Evaluation of a Driving Simulator for Ground-Vehicle Operator Training

DOT/FAA/AR-06/1
DOT-VNTSC-FAA-06-05

Office of Runway Safety
& Operational Services
Washington, D.C. 20024

U.S. Department of Transportation
Research and Innovative Technology Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

January 2006

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 2006	Final report October 2003 – December 2004

4. TITLE AND SUBTITLE
Evaluation of a Driving Simulator for Ground-Vehicle Operator Training

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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Research and Innovative Technology Administration
John A. Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02142-1093

8. PERFORMING ORGANIZATION REPORT NUMBER

DOT-VNTSC-FAA-06-05

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Federal Aviation Administration
Office of Runway Safety & Operational Services
Washington, D.C. 20024

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

DOT/FAA/AR-06/1

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Improving runway safety is part of the Federal Aviation Administration (FAA) Flight Plan (FAA, 2005) with annual goals established for the reduction of runway incursions, including vehicle pedestrian deviations (VPDs). Reducing VPDs is a difficult task since some VPDs are caused by people who are not authorized to drive on the airport surface. Some VPDs are caused by authorized ground vehicle-operators, however, and these events may be preventable through training. Most commercial airports require some form of training and licensing for drivers operating vehicles on the airport surface. The goal of the training is to instruct drivers in safe operating practices while on the airport surface. Efforts to improve training are underway at many airports with an emphasis on reducing VPDs. Some airport operators are considering the use of driving simulators as a tool in the training process. This report addresses the use of driving simulators as one potential component of a comprehensive ground vehicle operator-training program for the overall improvement of runway safety.

14. SUBJECT TERMS
Driving simulators, ground vehicle operators, runway incursions, runway safety, vehicle pedestrian deviations

15. NUMBER OF PAGES
44

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)
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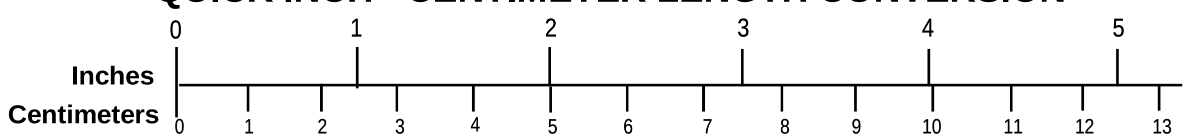

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°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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Preface

The Federal Aviation Administration's Office of Runway Safety sponsored the research in this report. The authors are grateful to Bob David and Bill Davis of the Office of Runway Safety for their support and guidance, and for reviewing previous drafts of this report. They would also like to thank the Minnesota Metropolitan Airports Commission (MAC) and specifically John Ostrom and Kyle Scapple at the Minneapolis-St. Paul International Airport for their support in setting up the validation testing of the simulator and for their assistance with the recruitment of drivers; their time and patience were invaluable to this project. The authors would also like to thank Kimberly Eis, Samual Toma , Gina Melnik, and Caroline Donohoe of the Volpe National Transportation Systems Center for their time running subjects and collecting data in Minneapolis. Their hard work made this project run efficiently throughout its duration.

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Executive Summary

Improving runway safety is part of the Federal Aviation Administration (FAA) Flight Plan (FAA, 2005). Annual goals are established for reducing runway incursions, including vehicle pedestrian deviations (VPDs). Reducing VPDs is a difficult task since some VPDs are caused by people who are not authorized to drive on the airport surface. Some VPDs are caused by authorized ground vehicle-operators, however, and these events may be preventable through training. Most commercial airports require some form of training and licensing for drivers operating vehicles on the airport surface. The goal of the training is to instruct drivers in safe operating practices while on the airport surface. Efforts to improve training are underway at many airports with an emphasis on reducing VPDs. Some airport operators are considering the use of driving simulators as a tool in the training process.

This report addresses the use of driving simulators as one potential component of a comprehensive ground vehicle operator-training program for the overall improvement of runway safety. A series of validation studies attempted to address a broad range of simulator fidelity issues. The starting point for this work was determining training requirements and potential uses of the simulator; this information was obtained through discussions with the training staff and experienced ground vehicle-operators at Minneapolis-St. Paul International Airport (MSP), as well as by reviewing the existing ground vehicle-operator training curriculum at MSP and reviewing relevant reports of VPDs.

An often-overlooked aspect of simulator use is validation of the simulation. It is important to determine how well the simulator represents the real world. The validity of the Minnesota Metropolitan Airports Commission (MAC) simulator was demonstrated on several dimensions, including visual accuracy, position and information awareness, and navigation. Differences found between the virtual and real-world environments on the distance legibility task pointed out how the simulator and real-world environments may differ when there is a lack of validity between the two. As the results from the validity studies show, having a perfect simulation of all aspects of the real world is not required. The combination of the task and specific training objectives determine how much fidelity in the simulation is required.

The second portion of this report describes the two types of training that were evaluated. The first involved training for inexperienced operators. The second involved training for experienced ground vehicle operators. After factoring out the effects of the classroom training, the use of the map, and practice driving the simulator, the study of inexperienced drivers illustrated the value of using the simulator for practicing specific procedures. The training of the inexperienced drivers revealed the particular value of structured practice, a finding that is consistent with the general idea that infrequently used procedures need to be practiced so that they are easily remembered and executed when needed. The evaluation of experienced drivers showed that the simulator could provide a meaningful scenario for advanced training. Although these situations are more complex in terms of evaluating the performance of the participant, experiencing complex and potentially dangerous situations in the simulator increases the awareness of the drivers and is likely to improve safety.

In a separate section this report discusses issues specific to the MAC simulator and simulator sickness along with potential strategies for dealing with the problem. Several steps were found to help minimize the potential of simulator sickness:

- Minimize exposure time for each session in the simulator to only the essential driving time. The initial session may have to be as short as a few minutes.
- Expose participants to the simulator over repeated sessions and gradually increase their duration. Some participants can build up a tolerance with repeated exposures.
- Reduce navigation speed. One of the reasons for simulator sickness may be the rapid movement of visual images in peripheral vision that indicates motion while the rest of the body feels as if it is stationary. Slowing down the motion creates less of a mismatch between the competing signals received by the brain.
- Allow the participant complete control over their movement in the simulator. Passive participation in the simulator is thought to increase feelings of sickness.
- Provide a stationary visual background behind the simulated movement. Any differential movement between the background (e.g., the projection screen) and the projected image will result in conflicting visual images. This will also induce sickness.
- Keep the room temperature for the simulator relatively low and provide a source of moving air to help reduce sickness symptoms.
- Have participants rate their level of sickness prior to getting into the simulator and screen people who appear to be nauseous ahead of time.

Of potentially greater interest is whether simulators can be made from low-cost hardware and still provide the same training value. A summary of criteria to consider with respect to this question is actively under investigation:

- How much of a field of view is needed to achieve effective training? Can similar results be obtained with a smaller field of view and/or with dedicated monitors instead of projected images? Switching to lower cost display technology can dramatically decrease the cost of the simulator.

- Can comparable training be achieved with lower fidelity controls? Can trainees learn as much using simpler control devices such as a joystick or a mouse? Instead of driving through the airport, can a positioning device or a ‘fly-through’ interface such as might be available in a hovercraft work as well? These devices would be simpler to integrate and would lower the overall cost.

List of Acronyms

ATC	Air Traffic Control
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

Improving runway safety is part of the Federal Aviation Administration (FAA) Flight Plan (FAA, 2005). Annual goals are established for reducing runway incursions, including vehicle pedestrian deviations (VPDs). Reducing VPDs is a difficult task since some VPDs are caused by people who are not authorized to drive on the airport surface. Some VPDs are caused by authorized ground vehicle-operators, however, and these events may be preventable through training. Most commercial airports require some form of training and licensing for drivers operating vehicles on the airport surface. The goal of the training is to instruct drivers in safe operating practices while on the airport surface. Efforts to improve training are underway at many airports with an emphasis on reducing VPDs. Some airport operators are considering the use of driving simulators as a tool in the training process. This report addresses the use of driving simulators as one potential component of a comprehensive ground vehicle operator-training program for the overall improvement of runway safety.

