies, simulators are used to train new drivers and specifically to teach defensive driving techniques, to “show them what they don’t know.” These training sessions equated to relatively short durations in the simulators of around 10-20 minutes per driver. Simulators are viewed as worthwhile for demonstrating to drivers techniques like “rock and roll,” in which the trainee check blind spots. Simulators offer the opportunity for drivers to see what they would miss by not implementing the technique. Several agency representatives mentioned the case of pedestrians in a blind spot as a particular situation which is effectively conveyed to drivers using a simulator.

It was reported by all agencies that drivers like to spend time in the simulator and that they see it as “cool” and a “change of pace.” However, there seems to be universal agreement that there is no replacement for on-the-road training. Simulators fit a niche for agencies but could never replace road training.

In general, experienced drivers aren’t using the simulator. Most of the agencies use simulators for new driver training, two agencies indicated that they use their simulator only “in spurts” for re-training on specific issues, often as the result of a specific incident or collision. Only one agency described a regular training regimen for experienced drivers in which drivers are evaluated every 2 years in the simulator to assess whether they have developed any “bad habits.”

Several training managers thought it likely that an experienced driver would not see the value of the simulator experience (for themselves) since they are well-equipped with on the road skills. However, a couple indicated that experienced driver perceptions would really depend on how convincing the scenario was. If it was possible to demonstrate to a driver how a new technique or device improved their driving in some way, they would be convinced. One person made the analogy to on-board cameras – drivers were skeptical of cameras at first, fearing they would be evaluated, but with time learned that cameras helped them to see more of the road.

There were no cases reported in which a simulator had been used by a transit agency to develop or test a new piece of equipment (e.g., a safety warning device). One agency said they could see that being possible only if the simulator manufacturer was involved in equipping the cab or adding special elements to a scenario.

2.2.4.4 Simulator Features Important to Transit Agencies

Several simulator features emerged as being important to agencies, as summarized below.

Number of stations. One agency representative identified a limitation of the simulator is that only so many drivers can use it at one time. He expressed that only so much can be accomplished in a short amount of time. However, another person pointed out that this is still more efficient than having to go out on the road in a bus.

Imagery. Two types of scenario imagery were identified. In one type, videotaped images of real world scenes are broadcast to drivers who can react but cannot influence the image. In the other type, animations of realistic scenes are shown, and these range in quality from “cartoony” to very realistic, likely based on the age of the simulator. Agency representatives all felt that the more realistic and interactive the imagery, the better perceived the simulator was by drivers.

Rabbit controls. Several agencies had these controls which allowed them to drive a secondary vehicle (such as a car) and to maneuver this vehicle around the bus in real-time. They found these very useful for training.

Mirrors. Two types of mirror placement were identified. At one agency, mirrors were “soft” and were part of the forward screen (i.e., “picture-in-picture”). This agency was pleased with these mirrors but had no experience with any other type. In the other cases, mirrors were “hard,” or fixed to the cab, and showed images reflected from screens. These agencies also liked their mirror style. One agency reported that any differences between the simulator cab and their fleet were usually insignificant. For instance, although the agency used convex mirrors on their fleet, they recognized the importance of training with traditional mirrors. “Drivers have to know how to use the standard mirrors or they’ll make mistakes.” The “spot” mirrors are misleading [because they lead drivers to misjudge distance]. Although they perceived that it would be nice to have current features (e.g., convex mirrors), this was not necessary to teach the basic procedures for which they used the simulator and, in fact, a simulator represented the different buses in their fleet sufficiently to give drivers a realistic experience.

Ambient noise. No agencies reported the use of ambient noise in the simulators, such as passengers talking or stops announced. However, there is usually some noise from the bus systems or from events (e.g., a tire blowing out). Agencies expressed that they hadn’t really considered such features before and thought it might be a good addition but not a necessary feature.

Motion and simulator sickness. All agencies felt that motion added to the realism of training for the drivers. However, the lack of motion was identified as a significant problem in that it was perceived to induce motion sickness. Approximate rates of motion sickness were reported from 3% to 85%. This disparity is probably is the result of varied recognition of the symptoms of simulator sickness, variations in tracking of simulator sickness, and varied use of mitigation methods. Agencies reported doing various things to counter sickness ranging from teaching drivers to "move around a lot," to limiting time in the simulator, to taping brown paper over the side cab windows for operators with known simulator sickness.

Data analysis. For the most part, agencies used the simulator by observing drivers and verbally instructing them. In some cases agencies used a replay feature (with street-level or bird's eye views) to demonstrate a driver's own performance. One agency reported using response time as a measure of performance. However, they explicitly declined ever to print out response times as they perceived this as a liability concern should a driver's response time ever be called into question; they reported that the union was also concerned about this issue. However, another agency collected this information and reported no concerns on the part of risk mitigation staff or the union.

2.2.4.5 Scenario Development

In all cases, the simulators purchased by agencies came with scenarios provided by the manufacturer. However, in many cases, the agencies had needed to develop scenarios to meet specific needs, often in response to a specific incident that they wanted to study or on which they wanted to retrain drivers.

In the case of the video-based scenarios, the manufacturer visited the agency city and recorded images for the purpose of creating realistic scenarios for training (i.e., at particular locations of interest to the agency).

In the cases of animated scenarios, the agencies were able to use tools provided by the manufacturer to create and edit scenarios. There were mixed reviews about the degree to which this scenario development was burdensome to agencies. It seems that in all cases it does require some specialized training from the manufacturer and there is a learning curve. It seems that in most cases, the agencies have at least one staff person who specializes in this role.

One agency expressed that it isn't hard to learn to create scenarios *per se*; however it takes a person who can think and plan ahead for the driving situations that need to be represented. One agency expressed that developing scenarios required using "waypoints" to stage the location of scenario events (e.g., a pedestrian crossing the road or a vehicle maneuvering in a specific way around the bus) and that this was tedious. However, this same agency commented that there are a variety of other very "easy to use" features of their scenario development tool such as the ability to adjust weather and lighting conditions or to adjust the "aggressiveness" of traffic along a scale using controls on the instructor screen panel.

