Ground-Vehicle Operator Training Using a Low-Cost Simulator

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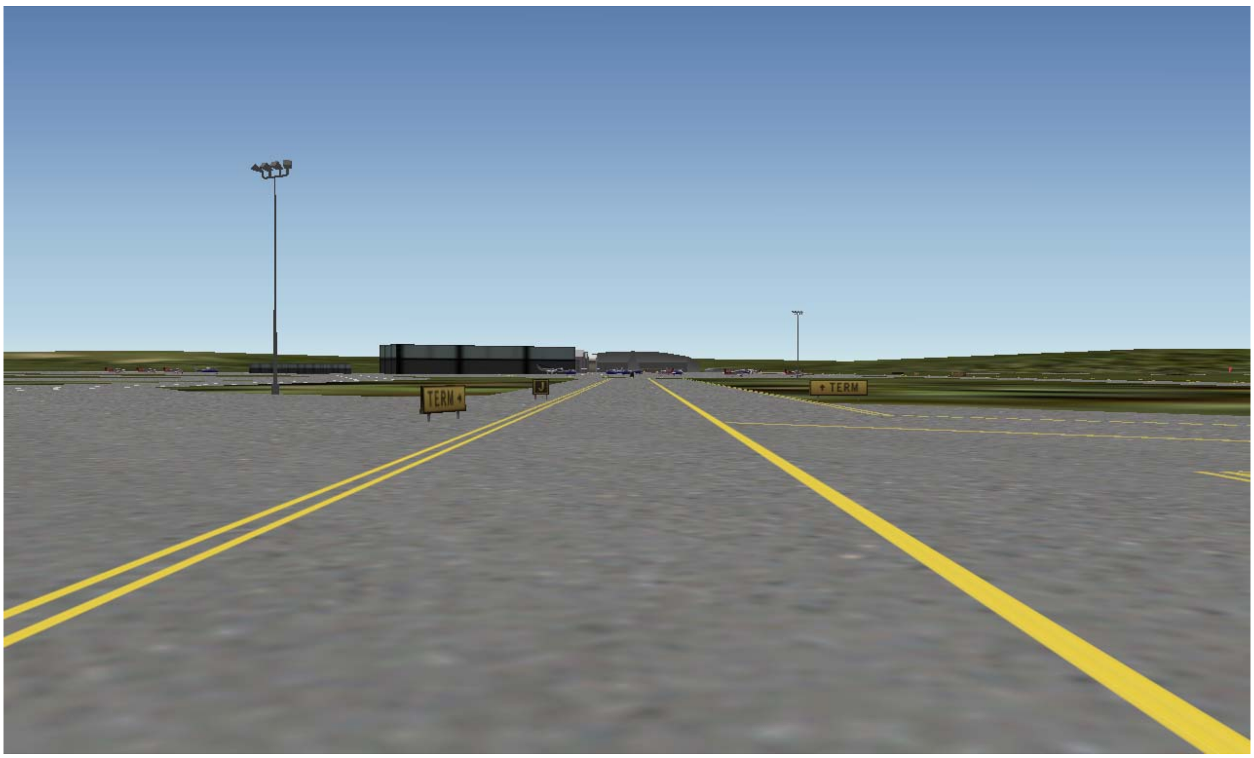
& Operational Services
Washington, D.C. 20024



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13. ABSTRACT (Maximum 200 words)

Pilots, controllers, and ground-vehicle operators all have an important role in runway safety. Their actions, either individually or collectively can cause or avert a runway incursion. The roles and responsibilities of pilots and controllers in this area are easily identifiable. However, the roles and responsibilities of ground-vehicle operator's runway safety are equally important. In addition, other vehicle operators who drive primarily on non-movement area surfaces such as ramps, may occasionally have a need to operate on the movement area, i.e., runways and taxiways, or may inadvertently enter such areas. Consequently, the training of ground-vehicle operators is an important component of runway safety. The airport operator is responsible for seeing that the drivers on his or her airfield are properly trained. The driver-training curriculum at an airport should address the many factors involved in runway incursions and allow for discussion of these factors in an open forum. As part of this training, it is important to discuss emergency maneuvers that a driver may need to take and allow drivers to practice emergency avoidance maneuvers. Training in a vehicle simulator can help satisfy all these training objectives. This report addresses the use of low-cost driving simulators as one potential component of a comprehensive ground-vehicle operator-training program for the overall improvement of runway safety.

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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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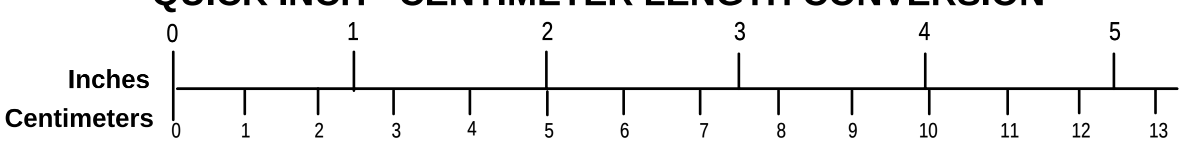

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286 Updated 6/17/98

Preface

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Executive Summary

Pilots, controllers, and ground-vehicle operators all have an important role in runway safety. Their actions, either individually or collectively can cause or avert a runway incursion. The roles and responsibilities of pilots and controllers in this area are easily identifiable. However, the roles and responsibilities of ground-vehicle operators for runway safety are equally important. Their responsibilities include such things as inspection of pavement surfaces, maintenance of airfield infrastructure, snow removal, wildlife mitigation activities, and responding to aircraft emergencies—all of which may be performed on or in close proximity to the runway. In addition, other vehicle operators who drive primarily on non-movement area surfaces such as ramps, may occasionally have a need to operate on the movement area, i.e., runways and taxiways, or may inadvertently enter such areas. Consequently, the training of ground-vehicle operators is an important component of runway safety. The airport operator is responsible for seeing that the drivers on his or her airfield are properly trained.

The driver-training curriculum at an airport should address the many factors involved in runway incursions and allow for discussion of these factors in an open forum. As part of this training, it is beneficial to discuss maneuvers that a driver may need to take in unexpected dangerous situations and allow drivers to practice emergency avoidance maneuvers. Training in a vehicle simulator can help satisfy all these training objectives. Past research has shown that a high-cost, high-immersive simulator is an effective training tool in ground-vehicle training for both initial and recurrent training (Chase and Hannon, 2006). The current research investigated whether use of a low-cost driving simulator in training could provide the same benefits as the more expensive version.

This report addresses the use of low-cost driving simulators as one potential component of a comprehensive ground-vehicle operator-training program for the overall improvement of runway safety.

The first portion of this paper discusses findings from vehicle pedestrian deviation (VPD) reports from FY 02 to FY 03. The results from analyzing the reports showed that the aircraft in an incursion involving a vehicle driver was most likely to be on final approach. This finding illustrates that need to scan for traffic in the air as well as on the airport surface. This procedure should be emphasized in drivers training. It was also found that General Aviation (GA) aircraft is the most common aircraft involved in an incursion with a vehicle driver. Lastly, daylight was seen as the most common time for a VPD to occur. Though this finding could be contributing to the fact that more operations occur in the daylight, it was interesting to note that low visibility is not a factor in most VPDs.

The second portion of the report addresses the needs of the airport operator and trainers regarding using a simulator in training of airport ground-vehicle drivers. This was investigated using in-depth phone interviews. It was found that the majority of trainers feel that their current training curriculum is adequate, but could be enhanced by incorporating more information on particular topics as well as incorporating a simulator into their program. However, there are many considerations in acquiring a simulator

such as cost, support, and ease of use. Overall, the feedback is very positive on the integration of a simulator into the training curriculum of ground-vehicle drivers.

The third portion of the report discusses the results from the studies testing the low-cost simulator built from the ground up. A series of studies attempted to address simulator fidelity issues in regard to performance in a low-fidelity, low-cost simulator. The starting point for this work was determining training requirements and potential hardware and software to use for building the simulator to keep costs low. After creating a simulator at the Volpe Center, psychologists and computer engineers tested it and the following information was concluded:

- Using a 1-panel screen is optimal for a low-cost simulator. The lowest cost option for a 1-panel screen is a desktop monitor. However, it did score lower in the drivers' ability to understand wayfinding tasks due to lack of environmental cues, such as a certain landmark being out of sight or too small to see. The results also showed that the desktop monitor was adequate/good for practicing signs, markings, and procedures.

- Off the shelf software, such as X-Plane performed well in regard to the pictorial realism needed. Though a couple of comments indicated that the participants felt like they were in a video game, many felt that the graphics achieved sufficient realism for training purposes.

- The overall results from the experienced and novice participants illustrate that a low-cost simulator with lower fidelity does not negatively impact the benefits of the simulator within the setting of ground-vehicle training.

- The issue of simulator sickness is a problem in the low-cost simulator as it was previously shown in the high-cost simulator (Chase & Hannon, 2006). Simulator sickness was more of a problem with participants who were given the 1-panel view with optional side-to-side viewing. Based on these findings, a stationary field of view is recommended for reducing simulator sickness symptoms.

- Participants who were given the drop-point task in training, did much better at integrating their classroom and practical knowledge, which helped them recognize their location on the airport surface. It appears that using this task in training helps participants to integrate their knowledge and simulator experience to create a "mental map" of the airport surface.

The final portion of the paper looks beyond the current project and into future endeavors. Future work would see a change of direction from current research from building and testing a simulator within a research facility to exploring the process of having a number of airport operators building and implementing low-cost simulators at their facilities. This work could provide a comprehensive understanding of what problems occur during the process of building a low-cost simulator; expectations of the simulator-in-training curriculum; and how the simulator can be integrated into the facility's current training curriculum and its potential benefits therein. Another idea for future work would be to develop training methods for use with a range of educational technology for the purpose of training airport vehicle operators.