A closer look at VPDs reveals several interesting facts. Aside from the VPDs caused by unauthorized drivers, VPDs are most commonly caused by authorized drivers where:

- The operator is unfamiliar with the airport or particular sections of the airport;
- The operator becomes disoriented and is not where he or she thinks he or she is;
- The operator misreads or is confused by signs and markings; or
- The operator accepts a clearance intended for another vehicle or an aircraft.

Training can address all of these issues. Simulator-based training may be especially well suited to these problems since each involves some form of spatial and/or operational awareness that can be recreated in the virtual environment of the simulator. Developing a simulator-based training program for ground vehicle-operators, therefore, may be an effective way to reduce runway incursions.

Conventional training programs for ground vehicle-operators include both classroom and practical instruction. Practical instruction typically involves the trainee riding as a passenger with an experienced operator for several days or weeks until he or she becomes familiar with the airport. Use of a simulator provides potential savings relative to conventional training by allowing trainees to experience the airport on their own time without always having to use the time of the more experienced person. Additionally, practice driving in a simulator is safer than practicing on the airport surface, especially for practice of potentially dangerous procedures or in adverse weather conditions. The use of a simulator, therefore, may provide both safety and cost-saving benefits.

Implementing a simulator program is not as simple as purchasing a system and allowing trainees to drive it. Planning is required to understand what type of system to acquire and how to use it. This report documents the results of a recent evaluation of a driving simulator conducted by the Volpe National Transportation Systems Center (Volpe Center) for the FAA. The goal of the project was to determine potential benefits and uses of the simulator in ground vehicle-operator training. Throughout this report, attempts have been made to highlight lessons learned and provide guidance for the reader who may be interested in implementing a simulator-based training program. The report is organized into the following sections.

- Section 1 describes the simulator facility that was evaluated.
- Section 2 describes methods for validating the simulator (i.e., determining how well the simulator actually replicated the real world).
- Section 3 focuses on two different types of training uses for the simulator.
- Section 4 addresses concerns with motion sickness that is induced in some drivers, known as simulator sickness.
- Section 5 provides an overall summary and deals with future work in simulator development.

In this report, the following terms are used:

- *Simulator*: the physical system of displays and controls used for simulating the airport.
- *Simulation*: a specific scenario or experience in the simulator that represents a situation on the airport.
- *Airport surface*: the Minneapolis-St. Paul airport.
- *Real world*: the environment found on the airport surface.
- *Virtual environment*: the representation of the real world generated in the simulator.

2. The Simulator

The Minnesota Metropolitan Airports Commission (MAC) recently developed a simulator facility at the Minneapolis-St. Paul International Airport (MSP). MAC provided access to this facility, and the information in this report is based on the evaluation of this simulator.

Environmental Tectonics Corporation of Orlando, Florida, developed the simulator. The system uses a generic truck cab equipped with a steering wheel, pedals, gauges, and auxiliary equipment, such as radios and snowplow operating controls. Figure 1 presents a top-down view of the simulator configuration. The cab is located in front of an arced viewing screen that provides a roughly 150° field of view, which covers the view straight ahead as well as out the side windows of the cab. Three projectors above and behind the cab provide the images on the front screen. Two projectors below and in front of the cab provide images for screens located behind and to the sides of the cab. These images can be seen in the side mirrors of the cab.

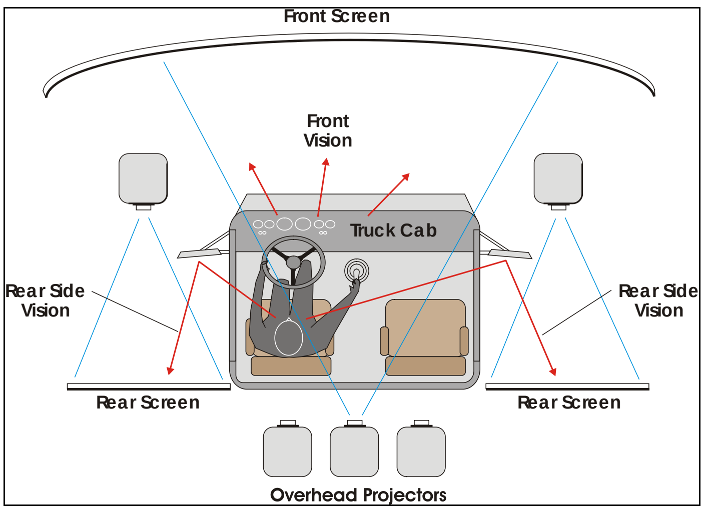


Figure 1. Diagram of simulator.

The driver, therefore, has a view in front, to the sides, and behind the cab. Figure 2 (A-E) shows the five images available to the simulator driver from a particular location on the airport surface.

The simulator hardware and projectors are controlled with a network of computers running Linux and proprietary software from the vendor. The software includes an instructor's control program and several databases containing images of the airport surface, vehicles, and airplanes.

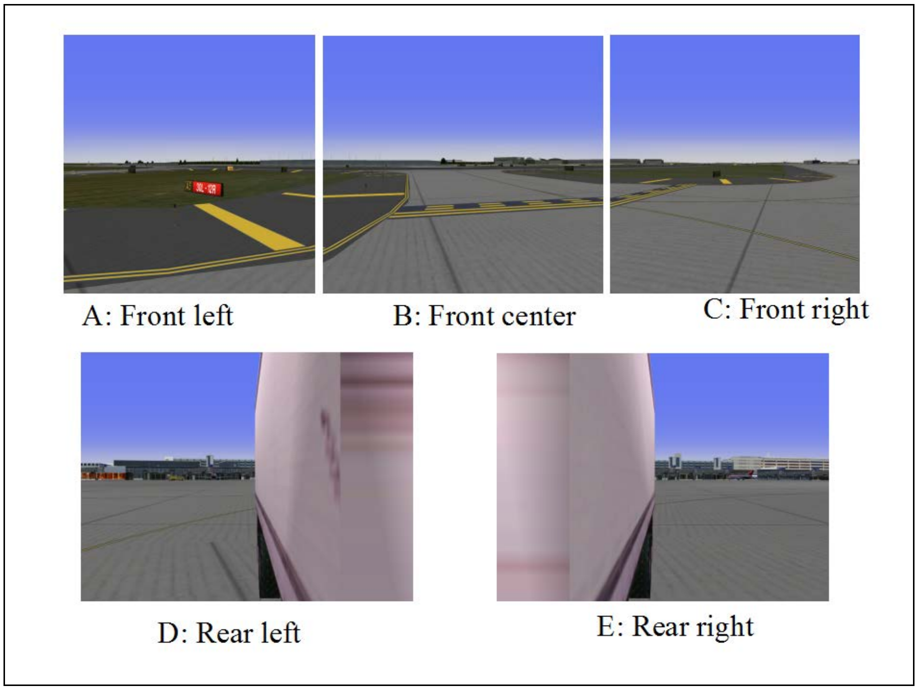


Figure 2. Simulator views.

2.1 Simulator Validation

The compelling images and dynamic controls of a simulator quickly convey the sensation for the driver of being immersed in the virtual world being simulated. By themselves, simulators are impressive systems. However, several important questions must be considered. How well does the virtual world of the simulator represent the real world? Are the images accurate with respect to what people would see if they were out in the real world? Do the images change in accordance with what people would see if they were moving in the real world? Do the images change appropriately in correspondence with control inputs, and do the controls themselves feel like a real vehicle? If a simulator is to be an effective training tool, then the virtual world experienced within it must correspond to the real world with enough fidelity to allow for a transfer of the training received in the simulator to actual practice out on the airport surface.

Understanding Validation Data

Making a comparison between the simulator and the real world is complicated. If a person's performance on a task is measured in the simulator and also in the real world, performance scores can be compared. If the scores are very different, it is evident that one environment (most likely the real world) allowed for better performance than the other. If performance is similar or even the same, it is tempting to believe that the two environments are equivalent. The problem is that there are several potential reasons why performance may be the same or similar between the real and virtual environments. These situations must be considered carefully before a conclusion can be drawn, as explained below.