2.2.4.6 Novel Uses of Simulators

Some agencies reported on the ability of the bus simulators to be configured to train other driver types such as commercial drivers, police officers, and fire fighters. Two agencies mentioned using the simulator as part of a mobile classroom. In one case, the agency had priced this option for setting up the simulator in a trailer with the potential for making it mobile. Another agency had actually implemented this approach with the simulator built within a tractor trailer serving as a mobile classroom and configurable for different drivers. Thus, this simulator could travel to different locations for training.

2.2.4.7 Conclusions Regarding Current Transit Agency Use of Bus Simulators

Discussions about current simulator use revealed:

- Simulators are promising in promoting driver acceptance, even among experienced drivers. One of the keys is to develop convincing and relevant scenarios.
- Agency discussions did not provide examples of application development or testing. However, it is likely that a convincing scenario could be developed to test the effectiveness of a new piece of equipment.
- Simulators are generally well received by agencies and drivers, indicating they are effective in engaging stakeholders.
- There is a limitation to how many drivers can use a simulator at one time. This constraint must be considered in selecting a simulator and determining a number of stations to establish.
- Interactive images of higher quality affect driver perceptions of the simulator.
- Rabbit controls have the potential to be useful for demonstrating specific scenarios such as the safety pilot scenario involving a vehicle turning in front of a bus.
- Simulator sickness is a risk to using a simulator and a simulator program should include methods for reducing the frequency or mitigating the effects of simulator sickness.
- Simulators need not be an exact replica of a fleet's buses in order to be effective for training. However, it seems likely that the cab design could be important in testing a specific device location or presentation.
- Custom scenario development requires some level of learning and may be facilitated by engaging a staff support person in this role. While no strict computer programming experience is needed, the scenario developer should be facile with technology, understand roadway scenarios, and have good planning/prediction skills useful for imagining scenarios.
- Recording driver performance on simulators may be a liability risk from the perspectives of unions and risk management staff. However, given the varied opinions on this, it is likely driven by unique agency culture.

Simulators need not be stationary although most are. There is potential for simulators to be designed for mobile operations and transported as needed.

2.3 Literature and Product Review Conclusions

In summary, bus driving simulators offer two basic benefits to users: cost and safety. When used for research, simulators can potentially offer a low-cost alternative to naturalist driving and can also enable the investigation into behaviors that may endanger subjects or other drivers if conducted in real-world environments. Training applications for simulators can save money as drivers are trained without using a real vehicle, thereby saving fuel and other operating costs. In addition, training simulators enable drivers to test and train for maneuvers that may present a risk to the driver or the general public if conducted in normal street traffic. Other advantages of using a simulator include experimental control, ease of data collection, environmental benefits that include reduced emissions and fuel consumption, the ability to analyze nonexistent road or vehicle elements, and the ability to present bus drivers with events that may occur rarely in the real world but can be practiced repeatedly in a simulator environment. Among the disadvantages of using a driving simulator include the possibility of motion sickness, incomplete replication of physical driving sensations and environment, costs related to purchasing and maintaining the equipment and facilities, user acceptance, and experimental validity.

Ultimately, the decision to use a bus driving simulator for research or training purposes requires transit agencies to balance these advantages and disadvantages while focusing on the underlying purpose of the research or training. A high-cost, high-fidelity simulator may not be required in all instances. On the other hand, a low-fidelity, low-cost simulator may not achieve the realism required for a particular research program purpose.

Chapter 3. Feasibility Assessment

This section discusses the approach to the feasibility assessment as well as the findings using this approach.

3.1 Feasibility Assessment Approach

While focusing on these two application areas described in the introduction to this report, the pedestrian warning application for transit vehicles and the right turn in front of transit vehicle application, the feasibility assessment considered using currently available transit bus driving simulators to support several research program purposes, as identified in the statement of work (SOW), including: human factors and interface testing, application development and testing, application evaluation, driver acceptance, driver training, and stakeholder engagement. These categories will be used in the Feasibility Assessment discussion below.

3.1.1 Human Factors and Interface Testing

Interface and human factors testing examines how well a system accounts for the capabilities and limitations of its users. The measures considered in performing a human factors evaluation include perception of alerts about messages, comprehension of messages and warnings, and impact on driver workload and distraction. In addition to directly asking drivers about their subjective feelings regarding utility and usability, there are several types of measures that can be used to ascertain the quality of a system's human factors. These include eye movement and driver response. Eye movements (through observation or use of an eye tracker) can provide information on whether drivers look in the proper location in response to a warning (e.g., to the location of a pedestrian in the road) and conversely the degree to which drivers remove their eyes from other important regions of the roadway that might put them at risk. Driver response can be assessed in terms of timing, accuracy, and rate of response. Often braking and steering (turning or evasive movements) is evaluated in terms of a response to a warning. There is particular emphasis on correct responses and false alarms, but also on whether correct responses occur within a sufficient time threshold and whether the rate of response is adequate (e.g., not a "hard" stop).

3.1.2 Application Development and Testing

Application development and testing usually involves various iterations of prototyping, from mockups to full-scale demonstrations. Prototyping can be used to determine the timing of alerts, the tone/volume of auditory alerts, shapes and colors associated with visual displays, the location of speakers or visual displays, message or information content, and potential instructional protocols and training materials. The measures used in testing are similar to those described as human factors and interface testing. In addition to testing these driver interface components, prototyping may also involve functionality testing (i.e., does the software react to environmental conditions as intended?) and interoperability testing (i.e., how can systems work together?).

3.1.3 Application Evaluation

This category of research is similar to the application development and testing described above. The distinction is that evaluating an application means being able to test a fully featured independent system which may have little likelihood of modification for use in a simulator. It is akin to buying a COTS device, installing it, and then testing it in a production environment. Application evaluation may also include assessing the impacts (e.g., benefits and costs) of the application.

3.1.4 Driver Acceptance

Capturing driver acceptance means understanding drivers' "liking" of a system as well as their willingness to use the system in the future. Driver acceptance is influenced by elements of the system, but also by other factors such as a driver's intrinsic feelings about technology, driving experience, and pre-existing opinions about agency policies. The quality and realism of the driver experience in a training or experimental event can have a significant effect on acceptance.