List of Acronyms

ATC	Air Traffic Control
BED	Hanscom Field Airport – Bedford, Massachusetts
DOT	Department of Transportation
FAA	Federal Aviation Administration
MAC	Minnesota Metropolitan Airports Commission
MSP	Minneapolis-St. Paul International Airport
Volpe Center	Volpe National Transportation Systems Center
VPD	Vehicle Pedestrian Deviation

1. Introduction

Pilots, controllers, and ground-vehicle operators all have an important role in runway safety. Their actions, either individually or collectively can cause or avert a runway incursion. The roles and responsibilities of pilots and controllers in this area are easily identifiable. However, the roles and responsibilities of ground-vehicle operators for runway safety are equally important. Their responsibilities include such things as inspection of pavement surfaces, maintenance of airfield infrastructure, snow removal, wildlife mitigation activities, and responding to aircraft emergencies—all of which may be performed on or in close proximity to the runway. In addition, other vehicle operators who drive primarily on non-movement area surfaces such as ramps, may occasionally have a need to operate on the movement area, i.e., runways and taxiways, or may inadvertently enter such areas. Consequently, the training of ground-vehicle operators is an important component of runway safety. The airport operator is responsible to see that the drivers on its airfield are properly trained.

The driver-training curriculum at an airport should address the many factors involved in runway incursions and allow for discussion of these factors in an open forum. As part of this training, it is beneficial to discuss maneuvers that a driver may need to take in unexpected dangerous situations and allow drivers to practice emergency avoidance maneuvers. Training in a vehicle simulator can help satisfy all these training objectives. Past research has shown that a high-cost, high-immersive simulator is an effective training tool in ground-vehicle training for both initial and recurrent training (Chase and Hannon, 2006). The current research investigated whether use of a low-cost driving simulator in training could provide the same benefits as the more expensive version.

This report is divided into a number of sections:

Section 1 examines the factors involved in runway incursions involving a vehicle. This was accomplished by providing data gathered from the Vehicle/Pedestrian Deviations FY 2000-2003.

Section 2 addresses the actual training needs expressed by airports. The needs assessment was accomplished by conducting interviews at nineteen airports across the country. Interviewees were asked to give candid responses about their current training curriculum as well as their needs for enhancement, including the potential use of a simulator.

Section 3 documents the empirical assessment of a low-cost simulator and how well it fits the needs of the ground-vehicle-training curriculum. This section also discusses the need for recurrent training and how using simulation can heighten awareness on the airport surface.

Section 4 addresses the symptoms of simulator sickness with an empirical assessment and with a post-comparison to a high-fidelity simulator.

Section 5 gives a summary of the findings and what it means in terms of benefits to the airport.

2. Vehicle Pedestrian Deviations

Vehicle pedestrian deviations (VPDs) are caused by many factors such as airport infrastructure, communication, environment, and operational procedures. Understanding the complexity of factors comprising a VPD incursion will potentially provide specific direction for future reduction of runway incursions. Also, modifications to current training curriculum of vehicle drivers (both novice and recurrent) could be instituted to help make drivers aware of potential issues and reduce the number of runway incursions due to vehicle driver errors.

The FAA (2004) put forth two different instructional CDs for tug and tow operations, and taxi basics for mechanics to provide better instruction for avoidance of runway incursions and began the implementation of recurrent training to assist in spreading awareness on similar issues. A second example of where training might deter future incursions is when working with “hot spots” of the airport surface that can be caused by signs and markings labeled in an unclear or incorrect manner. In the next few paragraphs, findings from FY 2000-2003 VPDs and their potential usage in ground-vehicle training will be briefly discussed.

2.1 Current Analyses

The data from 291 Runway Incursion VPDs from FY 2000-2003 helped provide a basic understanding of the problem locations on the airport surface as well as procedures, which are potential factors in a VPD. While this information is useful in helping to understand the factors that contribute to vehicle driver errors in general, airports are encouraged to identify their own “hot spots,” that is, locations that are particularly vulnerable to incursions, and use this information in their driver training.

The aircraft involved in an incursion with a vehicle driver was most likely to be on final approach, a finding that illustrates the need for vehicle drivers to scan for traffic in the air as well as on the airport surface. Driver training should stress the importance of looking for aircraft on approach, as well as on the surface, before crossing an active runway.

The most common aircraft involved in an incursion with a vehicle driver is a General Aviation (GA) aircraft. The number of GA airports greatly outnumbers the number of larger airports, thus illustrating the need of ground-vehicle training at airports of every size.

Lastly, daylight was seen as the most common time for a VPD to occur. Though this finding could be contributed to the fact that more operations occur in the daylight, it was interesting to note that low visibility is not a factor in most VPDs. These findings illustrate that every incursion is more complex than just one factor, and most likely occur from an interaction of factors.

2.2 Incursions and Training

The training the ground-vehicle driver receives (initial as well as refresher training) can be an integral component in reducing the number of incursions that occur on the airport surface. Based on the data gathered in VPD reports, a couple of questions (in regard to current vehicle driver training) arise:

- Are the factors involved in incursions discussed in training?
- How much time is spent on these topics in training?
- Are changes made in the curriculum based on incursions?
- Are there any enhancements that can be made to the current training curriculum?

To better understand the influence drivers' training can have on reducing incursions, it is important to understand the training curriculum from a number of airports differing in size, complexity, and location.

3. Interviews on Training Curriculum and Simulator Use

Twenty-three ground-vehicle driver trainers or airport operations managers were interviewed at 19 different airports.[1] The purpose of these interviews was to gather information regarding each airport's unique needs in meeting their required training curriculum and to understand the trainer or airport operator's opinion regarding the potential assimilation of a driving simulator into their ground-vehicle drivers training program. This would include training for novice drivers as well as recurrent training for experienced drivers. Any potential benefit or concern associated with using a simulator for this purpose was also discussed during the interview. Below is a list of issues covered in the interviews:

- What comprises the airports' current curriculum and experience
- Success/deficiencies of their current training curriculum
- Incorporation of simulation into their current training
- Which features of the simulator the trainers felt would be most beneficial
- Specifications for software/hardware (regarding ease of implementation and use)

3.1 Current Training Experience and Curriculum at Airports

Trainers. The majority of airports that participated in the interview employed 1-3 trainers (10 airports). However, other airports used between 4-6 trainers (6 airports), and a few airports reported having over 10 trainers (3 airports) available, though only one trainer is used per training session.[2] Trainers' qualifications most commonly consist of previous airfield experience and passing individual airport trainer training.

Trainees. The number of trainees per session differed by airport with the majority of airports having 1-5 trainees per session. Other airports were also found to have anywhere from 6-20 trainees per session. Many of the trainees were emergency response personnel (firefighter, EMT), FAA technician, airfield maintenance workers, and operations supervisors and personnel who all drive a variety of different types of vehicles.

Session Characteristics. The majority of vehicle driver training sessions take place on one day, and last on average 1-4 hours. Training sessions are available every 1-4 weeks depending, on the need at the individual airport. Most training sessions consisted of a visual (video, PowerPoint) and written (test, handbook) component. Lectures were also integrated in the majority of the training, though the lectures were not uniform in content across airports. All but one airport included airport surface training (i.e. driving on the airport surface) as part of the training curriculum.

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[1] The criteria used to select airports were based on the ATC level and region. A conscientious effort was made to select at least two airports from each region, one of a high ATC grade and one of a low ATC grade. Due to the response or lack thereof from the airports, the selection of airports was not optimally distributed. We included a larger number of low to medium ATC level airports than high ATC level airports.

[2] One airport stated that they use three trainers per session.

Updating Curriculum. Airports typically update their curriculum only “as needed” in response to issues such as surface reconfiguration, sign and marking changes, or an incursion. Three airports stated that they update their curriculum annually due to the feedback they receive from the trainees as well as the trainers. Changes to the curriculum are usually made by the trainers themselves or in collaboration with the airport operation director or others in the Safety Department. The most common change to the curriculum is to the airport layout, which includes construction, signage, and “hot spots.”

Refresher training. This type of training is usually offered annually at the airports. The majority of refresher training takes place because of recertification requirements. Some airports also require refresher training after an incident. Over half of the airports (12 airports), refresher training is identical to novice training in regards to the information covered. For other airports, factors such as test results and/or the type of driver establish what information is stressed upon. It seems that for only 12 of 19 airports, the actual amount of on-the-job experience a driver has is an important consideration. This is surprising since one could assume that experienced drivers would become bored sitting though information that is elementary to them and discussed in a way that related well only to the novice driver.

3.2 Success/Deficiencies of Their Current Training Programs

Beneficial components. Overwhelmingly, the trainers interviewed felt that practical driving on the airport surface was the most beneficial component of the training. This asserts that practical experience could in fact be more beneficial than classroom type learning.

Deficiencies. All trainers were asked if there is anything that is currently left out of their training curriculum that needs to be addressed or any topics that need to be covered more in-depth. The most common responses for requirements for airport vehicle driver training were:

- Ability to provide training suitable for different types of airport vehicles
- Need for training in how to drive in hazardous weather conditions
- Airport layout
- Driving in night vs. day
- Need for new Federal Aviation Administration (FAA) video on ground-vehicle training
- Increased time to practice (over what is usually provided)

3.2.1 Important Topics

There are a variety of topics that are covered in the training sessions at each airport. Some topics are given more attention than others based on the unique circumstances of each airport, which in many cases involve the complexity of the airfield, adverse weather conditions, and the volume of traffic. Many trainers feel the most important subjects covered in the classroom are the following:

- Situational awareness (position on the airport surface)
- Safety procedures
- Signs and markings
- Airfield configurations

3.3 Incorporation of Simulation into their Current Training

Experience with Simulation. Ten of the 23 trainers interviewed had experience in a simulator, but only a quarter of the trainers had experience with an actual driving simulator. All trainers who had been in a simulator considered it a positive experience.