Four potential sources can influence the comparison: the person performing the task, the task itself, the simulator environment, and the real-world environment. If the same person is tested in both the real and virtual environments, then the effect of the person is the same for both. Since the same or nearly the same task is used in both environments, the influence of the task is a constant as well. By holding these two factors constant, the differences in the results could be due to the differences between the real and virtual environments. It seems reasonable to conclude, therefore, that if there are no differences, the two environments must be the same. A complicating factor in this situation, unfortunately, is the fact that the task itself may not be sensitive enough to distinguish the real differences between the two environments. Looking at a hypothetical situation, assume that a driver in a real vehicle can stop to within 3 feet of an object and that in the simulator the driver can stop to within 5 feet of an object. If the driving task required a driver to stop within 10 feet of an object, then performance in both the real and virtual environments would be identical, but the performance results would also be masking the real differences.

The example above highlights the importance of carefully designing tasks and considering the evaluation criteria. If the task and evaluation criteria are appropriate for the intended training, then comparable performance between the real and virtual environments can be taken as evidence that the virtual environment provides a sufficient representation of the real environment to be used for training of that task. Throughout the use of a simulator it is important to keep in mind that measurable differences may actually exist between virtual and real-world environments, but that the differences do not matter for the task at hand.

The distance-viewing task was added as a validation study to highlight this concept. Distance viewing is a highly sensitive task allowing for the measurement of fine differences between people. Computer graphics may limit the distance at which some information might be read in the simulator; this would be a detectable difference between the real and virtual environments.

All technologies, including simulators, have their limits. It is not reasonable to expect perfection in every aspect of a simulator. What is critical to the success of a simulator-based training program, therefore, is to understand what skills are being trained in the simulator and the accompanying requirements for simulator fidelity. For example, if the simulator is being used for training familiarity with pavement markings (i.e., the skill being trained is familiarity with pavement markings), then images in the simulator must accurately depict pavement markings in the proper locations from the vantage point of the driver (i.e., simulator fidelity is measured by how closely the view in the simulator resembles the view seen on the airport surface). Delineating training requirements in terms of the information and controls that must be available to the driver in the virtual environment is one of the first steps in validating that the simulator accurately represents the real world. The second step is to assess the simulator with respect to these requirements.

There are many different types of tasks performed by ground vehicle-operators that could potentially be trained in a simulator. Each has different requirements with respect to simulator fidelity. Information processing tasks such as decision making, navigating, and orientation (i.e., knowing where you are) require accurate visual and auditory information. Tasks requiring action, such as driving (e.g., accelerating, braking, and turning) impose the additional requirement of dynamics on the visual scene as well as physical feedback in the controls. Tasks requiring a combination of information processing and action may require the highest level of fidelity in a simulator. Compromises on one or more dimensions of simulator fidelity may be acceptable if that particular aspect of the task is not considered important. For example, if the simulator will be used for operations or procedures training that is independent of the control of the vehicle (e.g., checking a runway for foreign objects or debris), the simulation does not have to have high fidelity in the controls. The focus of the training can be on the route followed, the visual scan used, specific operating procedures, communications with the tower, and other relevant task parameters that do not depend on the actual control of the vehicle. These tradeoff decisions are ideally made before the simulator is built.

2.2 Simulator Validation Studies

A series of simulator validation studies was performed on the MAC simulator. A summary of the methods, results, and a discussion of related ideas are presented here. This information is not intended to represent an exhaustive validation process. Rather, the intent is to provide readers with some guidance on assessing the fidelity of a simulator for their own training purposes.

The series of validation studies attempted to address a broad range of simulator fidelity issues. The starting point for this work was determining training requirements and potential uses of the simulator. This information was obtained through discussions with the training staff and experienced ground vehicle-operators at MSP, as well as by reviewing the existing ground vehicle-operator training curriculum at MSP, and reviewing relevant reports of VPDs. The list below indicates the major areas in the MSP training that were determined to be appropriate for training in the simulator:

- Positional awareness/orientation
- Understanding movement and non-movement areas
- Signs and markings
- Procedures
- Special driving conditions (e.g., low-visibility operations)
- Communications

Limitations of the MAC simulator at the time of the studies precluded further study of communications. Additionally, validating the fidelity of nighttime, low-visibility, and adverse weather conditions were considered secondary to the other items on the list and were not pursued in the validation studies.

Four areas of study were chosen for the validation effort:

- Visual accuracy,
- Position and information awareness,
- Navigation, and
- Legibility distance.

Visual accuracy was chosen based on discussions with the MSP staff. Much of their work to that point had focused on establishing the accuracy of the simulator database (e.g., ensuring that all driving surfaces were located where they are supposed to be located). *Position and information awareness* was chosen to accommodate the training requirements for position awareness, orientation, understanding movement and non-movement areas, and signs and markings. *Navigation* was chosen to incorporate elements of procedure training. *Legibility distance* was chosen as a means for demonstrating some of the physical limitations inherent in the simulator. The rationale for this area of study will be explained in greater detail below.

(For more information, see the boxed text in Section 2.1 for a discussion on interpreting simulator validity data.)

2.2.1 Visual Accuracy

The visual accuracy of the simulator is the foundation for all other validation efforts. Input for controlling a vehicle is primarily from the visual scene. Therefore, the virtual world has to look like the real world for the simulator to be a valid representation of it. In this study, an analysis was performed to determine what different visual objects and scenes should be visible in the simulator, comparing images of objects and scenes in the real world and corresponding objects and scenes in the virtual world. Judging the degree of similarity was difficult, and required many different considerations. For this study, the expert opinion of experienced MSP ground vehicle-operators was used to validate the appearance of the visual images in the simulator.

Objects and scenes visible in the real world that also would be expected to be visible in the simulator included the following:

- Buildings –provide information on specific locations and serve as landmarks for position awareness and orientation.
- Airplanes –many different types of aircraft operate on the airport surface; each is unique in appearance and all are expected to operate in specific areas and in specific ways when taxiing on the airport surface.

- Vehicles –a variety of ground vehicles, from luggage handlers to catering trucks, to fuel vehicles, snow removal equipment, and various emergency vehicles. These also have unique appearances and operate in specific areas on the airport surface.
- Driving surfaces – ramps, taxiways, runways, movement areas, and non-movement areas. To some degree these are defined by surface markings. Additionally, they are connected to each other at designated intersections, have specific lengths and widths, and cover extended portions of the visual field.
- Signs and Markings – signs and markings designate specific driving surfaces and must be appropriately located. Further, signs and markings have placement, size, color, and legibility requirements.

Figure 3 provides a comparison of an image from the Minneapolis St Paul Airport surface and a similar image from the simulator. The image from the airport surface while driving includes buildings, a driving surface, and various vehicles. The view from the simulator is from a similar location in the simulator. Comparing the two images reveals a general similarity in visual appearance between the two locations.

Figure 4. Comparable views from the airport surface (left) and simulator (right).

Similar comparisons were made for all of the different visual objects and scenes that were identified in the list above. Differences in the appearance of objects and scenes between the real and virtual environment were noted and discussed with respect to their importance and potential influence on training. While it may not always be possible to completely eliminate or even minimize the differences, knowing what differences exist allows the trainer to compensate for this during the training process. For example, if a trainer knows that a particular sign is not in the proper location, that portion of the virtual environment can be avoided during training until the database can be updated and the virtual sign is relocated.

2.2.2 Position and Information Awareness

Ground vehicle-operators at MSP are required to know a great deal about the airport surface, including movement and non-movement areas, signs, markings, locations of taxiways and runways, major landmarks, ramps, and gates. The simulator, therefore, must accurately represent these features of the airport surface. Unlike the Visual Accuracy validation study that relied on expert opinion, this analysis relied on performance measurements to determine whether vehicle drivers are aware of their position and other visual information around them to the same degree in both the virtual and real-world environments.