3.1.5 Driver Training

Driver training may mean different things in different circumstances. Training may mean a mere demonstration of functionality and instruction in how to use and respond to the system. This includes understanding the cases in which the system will perform (e.g., to a pedestrian in a crosswalk) and also those situations in which the system will not react (e.g., to a pedestrian crossing midblock). Training may also mean the ability to measure performance against a certain criteria, such as number of correct responses or perceptions of minimal distraction. Simulators should be sufficiently realistic for drivers to comprehend the system features and accept them as useful and should have the ability to use many of the human factors and interface metrics already described.

3.1.6 Stakeholder Engagement

In research, stakeholder engagement has to do with getting drivers and agency decision makers excited about the use of a new system. It is especially helpful to get drivers and those who make agency investment decisions involved early in the process of possibly implementing a new system so that they feel their opinions have been heard and awareness within an agency is raised.

Simulators should be realistic and convenient to involve agencies in observing testing and training at a simulator.

3.2 Feasibility Assessment Findings

The findings are described in terms of technical feasibility, economic feasibility, and institutional feasibility.

3.2.1 Technical Feasibility

The question of technical feasibility focuses around the capability of currently available bus driving simulators to support several research program areas: human factors and interface testing, application development and testing, application evaluation, driver acceptance, driver training, and stakeholder engagement. Three of the available systems (MB-2000, 460Bus, and 400 Bus) were developed for driver training and therefore would require modification to support these functions. One system, STISIMDRIVE-M100W Bus, was developed to support automobile research. The use of this system to support the stated research program areas would require significant adaptation and investment.

To understand the required adaptations, it is first necessary to understand the installed capabilities of bus driving simulators. A bus driving training simulator is designed to recreate, as realistically as possible, the experience of driving a bus in a typical driving environment for purposes of training drivers to safely perform the driving task. Currently, the safety applications, pedestrian warning application for transit vehicles and right turn in front of transit vehicle application, are not installed in bus equipment. Therefore, available simulators would have to be modified to mimic these capabilities to support the research program purposes. Figure 1 presents a high-level representation of a generic training simulator environment in order to describe the nature of these modifications. Note this depiction does not represent any one particular simulator design, but was constructed for purposes of illustration in this report.

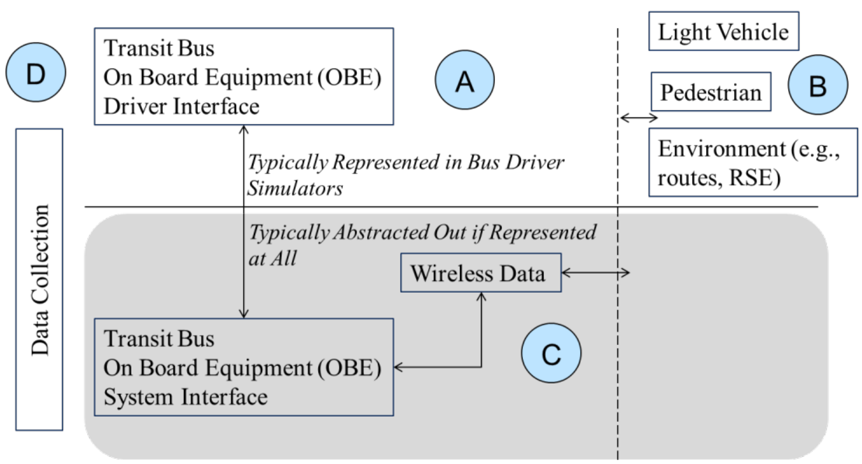

Figure 3-1. High-Level Representation of Bus Training Simulator System

From a technical standpoint, and for purposes of this report, a simulator system can be represented as four distinct regions: A) the transit bus itself with its driver interface including steering, braking, mirrors, and other onboard equipment (OBE); B) the representation of the driving physical environment, including light vehicles, pedestrians, and routes with traffic control devices and other road side equipment (RSE); C) the communication of data between the bus and its environment; and D) data collection. Region C includes wireless transmissions to and from other systems such as RSE and transmissions related to on-vehicle Controller Area Network (CAN) data.

Modifications will vary across the research/training need specified. Some of the modifications are described in more detail under the application areas below.

3.2.1.1 Human Factors and Interface Testing

Some of the key features required for this research program area are the following:

- Potential placement of video cameras to monitor driver facial expressions and particular head and eye movements; potential to integrate observations into software;
- Potential integration of eye tracker hardware and software into the physical space and software;
- Ability to capture vehicle performance metrics related to driver response, including throttle depression, brake depression, speed, steering, and lateral location.

Implementation of these features would require either a modification of an existing bus driving simulator or the development of a focused, experimental device such as the one used by some research universities (e.g., Chung Hua University, Taiwan). Referring to the system diagram above, modifications—or at least verification that the capability exists in a given system—could be required for regions A, B, and D. Modifications could be in the form of new or modified software (or data), the inclusion of a real or emulated device (e.g., a CWS), as well as scenario enhancements. Representation of the detailed flow of messages would not be required (region C). Modifications to place video cameras and eye trackers are of moderate cost, but integrating data capture, management, and analysis, which increase the expense, must also be considered.

From a stakeholder perspective, this type of task is useful to transit agencies, transit drivers, safety researchers, and transit system developers since data collected can be used for a variety of purposes, including system conceptual design and acquisition, policy decisions, training feedback, and detailed system performance tuning.

3.2.1.2 Application Development and Testing

The desired features for application development and testing are the following:

- The flexibility of physical space and hardware to accommodate different test system components;
- The flexibility of the simulator software to communicate with the test system;
- The time/cost/scheduling constraints associated with testing.

This type of task may be, along with application evaluation, among the most demanding. All four of the system regions would require modification since the very nature of this task implies that a new application is being developed. A new application most likely implies a new driver vehicle interface (DVI) of some kind, new system data and interfaces, and therefore a new, or at least updated, data collection approach. The environment (B) as well may change since a new application is likely being developed in reaction to a new threat or capability which would require a valid representation.

From a stakeholder perspective, the advantages (benefits) to the developer are clear in that a new application may be developed and tested in a robust and controlled environment. However, the cost to modify an existing simulator may not equate to a sufficient return on investment (ROI), especially if the developer already has access to appropriate test harnesses, both hardware and software, that enable such a controlled environment without all the other constraints and expenses of a bus simulator that is primarily intended for driver training.