3.3.1 Helpful Training

When asked if a simulator could help them meet their training criteria, the majority of trainers felt it would be very helpful and only one trainer felt it would not be helpful at all. A few additional trainers were not sure how helpful it would be since they had little experience with a simulator. For those who thought the use of a simulator might be helpful, the following components/type of training were thought to possibly be enhanced with its usage:

- Signs/Markings
- Airport configuration/Navigation
- Situational awareness/Drop points
- Safety awareness/Risky situations
- Rules and procedures
- Radio communication
- An "addition" occurring after classroom training and before the check ride
- Recurrent training

3.4 Most Beneficial Features of the Simulator

When asked which features of the simulator they felt would be most beneficial, over half of the trainers agreed on the following:

- Providing performance feedback to the trainee

- Exposing trainees to a number of different scenarios, including hazardous situations in which emergency avoidance maneuvers are required

- Allowing trainees to practice on their own time

The ability to use performance measures in the simulator, such as number of incorrect turns in a given route of the trainee's ability, was seen by less than half of the trainers as something beneficial to their training curriculum.

3.5 Hardware/Software Considerations

For many trainers the idea of a simulator is quite abstract since many of them have no simulator experience at all. For the trainers with simulator experience, most were experience in a flight simulator, not a ground vehicle simulator. About half of the trainers had a high comfort level with computers. Those who are not completely comfortable with computers stated that lack of experience wouldn't stop them from incorporating a simulator into their curriculum. Questions regarding software and hardware were also asked to better understand how the trainers envision their role with the simulator and how realistic it would be to integrate it into their curriculum.

3.5.1 Software

Overwhelmingly, trainers saw themselves designing the scenario (route, visibility, type of vehicle, etc.) that would be used in the simulator. The ability to incorporate multiple scenarios in a training session was seen as an important aspect of the simulator's usage. The ability to modify the following variables was found to be important to the trainer:

- Weather/Visibility
- Traffic activity
- Time/day
- Airport surface/Active runways
- Type of vehicle/Lighting in vehicle (e.g. dashboard)
- Radio Communications

Most trainers stated that they would be willing to spend up to 5 hours modifying a scenario for training. This modification would include any combination of the variables listed above. Other trainers stated that they would be willing to spend as much time as needed in modifying the scenarios. All trainers agreed that having the simulator supplied with ready-made templates and pre-programmed scenarios would also be of great value to them.

3.5.2 Hardware

After a discussion of the types of driving simulators that are available, trainers were split, with half of the trainers responding that they would want a PC based simulator with a steering wheel and pedals to implement in their training. The other half of trainers felt that both a full immersive cab with 360-degree field of view, or at minimum, multiple plasma screens with a steering wheel and pedals would be their choice of simulator to implement in their training.

3.6 Concerns of Including Simulation in Training

All but one airport[3] felt that it would be beneficial for their airport to purchase a simulator. Though trainers seemed very interested in having a simulator, there were also

[3] One airport wasn't sure if it would be beneficial due to the fact that the airport is very small in size.

other factors to consider. The following is a list of concerns that many of the trainers believed could prevent the use of a simulator at their airport:

- Cost of the simulator
- Space for the simulator
- Potential maintenance and upkeep
- Lack of FAA support for simulator development and usage
- Ability to train only one at a time
- Negative trainee feedback
- Inability to prove that skills learned in the simulator directly result in fewer incursions on the airport surface.

Some airports also addressed the possibility of airports that are geographically close to one another sharing a simulator so that more than one airport's scenarios would be available on a simulator. This would allow more flexibility with the cost of the simulator.

3.7 Summary from the Interviews

Based on the interviews from ground-vehicle trainers, the majority of trainers feels that their current training curriculum is adequate, but could be enhanced by incorporating more information on particular topics as well as incorporating a simulator into their program. However, there are many considerations in acquiring a simulator such as cost, support, and ease of use. Overall, the feedback is very positive on the integration of a simulator into the training curriculum of ground-vehicle drivers.

Many trainers expressed some concern that the high immersive simulator would be too costly and a low-cost simulator would not be as beneficial to their current program due to potential limitations, such as lack of realism due to its low cost. The cost of a simulator is an issue that needs to be dealt with directly at the airport and is administrative in nature, however testing a low-cost simulator in a training environment could help shed some light on its performance potential if incorporated into the curriculum. The remainder of this paper will describe the testing of a low-cost simulator with both the novice and experienced ground-vehicle driver.

4. Testing of a Low-Cost Simulator

After completion of studies that looked at the validation and usage of a high fidelity simulator airport developed by the Minnesota Metropolitan Airports commission (MAC) at the Minneapolis-Saint Paul International Airport (MSP), further research was needed explore the potential alternative of a low-cost, lower fidelity simulator for many airports who have monetary as well as space constraints.

4.1 Description of Low-Cost Simulator Hardware/Software

The low-cost ground-vehicle-driving simulator was constructed mainly from existing hardware that has been widely available commercially since 2000. The PIII CPU and 64mb video memory specification is very low by today's standards. The Hardware used for this simulator experiment is the minimum required to effectively run the software specified. The multiple visual displays used in the studies along with X-Plane software created a situation where four older networked computers were required. X-Plane version 7.63 was chosen as the commercial off-the-shelf platform for the low-cost airport driving simulator project. X-Plane 7.63 was chosen over other entertainment and open source flight simulators for its stability and ability to run on our low power Hardware and included tools and freeware for making and modifying airports. Below is a diagram (Figure 1) of the low-cost simulator and the hardware involved. Also see Appendix B for further details on hardware used in creating the low-cost simulator, see Appendix C regarding software used in creating the low-cost simulator, and see Appendix D & Appendix E for photos of the low-cost simulator hardware.

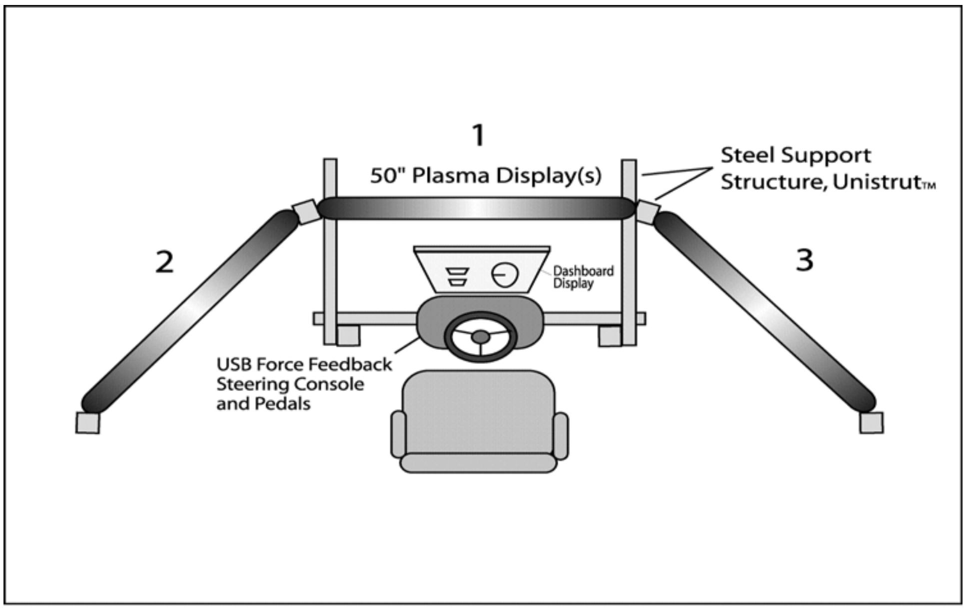


Figure 1. Diagram of Simulator[4]

[4] Participants in study 1 were given the single panel field of view, where display number 1 was used and display 2 & 3 were turned off.

4.2 Low-Cost Simulator Studies

Two studies were performed to explore whether there are benefits of using a low-cost simulator in the training of airport vehicle drivers. The first study had inexperienced drivers participate to examine the use in initial training. The second study had experienced airport ground-vehicle drivers from (BED) participate to look at the use of low-cost simulators in recurrent training.

The studies were created using elements of the studies run at Minneapolis/St. Paul (MSP) with the high fidelity simulator. The virtual environment was not MSP, but Bedford/Laurence G. Hanscom Field (BED), which is located in Bedford, Massachusetts. (See diagram below.) BED has an elevation of 133 feet and operates two runways; an east-west runway 11/29, which is 7001 feet long by 150 feet wide, with full ILS/DME instrumentation for all-weather operation; and a southwest-northeast runway 5/23, 5100 feet long by 150 feet wide. This airport is quite a bit smaller than MSP, but still requires training of their ground-vehicle personnel in the most efficient way possible.