The procedure developed for this analysis used a “drop-point task” in which the participant being tested was placed in a series of different locations and asked a number of different questions about what they saw, where they were, and where other airport features were located. Measurements were taken both in the simulator and in a vehicle on the airport surface. The simulator software provided a convenient interface for pre-positioning study participants at specific locations. On the airport surface, participants were blindfolded and driven in a ground operations-vehicle to the corresponding locations before the blindfold was removed.

The locations were chosen to represent a variety of different types of locations on the airport surface. Six different types of locations were chosen that included taxiways, simple taxiway-taxiway intersections (e.g., orthogonal taxiways), complex taxiway-taxiway intersections (e.g., the intersection of three or more taxiways), taxiway-runway intersections, runways, and ramps.

Data were collected on five different types of questions that represented different types of knowledge the participant might be expected to have given their specific location:

Spatial knowledge:

1. <u>Ego reference</u> – Evaluates spatial knowledge from a self-reference vantage point.
2. <u>Relative</u> – Evaluates spatial knowledge of relative position.
3. <u>Absolute</u> – Evaluates spatial knowledge with respect to cardinal directions.

Navigation problem solving:

4. <u>Way finding</u> – Evaluates a person’s navigation problem-solving ability.

Declarative knowledge:

5. <u>Signs and markings</u> – Evaluates knowledge of specific signs and markings.

The list below provides some example questions. The locations of all of the drop points as well as the questions asked are available in Appendix A.

1. <u>Ego reference</u> - Are the main fuel tanks to the left or the right of you?
2. <u>Relative</u> - Are you closer to the main terminal or runway 30R/12L?
3. <u>Absolute</u> - What two taxiways are to the southwest of you?
4. <u>Way finding</u> - Name three taxiways you could use to cross the runway you are on?
5. <u>Signs and markings</u> - What is the name of the surface you are on?

The results from this task revealed a high degree of position and information awareness on the part of most participants both in the virtual world and in the real world, with a tendency for slightly better performance in the real world than in the simulator. Small differences were found in performance for the different types of locations, but the pattern between location types was similar between the two environments. Results for the type of question were similar to the results for the type of location. For details of the results of this study see Appendix B.

Performance data collected in this study lend further support for the validation of the simulator. Although participants performed slightly better in the real world than in the simulator, the overall pattern indicates that participants performed the “drop-point task” similarly in both environments. This indicates that the simulator provides a sufficient level of information to allow drivers to answer questions pertaining to their position and information awareness with nearly the same accuracy as if they were on the airport surface. The ease with which the drop-point task was conducted in the simulator may prove it to be a useful technique for simulator training in the future.

2.2.3 Navigation

Getting from place –to place is the underlying goal for anyone attempting to drive on the airport surface. Whether conducting a time-critical emergency procedure, or repositioning an aircraft, the driver needs to know where he or she is and how to get where he or she intends to go. Navigation, therefore, is the basic task for performing any operational procedures and this task was captured in a measure of navigation performance that was given to the participants.

To keep the information-processing component of the task separate from the task of operating the vehicle, participants were located in the passenger seat of the simulator cab or surface vehicle and asked to give instructions to a trained driver who drove the simulator or vehicle as instructed. The same standard route was followed in the simulator and on the airport surface. On one day, the participant followed the route in one direction and on a second day, the participant followed the route in reverse. Half of the participants rode in the simulator the first day and the second day on the airport surface, and the other half rode on the airport surface first on the first day and in the simulator on the second day.

The navigation route included many different features of the airport, including taxiways, simple and complex taxiway-taxiway intersections, left and right turns, and runway crossings. Participants were given a list of directions and a map to follow. As they rode, they gave the driver instructions as to when, where, and in what direction to turn. The task required that participants anticipate turns and make decisions based on location while moving in a dynamic environment. Errors were counted for incorrect decisions as each step in the driving instructions was interpreted.

Overall, results showed a similar level of performance in the simulator and in the vehicle. Additionally, the results showed a tendency in all participants to perform better on the second day of testing than on the first, regardless of whether they rode first in the simulator or in the vehicle. These results clearly show that the simulator and real world are nearly identical for this task. The task of navigation itself was the element of the situation that most affected the outcome and the virtual environment of the simulator and the real environment of the airport surface provided similar and consistent information to the participants. See Appendix C for a more complete description of the results of this study.

2.2.4 Distance Legibility

In this task, participants were driven up to gate signs in the simulator and on the airport surface and asked to say ‘stop’ when they could read the sign. The distance from the sign was noted. This task was repeated three times, once heading straight at the sign, once heading at it from a 45-degree angle from the left, and once heading at a 35-degree angle from the right. Measurements taken at the different angles anticipated that the computer graphics in the simulator might degrade when viewed at different angles. Similar signs were used in the simulator and on the airport surface.

The distance legibility task was expected to show large performance differences between the virtual and real-world environments. Limitations in the computer graphics of the simulator were expected to require that participants had to get much closer to objects, in this case gate signs, in the simulator than in the real world to be able to read them. (Prior to this study, the MAC simulator software had been modified so that runway and taxiway designator signs were easier to read while driving in the simulator. This information validated the expectation that the computer graphics were a limiting factor in the legibility of signs in the simulator.) These results, therefore, can serve as a basis for understanding the results of the other validity tests. If the task limits the results, then performance between the two environments should be similar, as seen in the other validity tests. If the participants or the environment (i.e., virtual or real world) have the largest influence on performance, then there should be differences between the two situations and perhaps differences in how individual people perform.

The results of this task show a relatively large difference between the real world and virtual environments, with legibility distances much greater in the real world than in the simulator. Additionally, performance varied widely among the participants on the airport surface with greater consistency among participants when measured in the simulator. These data reveal the anticipated pattern of results when virtual and real-world environments do not provide the same information to participants when performing the same task. Large individual differences among participants are expected in the real world due to inherent differences among people. Larger legibility distances are expected on the airport surface than in the simulator due to limitations of the computer graphics for showing fine detail and the limitations of the viewing conditions in the simulator (e.g., the screen was a fixed distance from the participant). Lower variability among participants in the simulator suggests that the limitations inherent in the simulation affected the legibility distance for most if not all participants. The results of this study are provided in Appendix D.

2.3 Discussion of Validity Testing

(Please refer to the boxed text in Section 2.)

Determining the validity of the simulator required two critical steps. The first was to establish a relationship between training objectives and specific tasks. The second was to evaluate the simulator with respect to the task. For the purposes of this evaluation, data collected in the simulator were compared as closely as possible to data collected on similar tasks in the real world. This was done to highlight the similarities and differences between the two environments. Less elaborate measures may suffice for most simulator installations, provided that the required performance from the simulator can be independently assessed through evaluation by subject matter experts or other suitable observers.

Several different validity studies were performed in an effort to evaluate some of the dimensions on which the virtual and real world can be compared. The visual accuracy was perhaps the most obvious task to perform and the most intuitive to understand. The position and information understanding and the navigation studies were designed to highlight some of the more complicated aspects of the simulator. Combined with the distance legibility task, the results collectively indicate that the level of fidelity required to meet different training objectives will vary with the task.

Once the validity of the simulator is established, it is possible to begin to design training tasks. As the results from the validity studies show, it is not required to have a perfect simulation of all aspects of the real world. It is also not required to have a perfect simulation on the dimension that is required. The combination of the task and specific training objectives determine how much fidelity in the simulation is required.

3. Using the Simulator for Training

Potential uses for the simulator in training ground vehicle operators are many. One distinction that can be made is between using the simulator for basic training of drivers new to airport operations, and using the simulator with experienced operators for advanced training. Trainees who are new to the airport and to airport operations are most likely to concentrate on integrating information learned in the classroom or a textbook with the visual appearance of the airport surface. In this situation, the simulator provides an opportunity to safely explore the airport surface and visualize the information learned from other materials. Experienced operators, by contrast, are already familiar with the airport surface and with the basic signs, markings, and procedures of airport operations. Their use of the simulator can concentrate on practicing dangerous and / or infrequently used procedures (e.g., driving at night, or runway inspections). This may be particularly useful for re-certification following a runway incursion caused by an experienced operator.

Two types of training were explored as part of the evaluation of this simulator. The first involved training for inexperienced operators. The second involved training for experienced ground vehicle operators. The procedures followed and the results obtained from these studies are provided below.