3.3 Application Evaluation

Unless the application uses an existing and easily accessible set of interfaces (potentially both hardware and software) within the bus simulator, this type of task can be costly to implement. A critical factor here is how closely the simulator architecture reflects the bus system architecture.[3] For example, in the two safety applications considered in this feasibility assessment, the explicit representation of at least the interfaces of the Vehicle Safety Communications – Applications (VSC-A) components may need to be reproduced so that a developed application exists for evaluation purposes. The alternative is to develop an emulation or a mockup of the application for the bus simulator, but then this must be validated as a fair representation of the application, which also can be a costly endeavor. There is an interesting observation to be made here, however. Even though it may not be in the short-term interest of bus simulator developers to reflect the system architecture of bus system manufacturers, from an enterprise standpoint, it is worth considering how beneficial standardization of the two architectures (simulator and real equipment) might be. At a minimum, agreement on the importance of both using the same standardized (e.g., SAE) interfaces and protocols could lead to efficiencies and cost savings.

From all stakeholder perspectives—transit drivers, agencies, and developers—this type of task would seem to have poor benefit for the cost.

3.3.1 Driver Acceptance

The desired features for this research program area are the following:

- Driver perceptions of simulator quality and realism (keeping in mind this is related to specific characteristics of the fleet with which the driver is familiar);
- Objective ratings of system fidelity, with respect to motion, visual, and auditory experiences.
- Trainers need to be able to create and control realistic *events* that allow drivers to exercise their procedures and decision-making skills.[4]

This type of task requires a high-fidelity representation of regions A (driver interface) and B (environmental representation), but C (interface representation) and D (data collection) are not as critical. Using a bus simulator to achieve driver acceptance is more in line with standard usage such as driver training, and the features that are important for driver acceptance are also generally important for driver training.

All stakeholders benefit from using a bus simulator for driver acceptance, but especially the drivers and agencies who can use these devices to promote understanding of the utility of new

[3] It is important to remember how fleets vary. There can be many different buses and thus many different interfaces, controls, or devices (e.g., mirrors), as well as different underlying architectures. No simulator could represent all without great cost. Agencies reported how it didn't really matter for there to be great similarity across simulators and buses, since drivers had to be prepared to drive different buses. But agencies currently are training drivers on processes, not testing applications.

[4] An observation resulting from discussions with transit agencies is that it is important for trainers to be able to create and control realistic events which allow drivers to use their procedural processes and decision making skills. Agencies aren't necessarily training drivers to use a particular bus. They are training their drivers to follow the rules of safe driving.

features. The utility is less evident for application developers, but simulator developers will want to represent features accurately for training purposes, meaning a faithful representation of a feature for training purposes can also be used for driver acceptance.

3.3.1.1 Driver Training

The key features required for driver training include:

- Driver experience being sufficiently realistic for them to comprehend the system features and accept it as useful;
- The ability to use many of the human factors and interface metrics already described.

Clearly, driver training is the classic intended use of bus driver simulators. For this reason, existing bus simulators meet the required features and are primarily limited only by the cost of implementing a particular feature with respect to its corresponding training utility. With respect to the two case studies, it is important that no negative training occur for such safety-critical features as pedestrian and light-vehicle collision avoidance. This implies that it will be important to create a valid representation of the performance (including timing and system loading) of the interface aspects of the overall system, represented by region C in the system drawing. It is perfectly reasonable to create a parameterized or abstracted representation of this region, but it must accurately reflect the real system's performance in the real world. Identification of key performance parameters that are agreed upon by the sensor and processing systems' original equipment manufacturers (OEM), the bus manufacturers, transit and safety agencies, and other stakeholders may be a useful initial step in this process.

Transit drivers, agencies, and the general public all benefit enormously from this type of bus simulator usage, and this is the principal business of bus simulator vendors.

3.3.2 Stakeholder Engagement

The principal feature of stakeholder engagement is:

- Convenience to involve agencies in observing testing and training at a simulator.

The chief observation to be made here is that, depending on the nature of the task (DVI testing, driver training, etc.), various stakeholders may benefit from engagement. The power of recording information through good data collection, including video, to promote stakeholder engagement should not be overlooked. It should also be noted that the development of standard data models with common representations of entities such as pedestrians and light vehicles for simulator manufacturers as well as bus equipment OEMs will go a long way towards meeting the challenges of future connected vehicle endeavors.

3.3.3 Technical Feasibility Summary

Table 3-1 presents a qualitative assessment of the technical feasibility of current bus driver training simulators to support the various research program areas. It should be noted that the ratings in the table are qualitative and one rating can easily overlap with another; there are many considerations governing the technical feasibility of a given simulator system that relate directly to its particular use. Three factors are assessed: degree of similarity with current driving simulator technical capabilities, relative time and effort required to achieve desired technical capabilities with current driving simulators, and the reuse potential of enhanced technical capabilities (i.e., if the changes are implemented, can they be reused elsewhere?).

Table 3-1. Summary of Technical Feasibility Assessment

Research Program Area	Degree of Similarity With Current Driving Simulator Technical Capabilities	Relative Time and Effort Required to Achieve Desired Simulator Technical Capabilities With Current Driving Simulators	Reuse Potential of Enhanced Technical Capabilities
Human Factors and Interface Testing	●	●●●	●
Application Development and Testing	●	●●●	●
Application Evaluation	●	●●	●
Driver Acceptance Testing	●●	●	●●
Driver Training	●●●	●	●●●
Stakeholder Engagement	●●●	●	●●●

Key: Low: ● Moderate: ●● High: ●●●

The results presented in this table indicate that human factors and interface testing capability would require a higher degree of time and effort to implement using current driving simulators than nearly every other research program area. In addition, the reuse potential of changes that are made would not be as easily reused because of the potentially unique nature of such changes.

Specific adaptations required to serve this research purpose include:

- Developing an appropriate visual environment to mimic bus operations at signalized intersections and pedestrian behavior at the crosswalk;
- Installing alert interface equipment within the driving station or cab;
- Interconnecting driver responses to pedestrian behaviors and the visual environment as well as driver responses to vehicle behaviors; and
- Capturing driver and vehicle responses to simulated events and storing these data for analysis.