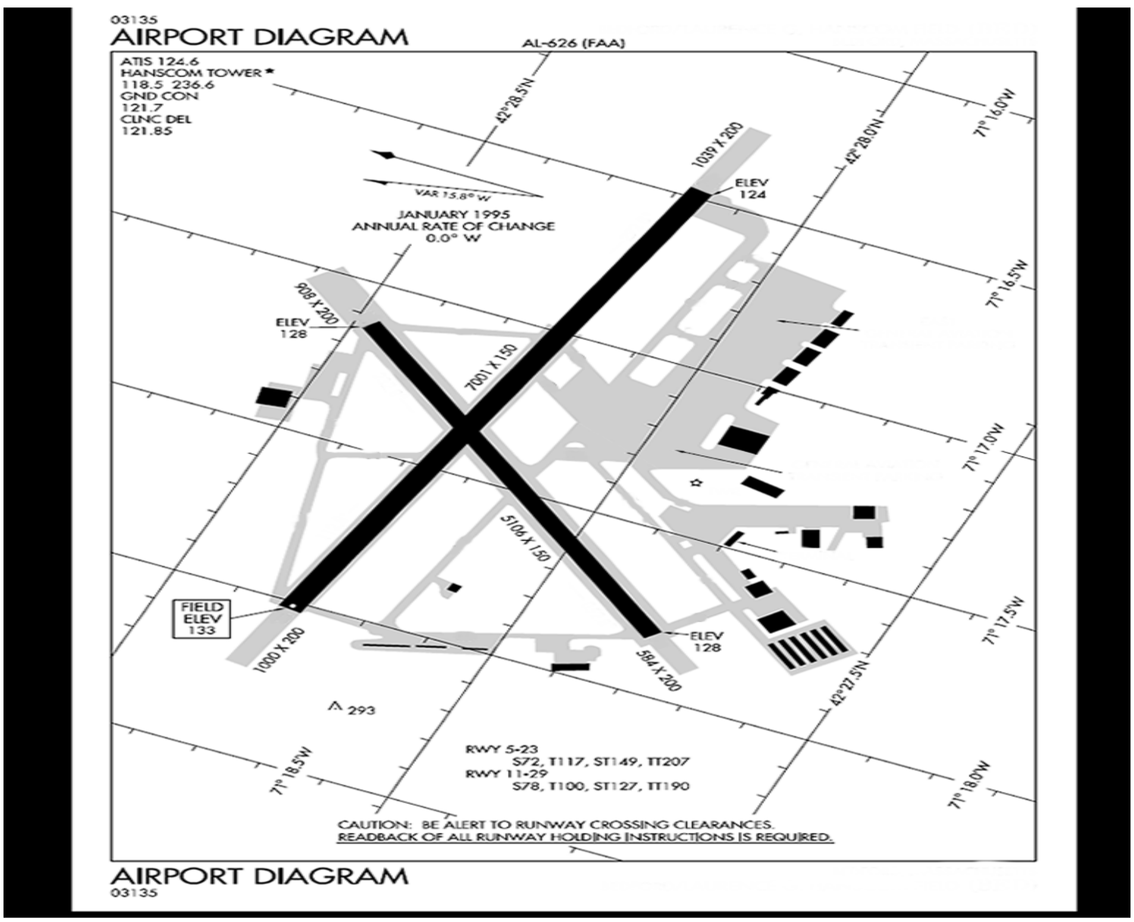


Figure 2. Diagram of Hanscom Field Airport (BED)

4.2.1 Study 1: Spatial Knowledge and Novice Drivers

Study 1 was created as a means to test the low-cost simulator's ability to enhance initial drivers' training. Since much of the training of ground-vehicle operators involved initial training, this study is deemed crucial to the simulator's assessment. Participants consisted of 31 Massachusetts Institute of Technology (MIT) students. None of the participants had experience with Hanscom but all had a driver's license and 40 percent of the students had experience with a simulator. Participants were split into groups so that 1/3 of the participants used the simulator with a 1-panel screen, 1/3 used a 1-panel screen with side- to-side viewing, and the remaining third used a 3-panel screen view (See Appendix E for illustrations of the 3 field of view conditions and Appendix F for comparison of real world airport surface vs. virtual airport surface).

All participants performed the following tasks during the study:

- An initial test of written knowledge about airport operations was given to see how much knowledge the individual came into the study with.

- Received classroom training on airport operations. This comprised reviewing the initial test as well as giving the participant time to ask questions accomplished this task.

- A map of the airport surface was given for participants to examine.

- Participants drove an initial navigation route of the airport surface in the simulator.

- Following the initial navigation route, the participants were given familiarity questions, which were asked at particular points along the route they just drove. An example of this question is "Have you been at this location in your initial navigation route?" in which the participant responded, "Yes," "No", or "I'm not sure." The participants were encouraged to choose "Yes" or "No" before answering with an "I'm not sure."

    - At each point along the route half of the participants also were given drop-point questions, which are a mixture of spatial knowledge questions, navigation problem solving, and declarative knowledge questions. (See Appendix G for examples of drop-point questions).

- A second navigation route was driven in the simulator, identical to the first. The two routes were compared.

- A second written test of airport operations information was given and scores were compared with the first. (See Appendix H for details of experimental methodology).

4.2.1.1 Field of View Findings

The navigation route participants drove in the low-cost simulator encompassed many of the landmarks and taxi/runway intersections, and access road at BED. The experimenter, who was seated behind the participant, gave the route directions (ex. turn onto taxiway Alpha). The route was driven in one of two visibility conditions (night or snow). Though no difference was found by visibility, a difference was found by type of Field of View (FOV) the participant had. The three types of FOV were 3 panels, 1 panel, or 1 panel with manual left-right side-to-side viewing using the steering wheel, if needed. Overall, the results showed a higher level of performance in the 1 panel view than the 3-panel and the 1 panel with side viewing. (See Appendix I – graph 1 for visual comparison) One-panel side-to-side viewing had the slowest route completion. This was an interesting finding due to the fact that the 3-panel view should create a higher-level immersion into the airport environment. Based on our findings, 1 panel is marginally optimal in allowing the driver to experience and learn the airport surface and incorporate the airport operations information into their driving experience.

Participants performed marginally better on the signs and markings test when given the 1-panel field of view than the 3-panel field of view. A considerable difference was found between the 1-panel field of view and the 1-panel field of view with side-to-side viewing with scores on the 1-panel test considerably higher than 1-panel side-to-side field of view. (See Appendix J –graph 2 for visual comparison of results) This allows one to assume that the signs and markings seen in the single panel view were more realistic and therefore were used in navigation and subsequently remembered in the signs and marking test.

Participants' opinion on visual accuracy. Participants in all viewing conditions felt that the signs and markings were either similar or very similar to what would be found at the airport surface. The majority of people, who found the sign and marking test easy, were participants who had a 1-panel field of view with the side-to-side viewing. With its wider field of view, the 1-panel field with side-to-side viewing was subjectively viewed as having clearer images than either the 3-panel or 1-panel views for this particular task. Participants with all three types of field of views felt that the view was realistic and did not find it to be a distraction (Detailed results are provided in Appendix I – graphs 3 and 4).

4.2.1.2 Spatial Awareness and Drop-point Findings

Thirty participants were given familiarity questions at each drop point. An example of a familiarity question is as follows: "Please decide if this location was on the route you just drove 1 = Yes; 2= No; 3 = Unsure." Additionally 5 participants from each field of view group were given both familiarity questions and spatial awareness questions at each drop point. An example of a spatial awareness question is as follows: "Where is the intersection of runways 5/23 and 11/29?"

Time to complete navigation route. The participants who were given the drop point spatial awareness questions with the familiarity questions were able to navigate more quickly than those given only the familiarity questions. (See Appendix H for a detailed description of the testing procedure.) The difference was dramatic, especially for individuals who were given only 1 panel for field of view. It appears that when someone is given drop-point questions and familiarity questions, the individual is better equipped to navigate a route, perhaps because they were able to create a mental map of the environment.

Accuracy on the written test. Participants given drop point questions scored slightly higher on the written test than participants who were given the familiarity questions only (See Appendix I - graph 5). This finding is consistent with the notion that asking spatial awareness and navigation questions can enhance understanding of signs and markings.

4.2.1.3 Summary of Findings with Novice Drivers

From this initial study of the low-cost simulator we have learned the following:

- In general, novice drivers performed better when they trained with a single panel view than with a 3-panel view or 1-panel with side-by-side viewing.

- Training that included spatial questions at drop points on the airport surface increased navigation skills and knowledge of signs and markings over training with familiarity questions alone.

- A 1-panel field of view provided sufficient realism for signs, markings, and depth perception and with the same clarity of the 3-panel view.

4.2.2 Study 2: Recurrent Training

Recurrent training has become an important aspect in the training of ground-vehicle drivers. Even the most experienced drivers who know the airport layout and procedures can be subject to errors and need to be aware of any changes, such as new regulations, construction, or changes in airport layout. Based on past studies at MSP with a high cost simulator, when experienced drivers were asked to drive a route in low visibility, scanning for debris, all drivers were able to stop or veer off the runway when an aircraft was placed on take off roll directly in front of them. This is a good example of how simulators can be used in recurrent training for airport vehicle drivers. Just as for pilots, recurrent training in simulators affords the opportunity to practice responses to hazardous situations.

In this study, we were interested to see if a low-cost, low immersion simulator with a NEC MultiSync LCD1550v 15" Flat Panel Monitor could create an adequate level of realism for the experienced driver. This comparison was used to validate the finding that the 3-panel view is not favored over a single panel (or single monitor) view. A monitor was also used as a “lowest cost” option for a single panel. If monitors do in fact compare well to the flat panel view, it will create a minimal cost of hardware for any airport wanting to build their own ground-vehicle simulator.

Six participants, all experienced drivers from (BED) with between 1 and 19 years experience, were to drive three routes around the airport surface in low visibility conditions. The participants drove their first and second route with no problems. When participants were asked to drive the third route, 2/3 of their way through the route they asked for clearance to cross the runway and after receiving clearance and crossing initiated, a GA aircraft came in front of them on take-off roll. The experienced drivers' reactions were recorded and follow-up questions relating to their experience were asked (See Appendix J for details of experimental methodology).

4.2.2.1 Reactive Results of Aircraft Avoidance

Results showed that all of the drivers were able to get out of the way of the aircraft taking off. Most participants veered off the runway into the grass to get out of the way. Participants mentioned that this act was done without conscious thought. They know the airport layout and knew what was available to them as routes of escape. As one participant pointed out, "When you see a plane right in front of you, your body goes on automatic pilot." Past research has found that mere exposure in the simulator benefits in heightening the drivers' awareness when they actually go out on the airport surface (Chase & Hannon, 2006). This reinforces to the driver that anything can happen out on the airport surface without a moment's notice.