3.1 Training for Inexperienced Drivers

Three groups of participants were provided training. All three groups performed a pre-test in the simulator and then received classroom training on airport surface operations, including signs, markings, and procedures. The participants also received an equal amount of practice driving time in a highway simulation to acquaint them with the simulator. In addition to these common elements, the first group was given a map of the airport surface to study. The second group was given the map along with free time in the simulator to explore the airport surface. The third group was also given the map, and also received structured practice in the simulator.

Performance was measured for all three groups on a written test, a test on the airport map, and on a practical post-test in the simulator. The written test included questions about the various topics covered in the classroom training, which included surfaces, markings, and procedures. Several questions were also answered referring to information on the airport map, which included questions on taxiways, intersections, landmarks, and runways. The practical test required drivers to navigate two different routes that had been implicated in VPDs. These test routes were different from the routes on which the participants in the third group were trained.

Results from the written test showed improved performance for all participants regardless of the group they were in, indicating successful retention of information from the classroom training. In general, participants also scored better on the map-related questions following the training regardless of the group they were in. These results indicate that all participants were able to use the map effectively. Participants in the third group, however, performed better on the practical post-test than participants in the other two groups. Given the results of the written test and the results on the map-related questions, the results from the practical posttest indicate that structured practice in the simulator improved a participant's ability to follow a route on the airport surface independently of the other training that was received.

3.2 Training for Experienced Drivers

To evaluate the use of the simulator in training experienced operators, seven experienced Minneapolis-St. Paul ground vehicle operators participated in a study simulating runway inspection. Participants included field maintenance drivers and firefighters. Participants were told that the goal of the study was for experienced drivers to try out the simulator to see how well different tasks can be performed, such as changing a broken taxiway light in a designated area. Each participant was given two routes to follow on the movement areas of the airport surface; their task was to drive the simulator on a route that included the inspection of a runway for some debris or foreign object.

The first route was a moderately low-visibility condition created by the level of snow used. The second route was also designed for moderately low visibility by the level of fog used. Air traffic control was simulated in this experiment to enhance the realism of the simulation. Each route lasted approximately 7 to 8 minutes. At the end of the second route, the participant encountered an aircraft on takeoff roll shortly after being cleared by the tower to cross the runway, an unexpected event since participants did not come across other traffic on the previous route. As the encounter occurred, the participant reacted to the event, and the simulator session ended. Participants were then asked to give feedback describing 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.

Initial examination of the data revealed that each participant was able to get out of the way of the unexpected event, the aircraft on takeoff roll directly in front of them. All participants veered off to the right as the easiest escape route, knowing that a grassy island and a feeder were located there. They made this maneuver based on their experience with the airport and with driving safely in these areas.

Participants were asked more in-depth questions regarding the unexpected situation of the aircraft on takeoff roll. These in-depth questions revealed that participants believed the experience of the unexpected situation played a role in the effectiveness of the simulation. Most of the participants felt that the situation of an aircraft coming at them was realistic and could happen. Three participants felt that this situation is one that should be included in training. All six participants agreed that experience played a large role in their effective reaction to the oncoming plane. Three of the six participants expressed concern that less experienced drivers might panic and, as a result, would not have made the hard right turn as the experienced drivers did.

When these participants rated the realism of the simulator on a scale of one to ten in which 1 equals poor and 10 equals excellent, the ratings ranged from 7 to 9 with a mean of 8.2. Half of the participants noted the lack of vehicle engine noise, and maintenance and ground radios as limiting the realism. Another participant commented that the pedals felt strange which made his experience seem less real. As a follow-up, participants were asked how they felt their actions mimicked what they would have done in the real-world environment. Again they responded using a scale of 1 to 10, in which 1equals poor and 10 equals excellent. Ratings ranged from 9 to10 with a mean of 9.8.

Participants were also asked about the benefits and weaknesses of simulation and whether it would be a good tool for recurrent training. All six participants felt that using the simulator in training is beneficial because it allows the driver to practice dangerous scenarios without incurring risk. All participants mentioned that simulation would be beneficial for the new drivers so that they are not overwhelmed out on the airport surface by trying to watch the action as well as learn locations on the airport surface.

Responses regarding weaknesses of this simulation included not having enough traffic to interact with while driving around from taxiway to runway, and not having realistic air traffic control communications through a headset. All participants noted the importance of being aware of many things at the same time, despite the many distractions typically encountered while driving. It was also believed that increasing traffic volume would increase the realism of the simulation.

3.3 Discussion of Simulator-based Training

The two uses of the simulator for training that were evaluated represent extremes with respect to the experience of the participants, and are just two of many potential applications for a driving simulator in training. The needs of novice participants in a simulator were quite different than the experienced participants. While the novices were concentrating on learning the details of the airport, the experienced drivers were noting many details that were missing in the simulation. This distinction further highlights the point made previously that no simulation will be perfect, and that the trainer needs to concentrate on the training objectives to get the most out of the simulation.

The training of the inexperienced drivers revealed the particular value of structured practice. All of the participants were able to take advantage of the classroom training and the information available on the map. Since everyone had practiced driving the simulator, the better performance of the third group on the practicum-driving test can be attributed to the similarity of the structured practice with the practicum test. Only the participants in the third group received specific practice with instructions and this procedure was similar to the practicum test. This finding is consistent with the general idea that infrequently used procedures need to be practiced so that when needed they are easily remembered and executed.

Providing training for experienced operators was a little more complicated than working with the inexperienced drivers. The procedures used had to be carefully scripted to seem credible to the drivers. Even so, the realism of the simulator was called into question with respect to issues like the level of traffic and the ambient noise. Measuring performance under these circumstances was also complicated since there was no specific quantitative measure that could be applied. In this situation, what was required was the evaluation of the overall behavior of the driver. Reviewing the outcome with other experienced operators proved instructive and represents another way in which the simulator can be used for advanced training. Though there is more than one correct way of dealing with a problem, the fact that the problems are encountered by experienced drivers and then analyzed, raises awareness of the issues for these participants and increases their vigilance and awareness of potential hazards when operating on the airport surface.

4. Dealing with Simulator Sickness

Simulator operators are aware that a proportion of simulator users (from 10 to 50%) experience some level of illness due to the simulation, with symptoms akin to motion sickness that one may experience in a car or airplane, and is referred to as simulator sickness. The MAC simulator was no exception to this phenomenon, with 30 percent of participants across all studies reporting some feelings of sickness. Simulator sickness is thought to be caused by the mismatch in cues received by the brain. One set of cues (i.e., visual information) indicates that the user is moving. Another set of cues (i.e., the body's sense of balance and motion) indicates that the participant is stationary. In this section, some issues specific to the MAC simulator and simulator sickness are discussed, along with potential strategies for dealing with the problem.

Experiencing simulator sickness is uncomfortable for the participants, and making simulator users ill on a regular basis is certainly not a recommended practice. Over time, users will come to regard using the simulator as an unpleasant experience and will be less likely to participate. This could even extend to people who previously had not experienced any problems. Indeed, in one of the studies conducted several of the participants had heard from other participants about the potential for sickness and were prepared for the simulator to make them sick. When feelings of sickness prior to entering the simulator were factored out, only about 13 percent of participants actually felt worse following use of the simulator.

Not everyone experiences simulator sickness and it is not possible to predict who will become sick. Therefore, completely eliminating simulator sickness may not be possible. There are a number of steps, however, that can be taken to minimize the potential of simulator sickness:

- Minimize exposure time for each session in the simulator to only the essential driving time. The initial session may have to be as short as a few minutes.
- Expose participants to the simulator over repeated sessions and gradually increase the duration of each session. Some participants can build up a tolerance with repeated exposures.
- Reduce navigation speed. One of the reasons for simulator sickness may be the rapid movement of visual images in peripheral vision that indicates motion while the rest of the body feels as if it is stationary. Slowing down the motion creates less of a mismatch between the competing signals received by the brain.
- Allow the participant to have complete control over their movement in the simulator. Passive participation in the simulator is thought to increase feelings of sickness.
- Provide a stationary visual background behind the simulated movement. Any differential movement between the background (e.g., the projection screen) and the projected image will result in conflicting visual images. This will also induce sickness.
- Keep the room temperature for the simulator relatively low and provide a source of moving air to help reduce sickness symptoms.