On the other hand, driver training and stakeholder engagement applications are the most consistent with current capabilities and would not require as extensive a modification as many other research program areas. Modifications to achieve these purposes also hold more potential for reuse.

In summary, the current bus driving simulators are technically capable of supporting a range of research program areas. However, the time and effort required to provide these capabilities varies. The more specific the focus of the application (e.g., human factors and interface testing), the greater the time and effort required and the lower the reuse potential of the research program area application. In any event, current bus driving simulators provide a potentially useful set of capabilities. Of course, the ultimate application of a simulator to provide these capabilities is dependent on their economic feasibility, which is discussed in the next section.

3.4 Economic Feasibility

As described previously, current bus driving simulators, appropriately modified, can be capable of supporting a range of research program area activities, including:

- Experiment and design;
- Evaluate;
- Train; and
- Demonstrate.

The use of a driving simulator also potentially offers several benefits including:

- Safety;
- Experimental control;
- Ease of data collection;
- Environmental benefits including reduced emissions and fuel consumption;
- The ability to analyze road or vehicle elements that have not yet been implemented in the real world; and
- The ability to repeatedly present events to participants that may occur rarely in the real world.

These benefits come with a cost, however, and in the case of driving simulators, the associated costs, which can be high, include:

- Acquisition, installation, and training costs;
- Facility costs; and
- Life-cycle costs including personnel, hardware and software maintenance and upgrade costs, and spare parts costs.

Table 3-2 presents the total estimated costs for a low-, medium-, and high-fidelity simulator. It is important to note that these total estimated costs do not imply an equal capability to support the research program. That is to say, a low-fidelity, low-cost simulator will provide a lower capability (e.g., the realism of the simulator will be lower in fidelity).

Table 3-2. Estimated Costs for Low, Medium, and High Fidelity Simulators

Simulator Fidelity	Purchase Price Range	Estimated Facility, Maintenance, and Operating Costs Range	Total Estimated Costs
Low Fidelity	$15,000 - $35,000	$20,000 to $45,000	$35,000 to $80,000
Medium Fidelity	$50,000 - $60,000	$25,000 to $50,000	$75,000 to $110,000
High Fidelity	$190,000 - $235,000	$50,000 to $75,000	$240,000 to $310,000

In addition to facility costs (e.g., space, heating, air conditioning), annual recurring maintenance costs (e.g., technician time) and annual recurring operating costs (e.g., researcher time) have to be added to the purchase price to develop a complete sense of the simulator costs. Furthermore, added costs will be incurred to produce the software required to support the research application. Therefore, these total costs can be considered as the minimum range.

Additional costs related to research execution would have to be added and would include:

- Preparing detailed experimental plans;
- Defining the scenario;
- Planning and implementing software model changes;
- Planning and executing data collection and data reduction (i.e., data analysis); and
- Planning and implementing recruitment and preparing test subjects.

3.4.1 Vendor Inquiries

In order to obtain more specific information about the cost of procuring a system to examine the two safety scenarios, one vendor agreed to provide an order of magnitude estimate and approximate time schedule required to adapt their system.[5] It should be emphasized that these inquiries primarily focused on purchasing a new system rather than some other arrangement such as leasing or borrowing. A rough order of magnitude for the cost of the first implementation of an embedded system, including the purchase of a new simulator, would be $500K. Additional

[5] The SAIC Team contacted three vendors in an attempt to obtain cost and schedule information to support development of the two safety scenarios: FAAC, Doron, and Systems Technology, Inc. Although all three vendors responded and were helpful in a general discussion, only one vendor, Systems Technology, Inc., provided a direct response to our high-level cost and schedule requests. The SAIC Team recommends that requests to vendors for cost and schedule information come directly from FTA/ITS JPO staff rather than contractor staff for two reasons. One, vendors may be hesitant to provide information they believe is proprietary or competitive. Second, vendors may wish to better understand how this information will be used and whether the information is part of a competitive procurement. The SAIC Team believes that, understandably, vendors may not be willing to invest much time in developing estimates if there is no business opportunity. Therefore, the cost and schedule information may be subject to wide variability if well-defined specifications are not included. Perhaps one way to obtain cost information is to issue a formal request for information along with specifications. This approach would permit vendors to engage directly with FTA/ITS JPO staff and provide the opportunity to address specific vendor questions.

versions of the simulation would be on the order of $200K. The first version of this simulation could be produced on the order of 6 months.

3.4.2 Summary of Costs

The cost effectiveness of an investment is dependent ultimately on the purpose of the application. For example, if training drivers is the highest priority, a high level of realism or fidelity will likely be required to capture the driving experience fully, which will likely result in improved driving behaviors. If conducting a focused experiment on a single aspect of the driving task is required (e.g., eye scanning behavior) then a lower cost, or lower fidelity simulator could be acceptable as the full range of realism may not be worth the added cost.

Outlined below are the advantages and disadvantages of three basic approaches for consideration: low cost (< $75,000), moderate cost ($75,000 to $110,000), and high cost (> $240,000).

Approach 1 (Low Cost – Use a Low Fidelity Simulator to Solicit Driver Opinion Data):

Description: Employ a low-fidelity simulator and install scenarios that demonstrate safety applications. Solicit opinions from drivers regarding the usefulness, effectiveness, and acceptability of the application. Simulator modifications may be required depending on the design of the experiment.

Advantages: Provides some ability to conduct experiments, provides driver feedback, requires less time and cost to implement.

Disadvantages: Drivers may not perceive the simulator as realistic enough and therefore the results may not be valid. Experimental applications would be focused on a topic and software changes which may limit reuse for other purposes.

Approach 2 (Moderate Cost – Use Medium Fidelity Simulator to do Experimental Research):

Description: Modify a medium-fidelity simulator and install scenarios that demonstrate safety applications. Design experiments to test the interface design and gather data regarding driver performance using a software system. Solicit opinions from drivers regarding usefulness, effectiveness, and acceptability.

Advantages: Provides the ability to conduct experiments, provides driver feedback, requires less time and cost to implement, and has a smaller space footprint than higher fidelity simulators.