4.2.2.2 Realism of the Simulated Environment

Most drivers felt that this type of scenario could be an effective training tool. Though they stated that they are trained to look before crossing, even when given clearance, it is important to remember that it only takes one instance when you forget to look, to have an incursion. Most agreed that one benefit of simulation in recurrent training is that the more practice the driver gets will heighten the driver's awareness of their surrounding, especially since some drivers will be more familiar with some parts of the airport than others. The simulator should therefore give drivers an opportunity to learn more about the less familiar parts of the airport surface. Many of the participants also felt that this scenario in the simulator should be given to drivers in initial training. Since many of the drivers believed they would act differently because they have experience with the tower, it is important for the initial training to cover issues that have resulted in incursions.

When asked how well they thought the simulator mimicked the real-world experience, they said that overall it was a good tool to have in training. Though many said it was very similar to the real-world experience there were a number of factors that degraded the realism:

- Gas pedals were a little stiff and hard to pick up speed
- Brakes in the simulator were quicker to react than in their own vehicle
- Some graphics looked too much like a video game

- There was no radio communication

4.2.2.3 Field of View Findings

All of the experienced drivers felt that signage and pavement markings were sufficiently realistic; that is, very similar to the real-world environment (See Appendix K). This was true of participants who had the desktop monitor or 3-panel field of view. The only difference in the two fields of view was that when participants had a 3-panel field of view, some of the objects appeared to have a 3-D "pop-out" effect. This was a similar occurrence to the MSP high-cost, high-fidelity simulator. This "pop-out" effect is something that can create distraction for the driver. With the desktop monitor view, all but one participant felt it was a great training tool with good depth perception, and would like to see something similar added in their training. The capability to practice responses to hazardous situations was attractive to all of the experienced drivers who participated in the study.

From the results, it appears that the training benefits seen with the use of a 3-panel or a desktop monitor were virtually identical. While training benefits were demonstrated, one problem that still needs to be dealt with regarding simulation in general is motion sickness (also known as simulator sickness), which affected participants in both studies.

5. **Simulator Sickness: Potential Factors Involved with Low-Cost Simulation**

Simulator sickness symptoms were reported in 70 percent of all drivers in these studies following simulator exposure. In study 1, approximately 68 percent of the 31 participants felt worse after simulator exposure; one driver became too sick to complete the experiment. In study 2, 71 percent of the drivers reported more symptoms following simulator exposure. (See Appendix L for a chart of symptoms).

The top symptoms reported post-simulator exposure were:

- General physical discomfort
- Nausea and other stomach-related symptoms

Even though the percentage of individuals in these experiments who felt symptoms of simulation sickness seems high, it is important to remember the following:

- In many cases, an individual only experienced one of the symptoms and it was not severe.

- Giving a questionnaire (Kolasinski, 1995) before the experiment primed the drivers into becoming more attuned to how they feel physically than they would be otherwise.

- Many of the participants came to the study with symptoms such as headache and sweating.

6. Conclusions and Future Developments

For those interested in buying or building a low-cost simulator for driver training at their airport, the following summary may be useful:

- Using a 1-panel screen is optimal for a low-cost simulator. The lowest cost option, which is a desktop monitor, was seen as adequate/good for practicing signs, markings, and procedures. However, it did score lower in the drivers' ability to understand wayfinding tasks due to lack of environmental cues, such as certain landmarks being out of sight or too small to see.

- Off the shelf software, such as X-Plane, performed well in regard to the pictorial realism that is needed. Though a couple of comments indicated that participants felt like they were in a video game, many felt that the graphics achieved sufficient realism for training purposes.

- Overall results from experienced and novice participants illustrate that a low-cost simulator with lower fidelity does not negatively impact the benefits of the simulator within the setting of ground-vehicle training.

- Simulator sickness is an issue with the low-cost simulator as it was shown with the high-cost simulator (Chase and Hannon, 2006). This was more of a problem with participants who were given the 1-panel view with optional side-to-side viewing. Based on these findings, a stationary field of view is recommended for reducing simulator sickness symptoms.

- Participants who were given the drop-point task in training did much better at integrating their classroom and practical knowledge in being able to recognize their location. It appears that using this task in training helps participants to integrate their knowledge and simulator experience to create a "mental map" of the airport surface.

While the low-cost simulator is seen as a positive addition for use in ground-vehicle training curriculum, some questions remain:

- Can the ability to train in a simulator with the use of a joystick or mouse, instead of a steering wheel or brake/gas pedals be just as effective?

- Is it necessary to adapt the simulator software to the specific airport to be trained, or would a generic airport give the same benefits for practicing the basics, such as signage and procedures? (The benefit of a generic airport is that it could be constructed at a lower cost than one that is adapted to a specific airport).

- Would a treatment type bracelet, such as the ReliefBand® for motion sickness, be enough to lessen simulator sickness symptoms felt by many drivers? If so, should this be tested in the simulator so that drivers could use it without physical discomfort? Other guidelines, such as limiting the exposure in the simulator, would potentially need to be implemented so that symptoms could be kept at a minimum.

Future work would involve the shift of research from building and testing a simulator within a research facility to exploring the process of having a number of airport operators build and implement low-cost simulators at their airport. This work could provide a comprehensive understanding of what problems occur during the process of building a low-cost simulator; expectations of the simulator-in their current training curriculum; and how the simulator can be integrated into the facility's current training curriculum and its potential benefits therein. Another idea for future work would be to develop training methods to be used with a range of educational technology for the purpose of training airport vehicle operators. In conjunction with prior research, it would provide airport operators with a technology-based approach to driver training that will meet the training needs of operators at many levels of experience. This would potentially involve the use of PowerPoint as well as other types of technology commonly available in most workplace settings.

7. References

Chase, S., and D. Hannon. (2006). *Evaluation of a Driving Simulator for Ground Vehicle Operator Training.* Washington, D.C.: Federal Aviation Administration. DOT/FAA/AR-06/1.

Federal Aviation Administration. (2004). *Runway Incursion Trends and Initiatives at Towered Airports in the United States, FY 2000 to FY 2003.* Office of Runway Safety.

Kolasinski, E. M. (1995). *Simulator Sickness in Virtual Environments*. Alexandria, Virginia, U.S. Army Research Institute.

Appendix A: Number of Ground-Vehicle Trainers per Airport

Airport Facility	Number of Ground-vehicle Trainers
ANC	1
BDL	4-5
BED	5
BIS	6
DEN	NO ABSOLUTE NUMBER; INDIVIDUAL DEPARTMENTS ASSIGN TRAINER
DLH	2
HLN	4
HNL	2
ICT	1
LGA	10-11
MHT	3
NEW	NO RESPONSE RECORDED
RIC	3
SAT	5
SLC	1
SRQ	4
STS	1
SUS	3
VRB	1

Appendix B: Software Used for Low-Cost Simulator

Below is a table of software (SW) used in the low-cost simulator experiment.

The table lists and describes the supporting or development SW used to construct the airport, vehicles, scenery, and objects.

Software Name	Description
X-Plane	Version 7.63 used for experiment. Version 8.50 Available for 2006 Commercial Off the Shelf Software. $60
TaxiDraw	GNU General Public License. Overlay X-Plane airport pavement files with satellite imagery and manipulate movement and non-movement areas to make accurate airport layouts. http://taxidraw.sourceforge.net/
Terraserver	GNU General Public License. Obtain quality satellite images of airport to import into TaxiDraw. http://terraserver.microsoft.com
MassGIS	GNU General Public License. Obtain high quality satellite images of airport to import into TaxiDraw or to see airport detail. http://maps.massgis.state.ma.us/massgiscolororthos/viewer.htm
GNU Image Manipulation Program (GIMP)	GNU General Public License. Create, manipulate or modify images that are used as textures applied to objects or vehicles. X-Plane requires Portable Network Graphics (PNG) or Bitmap (BMP) files. http://www.gimp.org
Taximaker (X-Plane Tools)	GNU General Public License. Automates the generation of taxiway signage. http://xsquawkbox.net/tools/xptools/index.php
Object Viewer (X-Plane Tools)	GNU General Public License. Provides a program to view objects with textures outside of X-Plane. http://xsquawkbox.net/tools/xptools/index.php
Blender	GNU General Public License. Open source software for 3D modeling, animation, and rendering. http://www.blender3d.org
World_Maker	Part of X-Plane SW Bundle. Place objects on airport or anywhere in X-Plane. www.X-Pplane.com
Plane_Maker	Part of X-Plane SW Bundle. Place objects on airport or anywhere in X-Plane. www.X-Pplane.com

Appendix C: Hardware Used for Low-Cost Simulator

Below is a table of hardware (HW) used in the low-cost simulator experiment and additionally a 2006 replacement recommendation. 2006 HW alternatives/replacement are mentioned for the benefit of anyone who might attempt to construct a simulator similar to the low-cost driving simulator but with newer hardware. Comments are also given to clarify the rationale behind the replacement.

Hardware Used in Experiment				2006 Hardware Recommendations		
Hardware	Description	Comment		Description	Comment	$
Computer	Pentium III CPU 1.2 Ghz. 256- 512 MB RAM	Polywell 2001 vintage desktop computer 4 computers used		Athlon 64 3200+ or 3Ghz. Pentium 4 CPU or better. 1GB RAM	Additional computers required for multiple monitors/views	800
Video Adapter	nVidia GeForce II 64 MB Video Memory			nVidia 7600GT 256 MB Video Memory PCI-Express or better.		200
Video Monitor	50” Plasma Monitors + 15” LCD			17-19” LCD	Additional monitors required for multiple views	300
Steering/ Accelerator/ Brake	Logitech Driving Force Pro	900 Degrees of rotation		Same		100
Network Switch	Linksys BEPSR81 Router			Workgroup Switch is sufficient	Not needed for single computer simulator	30
KVM Switch	Miniview 4 Port	Optional, used to reduce clutter for experimenter			Not needed for single computer simulator	50

Appendix D: Photos of Low-Cost Simulator

Steering Wheel

Break and gas pedal

Instructor's Station for the Simulator

Appendix E: Three Fields of View in Study 1

These photographs show the 3-panel view. The one-panel view is the center panel only and the one panel with side-to-side view was activated using the arrow buttons on the steering wheel.[5]

[5] In study 2 the same 3-panel view was used as well as a new 15' desktop monitor instead of the 1-panel view as in study 1.