- Have participants rate their level of sickness prior to getting into the simulator and screen people who appear to be nauseous ahead of time.

5. Conclusions and Ideas for Future Simulator Development

This report has presented the results of an evaluation of a driving simulator for use in training ground vehicle operators. The uses of a simulator are many and only a subset has been specifically addressed. The goal was not to be exhaustive, but rather to test a range of uses and issues that encompass some of the major issues encountered when developing a simulator-based training program. In part, the various tests were designed to address some of the more common causal elements of VPDs, such as position awareness and familiarity with signs and markings. They also were designed to address some of the specific training requirements at Minneapolis- St Paul Airport.

People interested in purchasing a simulator may find the following summary of the primary findings from the study helpful:

- One often-overlooked aspect of simulator use is validation of the simulation. It is important to determine how well the simulator represents the real world.
- It is argued that the validity of the simulator depends on the degree of fidelity needed for the tasks being performed in the simulator. If tasks are directly taken from training requirements, then the simulator can be evaluated with respect to how well it supports tasks being performed.
- The validity of the MAC simulator was demonstrated on several dimensions, including visual accuracy, position and information awareness, and navigation. Differences found on the distance legibility task between the virtual and real world environments pointed out how the simulator and real-world environments may differ when there is a lack of validity between the two.
- After factoring out the effects of the classroom training, the use of the map, and practice driving the simulator, the study of inexperienced drivers showed the value of using the simulator for practicing specific procedures.
- The evaluation of experienced drivers showed that the simulator could provide a meaningful scenario for advanced training. Although these situations are more complex in terms of evaluating the performance of the participant, experiencing complex and potentially dangerous situations in the simulator increases the awareness of the drivers and is likely to improve safety.
- The simulator was used in many different capacities, and each provided valuable training opportunities. The drop-point task allowed for rapid assessment of knowledge of the airport surface. The driving tasks allowed for assessment of navigation and procedural knowledge. Using the specific scenarios allowed for evaluation of complex and potentially dangerous situations. The same simulator accommodated all of these uses.

The MAC simulator represents one potential way in which simulators can be constructed, raising the question of exactly what constitutes a simulator. Of potentially greater interest is whether simulators can be made from low-cost hardware and still provide the same training value. There are several criteria to consider with respect to this question and these are actively under investigation:

- How much of a field of view is needed to achieve effective training? Can similar results be obtained with a smaller field of view and/or with dedicated monitors instead of projected images? Switching to lower cost display technology can dramatically decrease the cost of the simulator.
- How much pictorial realism is required for learning airport landmarks, signs, markings, and surfaces? Modern computer graphics software is capable of generating highly detailed images, including skid marks on the driving surfaces. Although these details add to the pictorial realism, do they increase the training value? Using simpler computer graphics tools to generate the imagery of the airport could reduce the cost of the simulation and reduce overall development time.
- How accurately do the surfaces, markings, signs, and landmarks need to be depicted for training? Can a ‘generic’ airport be used for the training of basic operations?
- Can comparable training be achieved with lower fidelity controls? Can trainees learn as much using simpler control devices such as a joystick or a mouse? Instead of driving through the airport, can a positioning device or a ‘fly-through’ interface such as might be available in a hovercraft work as well? These devices would be simpler to integrate and would lower the overall cost.

These issues are currently being addressed as a part of an ongoing research and development effort being conducted by the U.S. Department of Transportation, Volpe Center, and the Federal Aviation Administration. Results of a study of low-cost simulator development are anticipated in the near future.

6. References

Federal Aviation Administration. (2005). *Flight Plan 2005 – 2009*. Washington, D.C.: Federal Aviation Administration.

Appendix A – Questions Used in Drop-Point Task

List of questions used in drop-point task, arranged by type. Figure A-1 is a map of the drop-point locations.

Question type code:
A = Absolute
E = Ego Centric
R = Relative
S = Signs & Markings
W = Wayfinding

1.) At Complicated Intersection

A What building is to the South East of you?
E What two taxiways intersect in front of you?
R Are you closer to taxiway W or runway 30L/12R?
S What does the black sign on the left say?
W If you were to get to taxiway feeder M7, which way would you go?

2.) At Runway/Taxiway Intersection

E What runway is in front of you?
S What is the marking in front of you called?
W If you were to turn left onto the runway in front of you, the first right turn that you could make would be onto what taxiway?
A In which cardinal direction is the intersection of taxiways M & P?
R What is the closest parallel taxiway to the taxiway that you are on?

3.) At Taxiway/Taxiway Intersection

R The taxiway that you are on is to the left of what runway?
W If you were to cross the runway in front of you and turn right, what taxiway would you be on?
A In which cardinal direction is P9?
S What do the solid yellow lines on you left indicate?
E Where is the tower?

4.) At Complicated Intersection

W Which runway would you have to cross to get to the fire station?
S What does the black sign in front of you (perpendicular to you) say?
R You are closer to which of the two parallel runways?
E Name three taxiways that intersect in front of you?
A Name the taxiway near you that crosses 4/22 and runs NW-SE?

5.) At Taxiway/Taxiway Intersection

E What runway is directly behind you?
A In which cardinal direction is the fire station?
S What does the sign D<=S=> mean?

R	What taxiway runs parallel to the runway to your right, and is on the opposite side of that runway?
W	If you were to turn right at the intersection in front of you, what is the next intersection you would come to?

6.) On Ramp

R	What is the name of the taxiway on the opposite side of the runway to your left?
S	What does the marking that you are on top of mean?
E	Where are the closest hangers?
W	What is the quickest way to get to taxiway P?
A	In which cardinal direction is the main parking garage?

7.) At Runway/Taxiway Intersection

S	What do the white markings in front of you say?
W	How many runways would you have to cross to take the most direct route to the Fort Snelling golf course?
R	Where is the tower in relation to the main terminal?
A	In which cardinal direction is taxiway H?
E	What is the name of the taxiway feeder to your right?

8.) On Taxiway

S	What is the red and white marking to your right?
E	What taxiway is directly behind you?
W	If you were to turn around on the surface that you are you, travel straight ahead, turn left at the next taxiway intersection, and continue straight on that taxiway, which runway would you come to?
A	What is the closest taxiway to the North East of you?
R	Are you currently closer to P10 or P1?

9.) On Ramp

A	Which runway is North East of your position?
R	Is the fire station to the left or right of the tower?
W	If you were to drive straight out of the terminal area, which 4 surfaces would you cross, in order?
E	What runway is behind you?
S	From the lack of pavement markings, name two surfaces that you know you are not on?

10.) On Runway

W	Name three taxiways you could use to cross the runway you are on?
E	Where are the main fuel tanks?
R	Are you closer to the main terminal or runway 30R/12L?
A	What two taxiways are to the South West of you?
S	What is the name of the surface you are on?

11.) At Complicated Intersection

R	What is the name of the taxiway to the right of taxiway P?

S What does the red sign in front of you say?
E What two runways intersect nearest to you?
W What is the most direct route from your current position to the fire station?
A What runway is South of you?

12.) On Taxiway

A What two runways intersect to the South West?
W If you were to travel on taxiway D toward runway 30L/12R and turn left at the first intersection, what surface (type and name) would you be on?
E What is the name of the taxiway behind you?
S What does the sign to your left mean?
R Taxiway P is to the left of what runway?

13.) Ramp Area

E What runway is in front of you?
R What taxiway is to the right of taxiway B?
S What is the structure behind you to your left?
A In which cardinal direction is the tower?
W What is the closest taxiway feeder to get you onto runway 30L/12R?

14.) At Complicated Intersection

R Which taxiway intersects with taxiway W in front of you?
S What does the sign in front of you say? (sideways, can't read)
A Where is the fire station in relation to you?
W Give me directions to get to taxiway feeder P6?
E What taxiway is to your right?