Disadvantages: May not enable interaction between driver, vehicle, and road environment. May not provide a sufficient level of realism for some research applications, which may impact the validity of the findings.

Apporoach 3 (High Cost – Use a High Fidelity Simulator to Gather Vehicle and Driver Performance Data):

Description: Modify a high-fidelity simulator and install scenarios that demonstrate safety applications. Design a driver training module to train drivers on the use of the application. Design experiments to test the interface design and gather data regarding driver performance using a software system. Solicit opinions from drivers regarding usefulness, effectiveness, and acceptability.

Advantages: Provides a range of capabilities to conduct experiments, train drivers, and demonstrate application capabilities. Provides a high sense of realism and, therefore, greater physical validity.

Disadvantages: High initial and on-going cost. May provide more capability than required for some applications.

3.4.3 Economic Feasibility Summary

Driving simulators range in price and, therefore, in capability and fidelity. The price of the options outlined range from less than $75,000 to more than $300,000. Ultimately, the determination of the cost-effectiveness of an alternative is based on the extent to which it fulfills its intended purpose when compared against other options.

Each of these alternatives presumes “ownership” of some kind of simulator. Another “business model” to consider is collaboration with one or more local or regional agencies. This model would use simulator assets already in place at such an agency. Available funds could then be used to make modifications and purchase time on the systems. An advantage to this approach is that an agency interested in the particular issue to be investigated may also be the one that is most likely to have simulator devices that are ready to be adapted (or that would benefit from the adaptation of the necessary simulation system).

3.4.3.1 Institutional Feasibility

The ownership, ongoing maintenance, and operation of a bus driving simulator must be supported by an appropriate physical, financial, and staffing infrastructure. The institutional arrangements needed to provide this infrastructure requires that a number of questions be addressed, including:

How will the system be procured?

Options include purchasing, leasing, or borrowing a system. Factors to consider when selecting a procurement option include whether a system will be procured for a one-time or recurring purpose; the level of available funds to procure a system; and whether there are options to lease or borrow a system on acceptable terms.

Who will maintain and operate the system?

Options include maintenance and operation by Federal or contractor staff, university staff, or by other governmental or non-governmental entities. Leasing or borrowing a system may enable support from simulator experts on a short-term basis with supervision from other staff familiar with the research goals.

Where will the system be housed and stored?

The overall operational footprint must be considered, including power, heating, ventilation, air conditioning (HVAC), and floor space both for operations and storage. Options include Federal government sites, a university, or other governmental or non-governmental site. The advantage of leasing or borrowing a system is that the operating costs are prorated for the period of use. Additionally, borrowing a mobile system offers the advantage of being able to use the system at different locations compared to the access limitations inherent in a fixed site.

How will on-going system costs be financed?

Driving simulators provide a capability to support a range of research program areas. Institutional arrangements must be developed to support the ongoing operation and maintenance requirements to exploit these capabilities fully. A number of potential business models exist with which to manage the procurement, maintenance and ongoing operation of a bus driving simulator. In broad terms, these arrangements will reflect the role of driving simulator research and training within the context of an overall program. For example, if the goal is to develop a centralized driving simulator research capability to support a long-term research and development plan, the business model may involve dedicated Federal funding to purchase a driving simulator and cover expenses necessary for appropriate storage, operating space, and technical and research labor to operate and maintain the system. Those expenses may be offset through lease or rental income received from temporary use of the simulator by other interested research organizations. However, if the purpose is to demonstrate how a simulator can be used to encourage others to use simulators for training and research, perhaps leasing or borrowing a simulator for a short-term, specific demonstration would be the appropriate course of action.

In any scenario, financial resources are required to support ongoing maintenance and operation.

Chapter 4. Summary of Key Findings, Recommendations, and Plan of Action

4.1 Summary of Key Findings

Table 4-1 summarizes the key findings emerging from this feasibility assessment. The investigation into the technical, economic, and institutional feasibility of applying bus driving simulators to support research program areas suggests that a powerful technical capability exists; however, systems can be costly to purchase and require a financial commitment to long-term maintenance and operation.

Table 4-1. Summary of Feasibility Assessment

Feasibility Dimension	Conclusions
Technical	Currently available bus driving simulators provide a powerful technical capability to support a range of research program areas. However, the degree of similarity of simulator technical capabilities varies by program area, as does the relative time and effort to modify simulators to achieve required capabilities. Contacts with vendors indicated that modifications to their systems could be accomplished to support both safety scenarios.
Economic	The initial purchase costs and ongoing maintenance investments required to own and operate a bus driving simulator are generally high. High-fidelity systems can cost over $200,000. The cost to modify systems to support simulation of the two safety systems will increase this cost. For example, one vendor estimated a cost of $500,000 and a development period of 6 months to develop a system to meet the requirements of simulating the two safety scenarios.* Note that leasing or borrowing a system will obviously reduce this cost.
Institutional	Bus driving simulators are widely used throughout the transit industry to support driver training. Drivers generally find them credible and useful in learning important driver safety techniques and principles. However, space must be provided to store and operate systems and funding sources must be identified to provide the necessary resources to maintain the operation of a driving simulator.

*Note that this is a single data point with multiple assumptions and cannot be considered completely representative.

From a practical perspective, the analysis results can best be understood by focusing on the following three questions:

- Can current bus driving simulators be used to support Initiative purposes?
- What are the alternatives from among which a solution can be chosen?
- Is there a preferred alternative among these potential solutions?

Can current bus driving training simulators be used to support Initiative purposes?

The results of this feasibility assessment demonstrate that current bus driver training, appropriately modified, meet the technical requirements of the Connected Vehicle program. High-fidelity driving systems are technically capable of supporting human factors and interface testing, driver acceptance, application development and testing, application evaluation, driver training, and stakeholder engagement goals. Lower and moderate cost driving simulators also provide a basis for many of the capabilities required for this effort. Current bus driving simulators are generally mature systems that are widely used and accepted by drivers and trainers throughout the Nation. From a total cost of ownership (TCO) perspective, all of these systems, however, can be expensive to purchase, operate, and maintain.