Appendix F: Comparison of Real and Virtual Airport Surface

Real World

Virtual Night

Virtual Day

Appendix G: Drop-Point Questions used in Studies of Low-Cost Simulator

Drop Point #1

- Is taxiway Whiskey to the northeast or the southwest? *Northeast*
- What does the red sign to your left mean? *Hold short Runway 5*
- Where is the terminal? *Behind to the right; East*
- What taxiway begins across the runway in front of you? *Mike*

Drop Point #2

- What direction is Runway 5/23? *East; to your right*
- Where is the intersection of M/W? *South; directly behind you*
- Are you closer to taxiway Romeo or Hotel? *Romeo*
- What does the sign to the left indicate? *On taxiway Mike; Holding short Runway 11*

Drop Point #3

- What does the sign to your left indicate? *On taxiway Tango; Sierra is to the upper right (SW)*
- Where is the General Aviation Parking? *East; to the left*
- Is taxiway Mike to your right or left? *Right*
- What is the name of the line that you are centered on? *Taxiway centerline*

Drop Point #4

- Where is the intersection of runways 5/23 and 11/29? *Straight ahead (west)*
- What is the name of the taxiway to your left (south of you) that is parallel to the runway you are on? *Echo*
- What is the name of the taxiway parallel to Golf? *Foxtrot*
- What do the two signs in this view mean? *Golf is right; Hotel is left*

Drop Point #5

- What type of line is the white line to your left? *Runway edge line*
- Where is taxiway November? *Northwest; behind you*
- Are you closer to taxiway F or G? *Foxtrot*
- What do the red signs in front of you indicate? *Hold short Runway 23/5*

Drop Point #6

- Where is the intersection of runways 11/29 and 5/23? *Right; South*
- What are the pavement markings in front of you called? *Hold short line*
- What taxiway are you on? *Romeo*
- What taxiway continues on after the runway in front of you? *Hotel*

Drop Point #7

- Where is runway 11/29? *NE; Straight ahead*
- What do the signs ahead mean? *Whiskey is to the left, Echo is to the right*

- What runway are you on? *Runway 5-23*
- Is taxiway Tango to the east or the west of your location? *East; to the right*

Drop Point #8

- What do the markings in front of you (1 solid, 1 dashed line) tell you about where you are located? *In non-movement area*
- What do the signs in front of you mean? *Runway 5-23 is to the left; Runway 29 is to the right; and the taxiway perpendicular to you is Sierra*
- Where is the tower? *Southeast; Behind to the right*
- Name one taxiway that intersects with taxiway Sierra. *Tango or Echo*

Drop Point #9

- Where is runway 11/29? *North; Straight ahead*
- What are the names of the two taxiways parallel to the taxiway that you are currently on? *Alpha and Charlie.*
- What is the area behind you? *Parking*
- What does the sign in front of you mean? *On taxiway Bravo about to intersect with taxiway Echo*

Drop Point #10

- Where is the approach end of runway 23? *Northeast; Behind you*
- What do the signs and markings in front of you mean? *Hold short Runway 11/29*
- What taxiway intersection is behind you? *Taxiways Romeo and Hotel*
- What is the name of the next taxiway intersection in front of you? *Taxiways Echo and Whiskey*

Appendix H: Study 1: Spatial Knowledge and Novice Drivers

The ground-vehicle-driving simulator used in this study was developed at the Volpe Center/ Department of Transportation in Cambridge, Massachusetts. The simulator is a low-fidelity simulator built with Laminar Research X-Plane 730 software package, and Driving Force Pro steering wheel with force feedback and gas/brake pedals. Three different fields of view (FOV) were tested with this simulator: 1-panel, 1-panel with side-to-side viewing, and 3-panel. A video camera was used to record the time and behavior of the participants in both driving environments.

Data were collected from the following tasks:

Sign/marking test: A written test of knowledge of signs and markings on the airport surface was given to each participant at the beginning of the session and at the end of the training sessions. Then scores on the pre- and post-session were compared.

Drop-point task: This task required half of the participants to answer spatial awareness questions after being dropped onto one of ten locations on the airport. The other half of the participants were asked only familiarity questions (such as, "Was this location on the route you just drove?" Yes; No; Unsure." This task was performed after classroom training and a driving session in the simulator.

Drop-point route: Participants followed progressive taxi instructions (e.g., turn left onto taxiway bravo). Performance measures were the time required to drive the route, the number of wrong turns, and the number of times that the participant stepped on the brake. This task was performed before and after completion of the drop-point task.

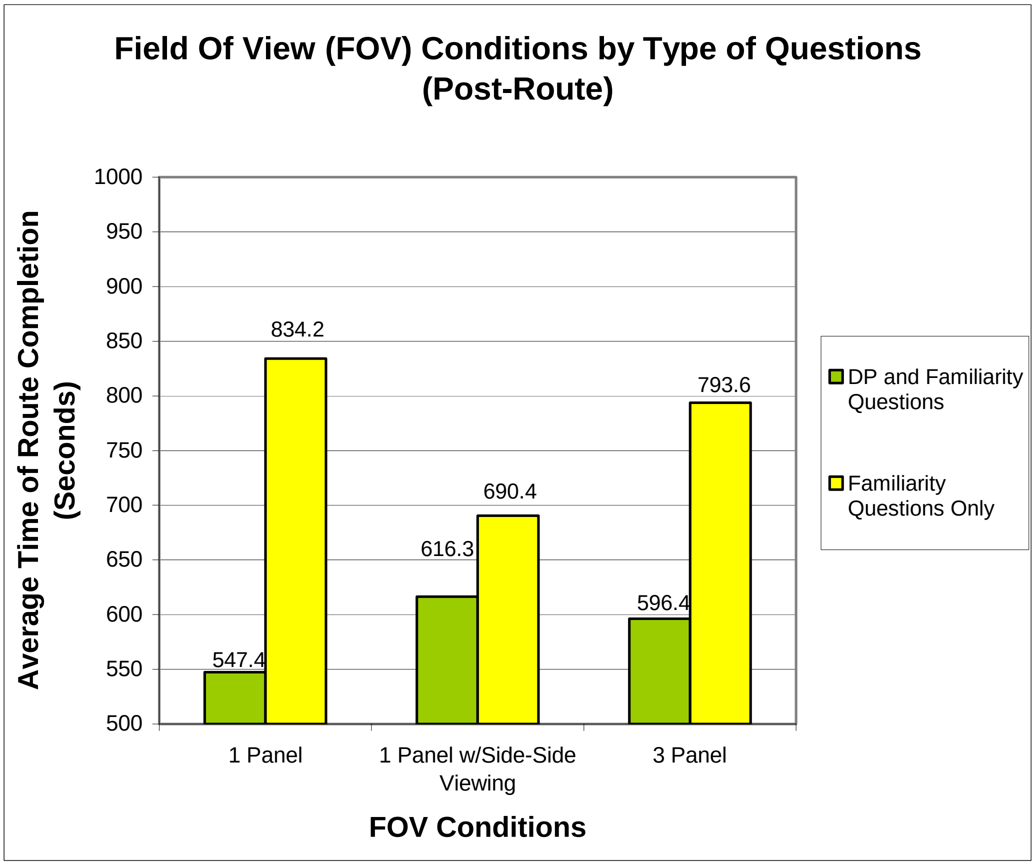
Drop-point route drawing: Participants outlined their route on an airport diagram and the number of errors in the route was recorded. This task was performed before and after completion of the drop-point task.

Method of Study:
Participants were split into six groups. Two different numbers of panel screens were used with the addition of a single panel condition that also includes an additional side-to-side viewing ability. One group of participants were run in the experiment in a simulator with 1 panel; one group with 1 panel and side-to-side viewing; and a third group of participants were run in a simulator with 3 panels. Participants were also be split into 2 drop-point conditions: one with spatial awareness questions and a familiarity question asked at each drop-point and another where only a familiarity question is asked at each drop-point. The route and specific locations along the route for the drop-point task were created to include situations in which signs/markings and spatial awareness can be evaluated. Some of the drop-points were beyond the FOV during the driving task and therefore would be expected to be less familiar.