15.) On Taxiway/Taxiway Intersection

A In what cardinal direction is the main terminal?
E Runways 4/22 and 30R/12L intersect where?
S What does the dashed yellow line mean?
W Which direction would you travel to get to T?
R Which taxiway is farther from you: H or T?

16.) On Runway/Taxiway Intersection

W If you were to cross runway 30L/12R and turn right on the first taxiway, what is the first taxiway it would intersect with?
R What taxiway runs parallel to, and to the left of taxiway C?
A In which cardinal direction is the tower?
S What do you need to do before crossing the marking in front of you?
E What runway is in front of you?

17.) On Taxiway/Taxiway Intersection

E Where is the tower?
A In which cardinal direction is the main fuel storage area?
S What does the black sign with white lettering tell you?

W If you were to cross runway 30L/12R, which taxiway would you be on when you get to the other side?

R Is taxiway B farther from you than taxiway A?

18.) Ramp Area

R From your perspective, is S2 to the right or left of S3?

S What does the sign S4<=S=> mean?

A In which cardinal direction is the main terminal?

E Where is the tower?

W If you were to turn left onto the taxiway in front of you and head North, which taxiways would you intersect with in order?

19.) On Runway

E Where is the intersection of M and H?

W If you were to travel forward, what is the first intersection you would come to?

R Are you closer to runway 30R/12L or runway 30L/12R?

A What cardinal direction is the main fuel storage area?

S What does the 2 sign tell you?

20.) On Runway/Taxiway Intersection

A Name two taxiways that are North of your position?

E Where is taxiway feeder A1?

R What is the closest taxiway to the left of taxiway G, that crosses runway 30R/12L?

S What does the red sign to your right say?

W What is the closest taxiway feeder that is perpendicular to the runway that you are facing?

21.) Taxiway/Taxiway

E What two taxiways intersect in front of you?

A What cardinal direction is the main terminal?

R Which runway is farther – 30L/12R or 30R/12L?

S What does the 4-22G sign mean?

W Which way would you go to get to runway 4-22?

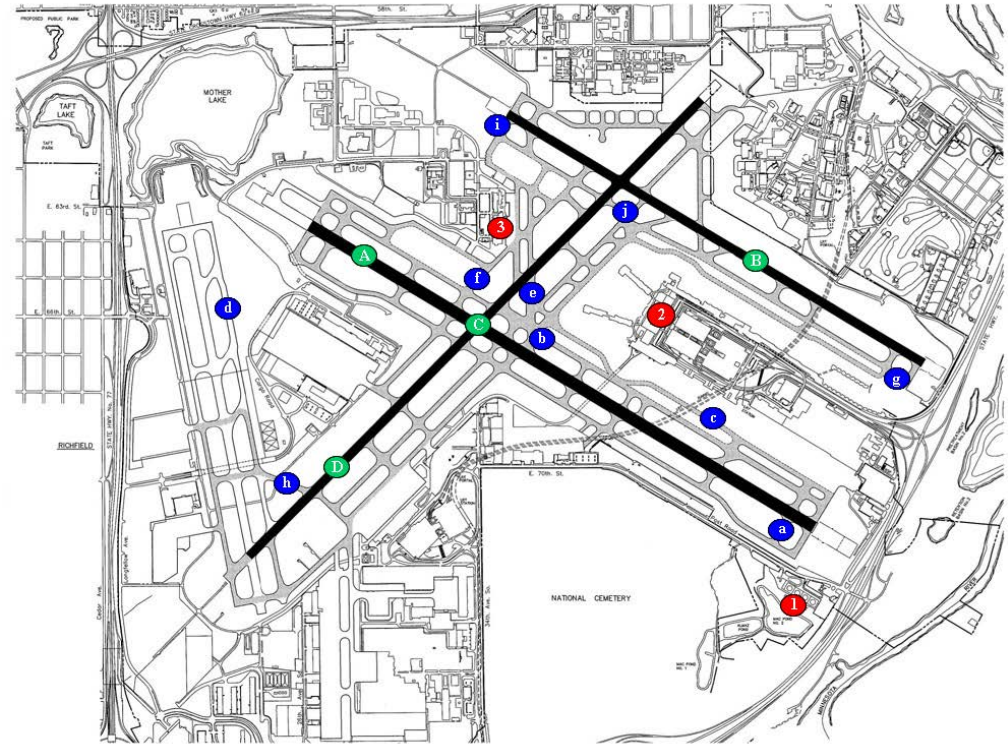


Figure A – 1. Map of drop-point locations. Points A-D are on runways, points 1–3 are in ramp areas, and points a–h are on taxiways.

Appendix B - Position and Information Awareness

Participants were taken to specific locations on the airport, both in the simulator and on the airport surface and asked questions to assess their knowledge of the airport surface, signage and markings. There were a total of 10 “drop –points.” These drop points were chosen after a review of VPDs at MSP and consultation with airport operations experts. At each drop point, participants were asked to orient themselves on the airport surface and then mark where they believe they were located on a paper map of the MSP airport. Participants were also asked 5 questions at each drop point. (See Appendix A for a list of drop-point questions.)

When participants were out in the real world environment - the airport surface, a blindfold was used to create equality between the two environments due to the simulators ability to “drop” individuals in a designated area on the airport surface.

Participants

Ten drivers participated. Four were experienced drivers, defined as individuals who had taken training classes and/or currently were employed as ground vehicle operators at MSP participated. Four were inexperienced drivers, defined as individuals who had not previously received training and had never been employed as ground vehicle operators at any airport. Two had to be excluded after developing simulator sickness.

Results

The results from this task are plotted in Figures B-1 and B-2. Slightly better performance in answering the questions was found in the real world than in the simulator for all question types and location types. Small differences existed among the different types of questions and locations for both the real world and the simulator. However, the pattern across type of question and type of location was similar in the simulator and in the real world. These results indicate that the participants responded to the questions in a similar way, regardless of whether they were in the simulator or in the real world.

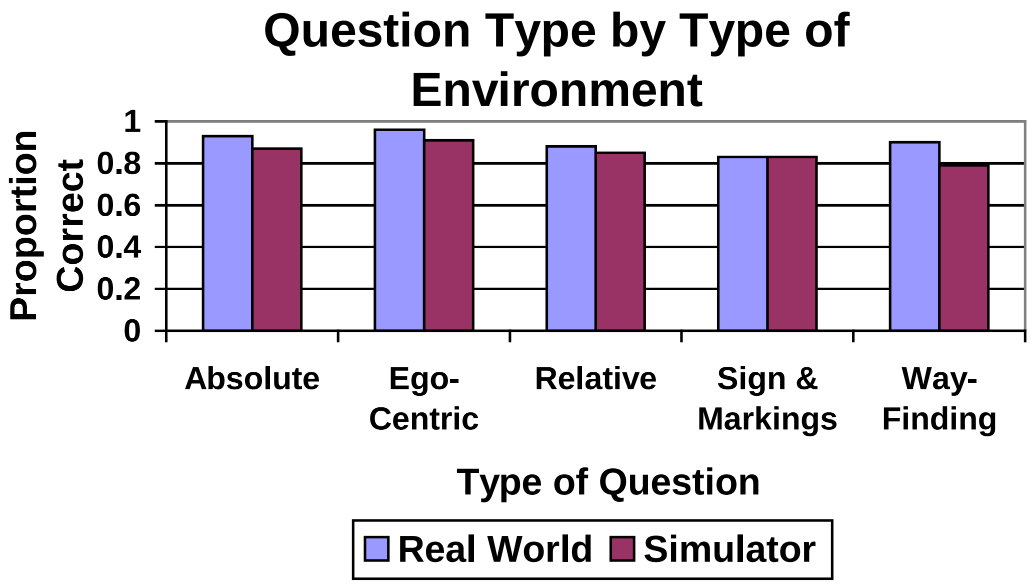


Figure B-1. Proportion of correct answers to questions are plotted as a function of the type of question. Results from the real world are plotted in blue, and results from the simulator are plotted in purple.