Specific adaptations that may be required to support program purpose include:

- Developing an appropriate visual environment to mimic bus operations at signalized intersections along with other vehicles and pedestrian behavior at the crosswalk;
- Installing alert interface equipment within the driving station or cab;
- Interconnecting driver responses to pedestrian and vehicle behaviors and the visual environment as well as driver responses to vehicle behaviors; and
- Capturing driver and vehicle responses to simulated events and storing these data for analysis.

Additional costs related to using a driving simulator include:

- Preparing a detailed experimental plan;
- Defining the scenario;
- Planning and implementing software model changes;
- Planning and executing data collection and analysis; and
- Planning and implementing for recruitment and preparation of test subjects.

What are the alternatives among which a solution can be chosen?

Alternatives[6] are outlined in Table 4-2, including costs, advantages, and disadvantages.

The costs include an estimate of the amount necessary to procure a simulator, provide space and utilities, and operate for a period of 1 year. Costs to modify software and additional hardware (if required) to support specific research program purposes would add to these costs.

[6] Reference Economic Feasibility in Section 3, Feasibility Assessment for options.

Table 4-2. Summary of Options

Option	Total Estimated Range	Advantages	Disadvantages
1	$35,000 to $80,000	♦ Low cost ♦ Designed to conduct research ♦ Can be tailored to address specific questions ♦ Mobile- can be easily moved from location to location	♦ Low level of simulator ♦ fidelity ♦ Requires purchase and integration of hardware
2	$75,000 to $110,000	♦ Moderate cost ♦ Reasonable level of fidelity ♦ Somewhat mobile	♦ May not provide sufficient capability for some applications
3	$240,000 to $310,000	♦ High level of simulator fidelity ♦ Effective training tool	♦ High cost ♦ May provide more capability than required for some research applications ♦ High space requirements

Is there a preferred alternative from among the alternatives identified?

The decision will be driven by several considerations including:

- Priorities for use of the simulator;
- The available budget;
- The available schedule; and
- Long-term ownership and future potential applications.

The principal strength of currently available bus driving simulators is in driver training. Therefore, the simulators include a high level of fidelity designed to capture the look and feel of the driving experience. Providing this look and feel to the user can be expensive; however, other uses, such as interface testing and design, can be accomplished using these high-fidelity simulators with the necessary adaptations. On the other hand, lower cost and therefore lower fidelity driving simulators can be used to examine specific research and development questions.

Driver simulators can be adapted to support the research program areas provided sufficient time and investment resources are available. Indeed, the more research applications that are pursued using a simulator, the more experience and expertise will be developed in using the simulator. It must be appreciated, however, that the operation and maintenance of a simulator will require an ongoing level of investment. In a certain sense, the use of driving simulators to support non-driving-related research and development efforts in the transit field requires breaking new ground.

Ultimately, the use of driving simulators will require a certain amount of “trial and error” to fully understand their potential.

Next Steps

The result of the feasibility assessment concludes that bus driving simulators offer the potential to support a full range of program research purposes from interface testing and design to driver training and stakeholder engagement. However, software modifications would have to be made to replicate both the pedestrian warning application for transit vehicles and right turn in front of transit vehicle applications.

The high-fidelity, high-cost option provides a full range of capability. However, investing in this level of simulator capability may not be supported by available budgets. Similarly, the low-cost operation provides some capability to test and evaluate; however, these systems may not provide the high level of fidelity that is important for training and driver acceptance. The middle cost option represents an appropriate compromise in cost, capability, and fidelity.

Choosing a course of action from the options available depends on the answers to the following questions:

- **What is the long-term vision for simulator use?** Driving simulators are expensive to purchase, operate, and maintain. Investing in a high-fidelity, high-cost simulator could provide a powerful platform to support a long-term research vision.   It must be understood, however, that simulators require ongoing staffing and maintenance; therefore, ongoing financial support will be required. In brief, as outlined in Table 4-3, the long-term vision establishes the general level of investment required.

- **What are the research program priorities?** What are the most important reasons for using the simulator? If the focus is on conducting interface testing and development, for example, a lower fidelity and lower cost simulator could accomplish the purpose. If training is a priority, then a higher fidelity simulator is appropriate.
- **What are the anticipated institutional arrangements?** Ownership, operation, maintenance, and financing arrangements for the simulator will impact the next steps. A business model that requires the purchase of a simulator for long-term use is different from a business model that anticipates a one-time demonstration of simulator capability.

Table 4-3. Relationship Between Long-Term Vision and Investment Requirements

Long Term Vision	Simulator Investment Level Required		
	Low	Moderate	High
Full complement of research program capabilities			●
Limited capabilities to support occasional application		●	
One time application of driving simulator focused on a single application	●		

4.2 Recommendations

The overall conclusion of this feasibility assessment is that it is indeed feasible to use existing, state-of-the-practice bus simulators for the subject research topics. The technical feasibility is not in question, though it is likely that any of the existing devices would require some modification, even if it is just to develop new scenarios for the research programs under consideration. The economic and institutional factors are more significant in the overall decision process; these factors provide both challenges and opportunities for FTA. The challenges lie in the inherent difficulty of coordination through the U.S. transit “enterprise” to include local agencies and other entities that may have assets that can be leveraged to the broader benefit of the enterprise beyond their own local needs. There are also challenges in determining the course of action with the highest return on investment (ROI) with an allowable and reasonable risk. The opportunities exist in the benefits to local, State, and Federal agencies as all levels gain added visibility into the technical simulator capabilities across the enterprise. This can have a long-range benefit of increasing standardization as well as saving money.

The feasibility assessment can be summarized as two broad courses of actions (COA) each with two recommendations. The first COA is essentially to purchase a bus simulator for use at an FTA site and establish a research facility—even a modest research facility. The second COA is to establish an inter-agency cooperative program. Table 4-4 provides a summary of the recommendations. A further explanation of the recommendations is discussed following the table.