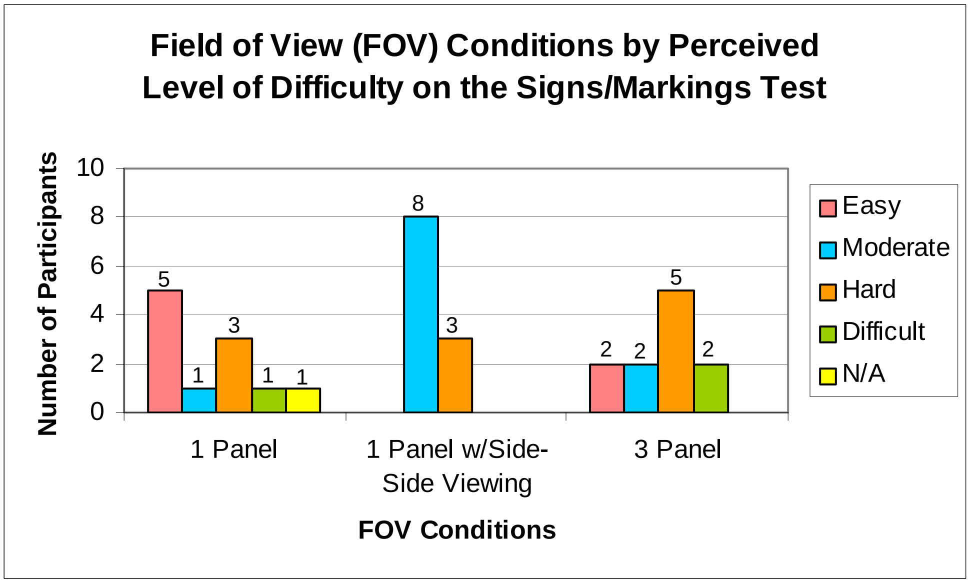
In each condition, the participant first completed a short test on their knowledge of signs and markings on the airport surface. This test consisted of 10 questions. After the test, the experimenter went over the correct answers to make sure all of the participants were given the same amount of knowledge on signs and markings for the remainder of the experiment. Participants were then given a diagram of the airport surface at BED to study for 5 minutes. The participant was then seated in the driver's seat of the simulator and the experimenter was situated in the "passenger seat". The experimenter gave directions to the participant on where to turn to follow the designated route. After the route was completed, the participant was given an airport diagram and asked to trace the route they believed they had just driven. All participants were then placed into a drop-point task in which participant will be dropped into static points along the airport surface. Some (2/3) of the points were from the route they just drove and others (1/3) were not. Half of the participants were given spatial awareness questions at each point with the addition of a "familiarity question." There were a total of 10 "drop-points" during this task. For participants who did not receive spatial awareness questions, each drop-point had only one question asked of the participant, "Please decide if this point is familiar 1 = Yes; 2= No; 3 = Unsure."

After the drop-point task was completed, participants were asked to complete the initial route again with the experimenter verbally giving directions to the participant. After the route task was completed the participant was given an airport diagram and asked to trace the route they just drove. The final step in the experiment was to complete the written post-test of signs and markings on the airport surface. A demographic questionnaire and a post-experimental questionnaire were given out to allow the participant an opportunity to give feedback. Debriefing took place at the end of the experimental session. The experiment lasted approximately two hours.

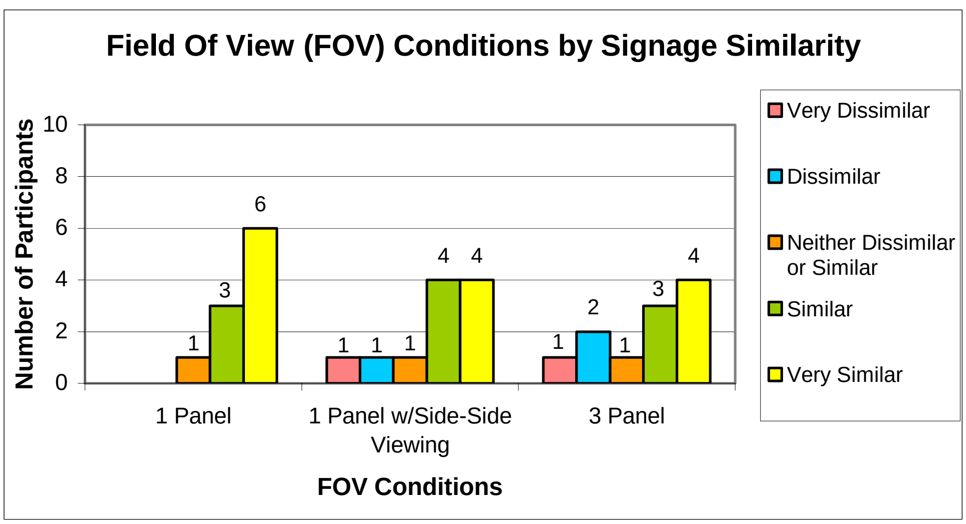
Appendix I: Results from Study 1



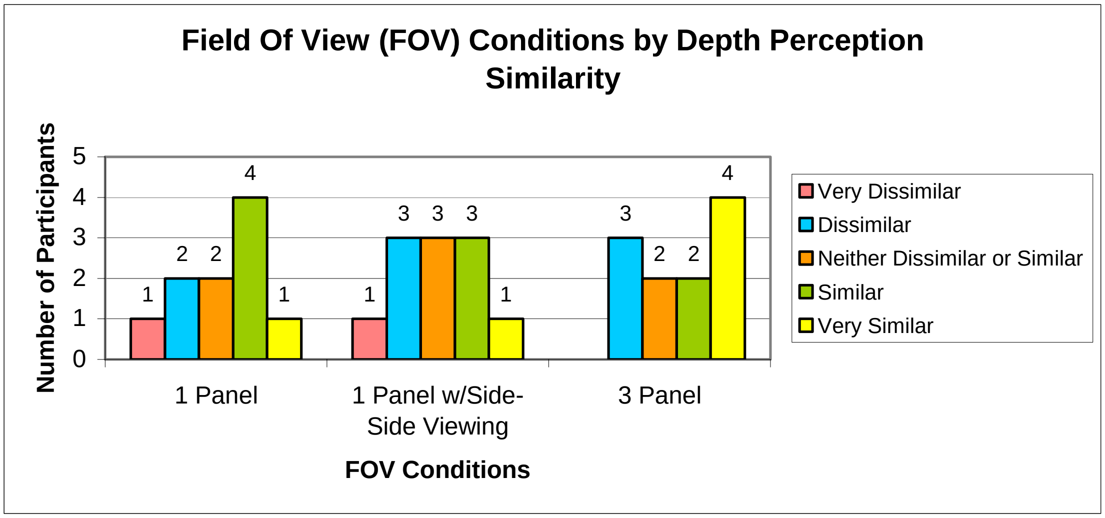
This graph illustrates the shorter driving time for participants who were asked drop-point questions and familiarity questions instead of familiarity questions only.



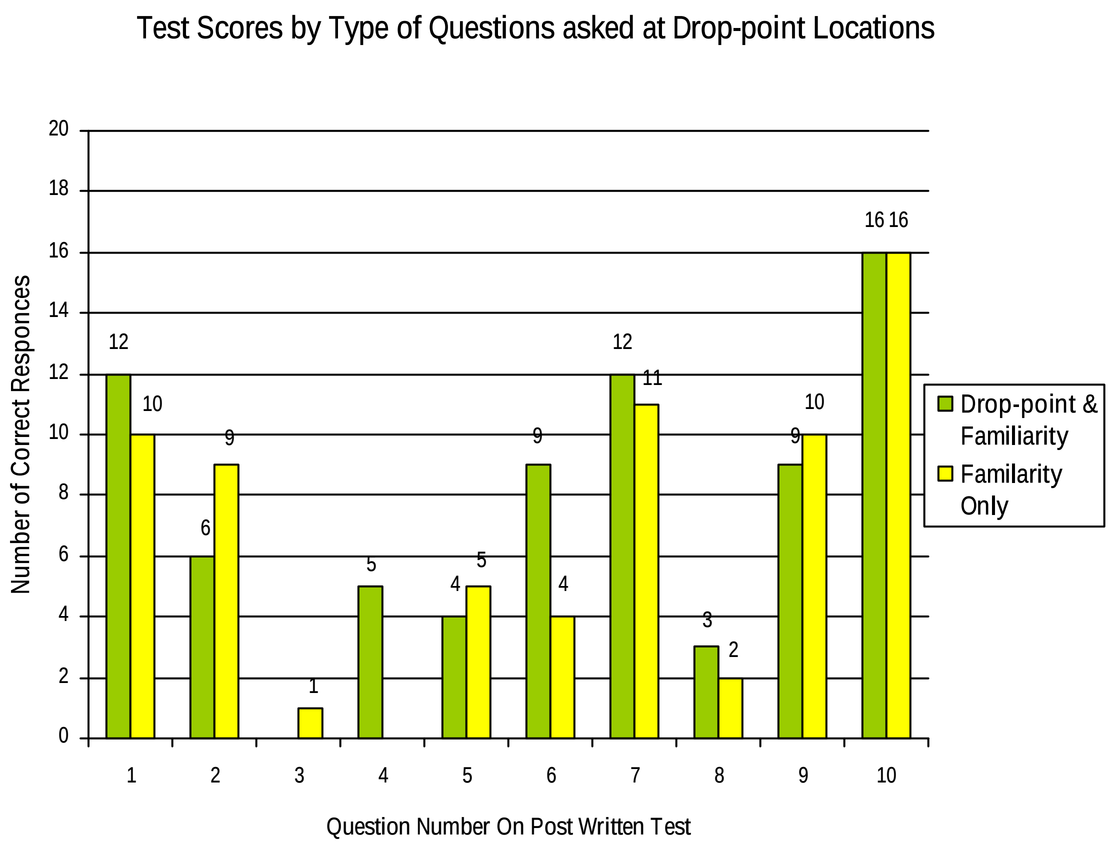
This graph illustrates that those individuals who had 1-panel with side-to-side viewing found the signs and markings test more challenging than the 1- or 3-panel field of view.



This graph illustrates that participants who used the 1-panel field of view found the signage more similar to the real world than individuals in the other 2 field of view conditions. However, the differences aren’t very large.



This graph illustrates that depth perception was seen as more similar without the side-by-side viewing.



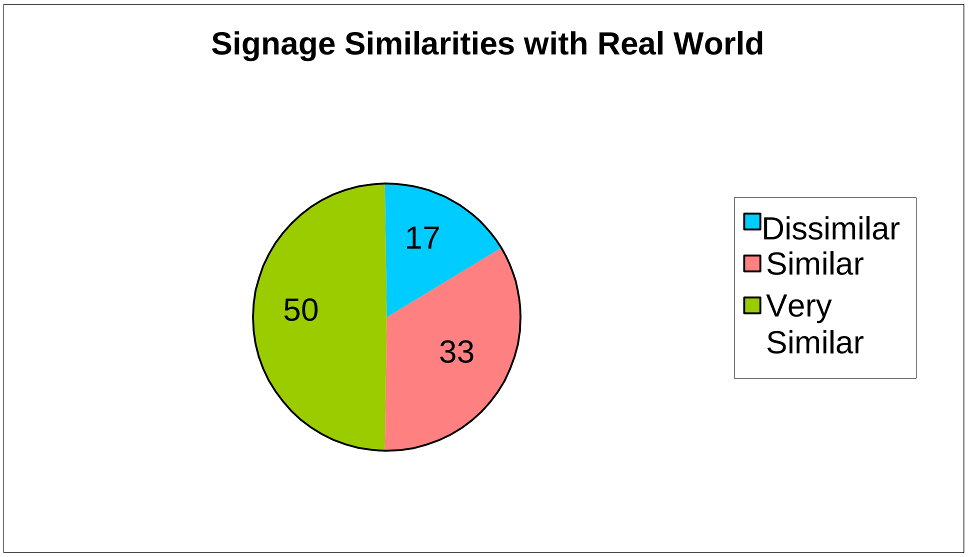
This graph illustrates the number of correct responses for each question on the written exam at the end of the study. For the majority of questions, participants did better when given drop-point questions at points along the navigation route.

Appendix J: Study 2: Recurrent Training

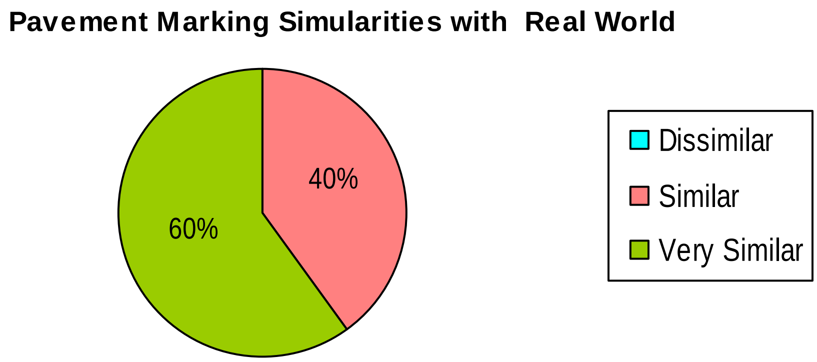
This study was designed to assess the role of simulation in ground-vehicle operator recurrent training. Much of recurrent training is used to address particular elements that add difficulty to the ground-vehicle operator's job, such as low visibility. Therefore, if recurrent training was available in a simulated environment, benefits could be gained to help limit VPDs and improve runway safety. Six experienced drivers rated the usefulness of simulation as a training tool. Half of them used a 15' monitor and the other half was given a 3-panel view.

There were two parts to the study: the spatial awareness task and the navigation task. During the spatial awareness task, at each of the 10 drop-points, participants were asked spatial awareness questions (see Appendix F for examples of these questions). In the navigation task, participants were told that the goal of this task was to have them try out the simulator to see how well different tasks can be performed, such as inspecting airfield signage. Each participant was given three routes to follow at BED movement area. During the first route, five different directions were given verbally to the driver by experimenter 1 who was seated in the "passenger seat" of the simulator. These routes were identical for each participant, but the visibility (snow, fog, or night) was counterbalanced. Air traffic control was simulated with experimenter 2, giving ATC instructions from behind the simulator. On the third route, an aircraft was close to rotation on takeoff roll after the driver was cleared to cross the runway by ATC. This was done to afford them the opportunity to see their reaction to an unexpected hazardous situation. After the drop point task was completed, participants were given three routes to drive in the simulator. Each route lasted approximately 3-4 minutes in duration, depending on driving speed. At the end of the session, participants were asked to describe their reaction to the unexpected event (aircraft on takeoff roll) and their thoughts and suggestions on using the simulator as a tool in recurrent training. A demographic questionnaire was also administered. The entire experiment lasted approximately 90 minutes.

Appendix K: Results from Study 2

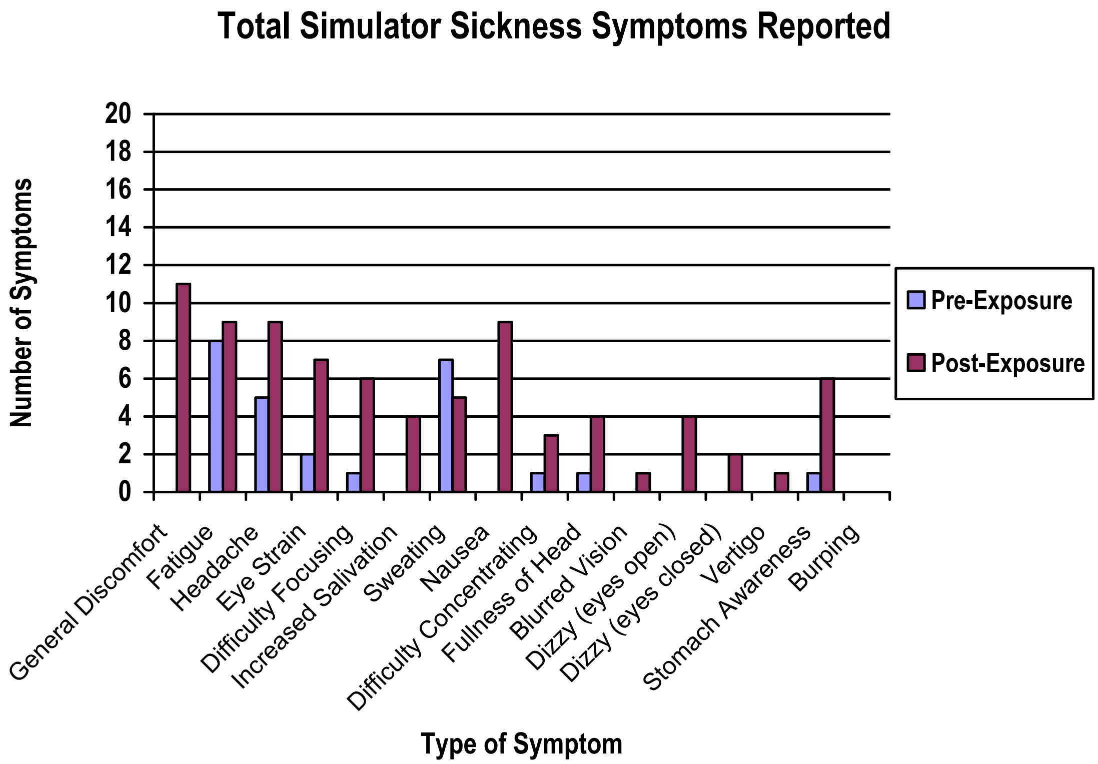


This graph illustrates that 50 percent of the participants felt that signage was similar to signage in the real-world environment.



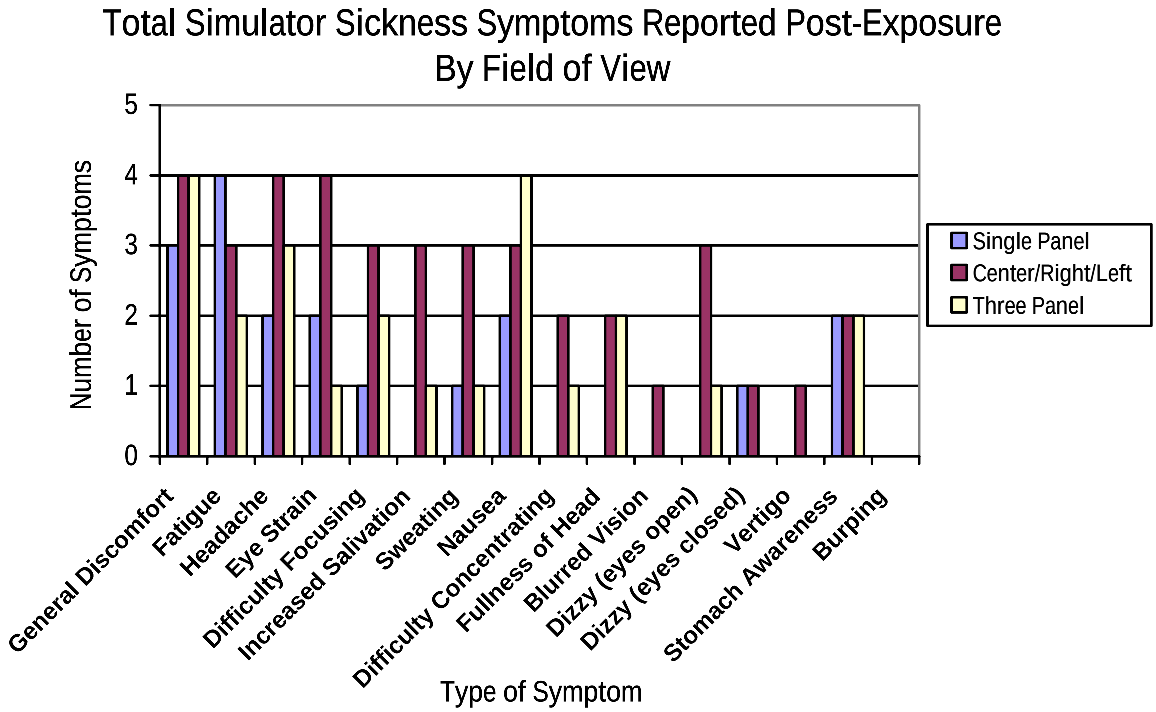
This graph illustrates that 60 percent of the participants thought that pavement markings were similar to pavement markings in the real-world environment.

Appendix L: Simulator Sickness Results



This graph illustrates that there were a number of symptoms that were felt in the participants' simulator experience. It also illustrates that some of the symptoms were already present before the study began.

Note: Burping was not recorded as a symptom for any participant pre- or post- study.



This graph illustrates that more symptoms were felt when the participant had a 1-panel side-to-side field of view (center/left/right). Though nausea was seen to be most prominent in the 3-panel field of view.