Table 4-4. Summary of Feasibility Assessment Recommendations

Course of Action (COA)	Activity	Recommended? (Yes/No)	Rationale
COA 1 – Establish Simulator-Based Research Facility	1. Purchase Bus Driver Simulator / Establish research facility.	No	Total cost of ownership (TCO) may be too large as an initial step, considering other options (COA 2) may be available.
	2. Publish sources sought notice (SSN) soliciting technical details from industry.	Yes	Although not required at this time as an initial step towards purchasing a system, this can be helpful in establishing terms of reference between industry and the FTA.
COA 2 – Establish Inter-agency Cooperative Program	3. Publish inter-agency request for information soliciting information on existing simulators/facilities.	Yes	Systematically obtaining the information on existing simulators and/or facilities is a necessary step for this COA.
	4. Establish inter-agency cooperative program.	Yes	This action provides both a means of executing the research in the two application areas in a cost-efficient manner.

Course of Action 1: Establish a Transit Simulator-based Research Facility (NOT recommended)

Activity 1 – Establish a Simulator-Based Research Facility – NOT recommended: One of the possible steps that could be taken by FTA is the purchase of a simulator system and the establishment of a research facility. Purchasing a simulator without some plan or intent to use it on a regular basis, however, is not advised. This implies that the recommendation to purchase a simulator would also include a recommendation to establish a research facility and/or program around the simulator. Even a modest research center has advantages, including an ability to control the experimental agenda directly such that the research required in the two application areas considered in this study and other similar programs could be conducted in a timely fashion. Such a central facility, however, requires a commitment not just in the purchase of a simulator system (whether on the low or high end), but also a commitment to a program of study, including operations and maintenance costs, facilities costs, and at least a minimum of staff. This kind of commitment would be required in order to realize an adequate return on investment (ROI). This action is NOT recommended to FTA at this time both because 1) there are other steps that can be taken in the near term that have the prospect of being a more suitable "business model" for FTA (see Recommendations 3 and 4); and 2) this step can be taken at a later date if needed.

Activity 2 – FTA publish a Sources Sought Notice –Recommended: During the course of this feasibility study, design and cost details made available by vendors were sufficient for the purposes of this study, but to make the most informed decision about which system or systems to purchase for one or both of the research programs under consideration will require a level of detail and specificity not allowed by a general study of this nature. Some of the information required will be proprietary, potentially both in design and cost. One solution to this is for FTA to publish a sources sought notice (SSN) or request for information (RFI) to gather more details of industry capabilities related to these two programs. Although it is not recommended to purchase a simulator system at this time, this action can be useful in establishing a baseline of terms of reference (TOR) for these and related application areas—even if an SSN or RFI is not followed up by a request for proposal (RFP).

Course of Action 2: Establish an interagency cooperative program (Recommended)

Activity 3 – FTA publishes an interagency call for available simulator systems – Recommended: FTA publishes an interagency call for information to learn the types of simulators available at existing local agency facilities. Several such agencies were located during the course of this study including the ***University of Minnesota / Minnesota Valley Transit Authority; Paducah, Kentucky; and Washington Metropolitan Area Transit Authority (WMATA) New Carrollton Station.*** Facilities such as the ones cited, as well as others, have the potential to support research programs of interest to FTA. This is largely an information gathering activity, initially requiring minimal effort, but can provide a baseline of capabilities across the U.S. transit "enterprise." This also has the potential to benefit both FTA and the local agencies. FTA would benefit by locating facilities that closely matched the needs for the particular research program; the local agencies benefit by making known their capabilities to a larger market (including other transit agencies).

Activity 4 – FTA establish an interagency cooperative research program – Recommended: Using the information learned in Recommendation 3, the FTA should establish a program whereby the best suited existing facility can be used for research on a "pay as you go" basis. Modifications would be made to the simulators at the individual sites. Costs would include making modifications to simulators and/or scenarios, travel to and from the local site, and other items such as facilities cost sharing as negotiated with the local agency. Individual agencies/sites benefit by the modifications and upgrades. FTA benefits by using these on a negotiated, as-needed, basis. This approach would require some additional coordination at the FTA level, but the investment in coordination is likely to be less than that required to purchase a simulator and have a greater ROI. The ROI is likely to be not only the ability to conduct research programs as needed, but also a significant step towards uniformity and standardization of bus driving simulator systems and training programs.

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Appendix A. List of Contacts

Agency/Organization	Contact
Delaware Transit (DART), Wilmington, DE	Denise Beaston, Employee Development Manager
Doron Precision Systems Incorporated	Lawrence De Mayo, Contracts Manager
FAAC Incorporated	Steve Mentzer, Manager, Transit Simulations
LA Metro, Los Angeles, CA	Michael Turk, Assistant Manager - Metro Operations Central Instruction
Mass Transportation Authority (MTA), Flint, MI	Sybil Ford, Training Coordinator
Nashville MTA, Nashville, TN	Steven Fields, Training Manager
Orange County Transportation Authority (OCTA), Orange County, CA	Mark Andrews, Operations Training Manager
Paducah Transit, Paducah, KY	Jim Eastwood, Marketing/Simulator Instructors
Palm Tran, Palm Beach, FL	Jeanne Rougeau, Safety and Training Supervisor
System Technologies Incorporated	Wade Allen, Technical Director
University of Minnesota	Craig Shankwitz, Intelligent Vehicles Lab
WMATA (Washington, D.C.)	Jimmie Colclough, Assistant Supervisor

Appendix B. Acronyms

Acronym	Meaning
BOK	Body of Knowledge
CAN	Controller Area Network
CGF	Computer Generated Forces
CHU-DS	Chung Hua University Driving Simulator
COP	Community of Practice
CWS	Collision Warning System
DAS	Driver Assistive System
DOF	Degrees of Freedom
DVD	Digital Video Disc
DVI	Driver Vehicle Interface
FOV	Field of View
GSA	General Services Administration
IEEE	Institute of Electrical and Electronics Engineers
IG	Image Generator
LCD	Liquid Crystal Display
LIDAR	Light Detection and Ranging
MTA	Mass Transportation Authority (Flint, MI)
NYCT	New York City Transit
OCTA	Orange County Transportation Authority
OEM	Original Equipment Manufacturer
PATS	Paducah Area Transit System
SAE	Society of Automotive Engineers
U.S. DOT	United States Department of Transportation
V2V	Vehicle-to-Vehicle
VSC-A	Vehicle Safety Communications - Applications
WMATA	Washington Metropolitan Area Transit Authority

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