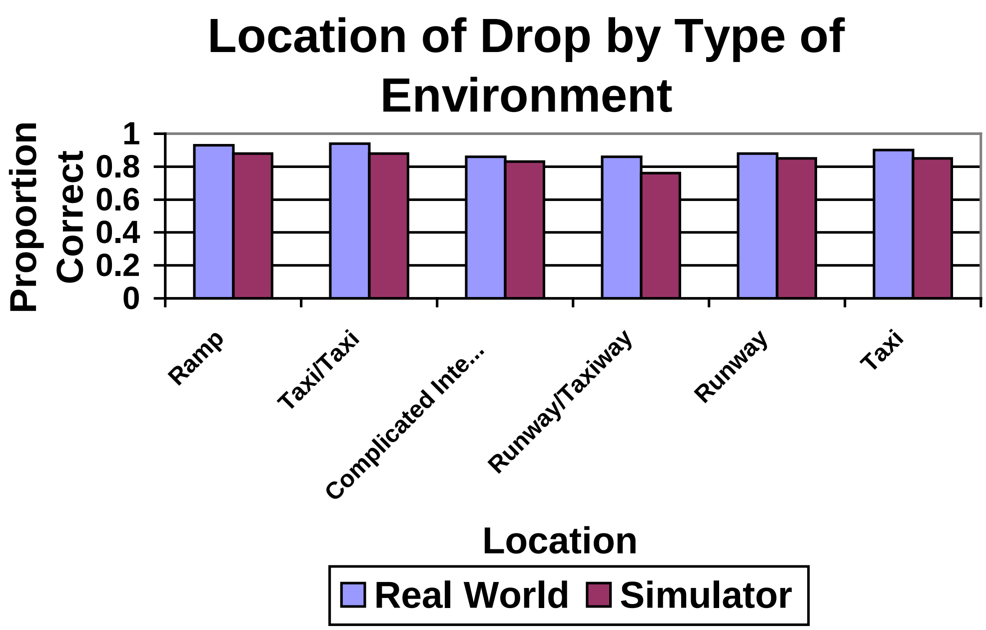


Figure B-2. Proportion of correct answers to questions are plotted as a function of the type of location. Results from the real world are plotted in blue, and results from the simulator are plotted in purple.

Appendix C - Navigation

Navigation

All participants were run in both the real world and simulated environments. Participants were run in a two-day period – one condition per day. In each condition, the participant was seated in the passenger seat of the vehicle and the experimenter was in the driver's seat. Within each condition, the participant was told to direct the driver to follow a specific route on the airport surface. Figure C-1 shows a map of the route. On the first day, the route was followed in one direction and on the second day, the reverse order was followed. The route was designed to incorporate many elements of the airport surface, including taxiways, taxiway-taxiway intersections, and taxiway-runway intersections.

Participants

Ten drivers participated. Four were experienced drivers, defined as individuals who had taken training classes and/or currently were employed as ground vehicle operators at MSP participated. Four were inexperienced drivers, defined as individuals who had not previously received training and had never been employed as ground vehicle operators at any airport. Two had to be excluded after developing simulator sickness.

Results

Performance on the navigation task in the simulator was comparable to that in the real airport environment. On average, participants completed 94 percent of the task correctly in the simulator and 93 percent of the task correctly on the airport surface. Figure C-2 shows the performance of the participants who rode in the simulator first in comparison to the participants who rode in the real world first. The labels at the bottom of the bars indicate which route and environment was experienced first. The blue bar plots the results for the first day and the yellow bar plot the results for the second day. As the graph shows, the results from the second day always improved compared to the first day, regardless of the environment that was experienced on the first day. These results indicate that the training from the first day in the simulator transferred successful to the real world on the second day, and was about as effective as if the participant had been on the real world the first day.

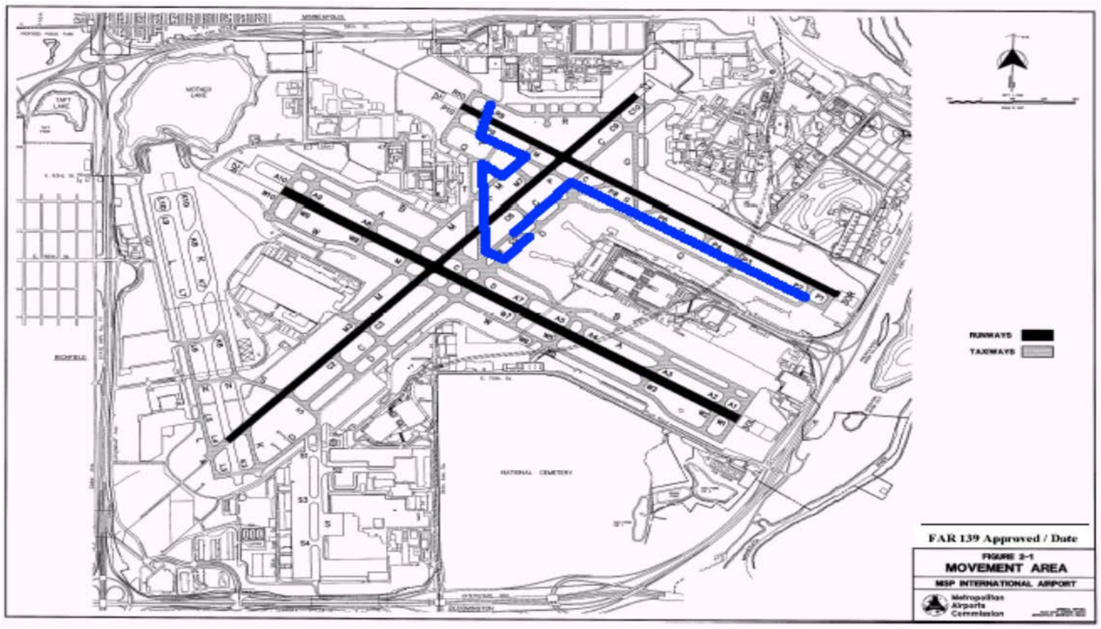


Figure C-1. Map of MSP surface. Blue line indicates the route followed in the navigation task. The route was followed in different directions on subsequent days.

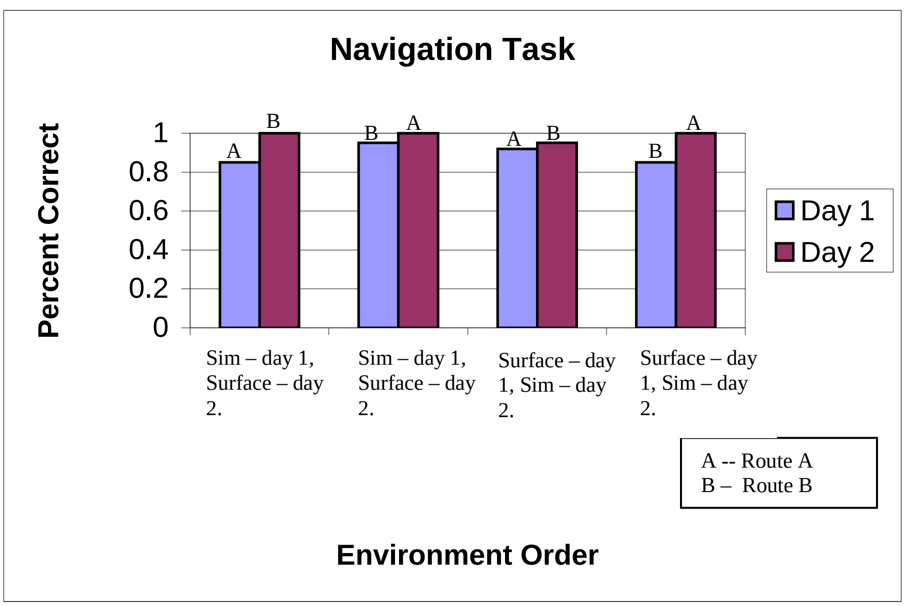


Figure C-2. Plot of percent correct performance in following the route in the navigation task. The blue bars plot performance on day one and the purple bars plot performance on day two. The labels A or B above each bar indicate which route was followed on that day. The labels below each pair of bars indicate the sequence of environments tested on the first and second days.

Appendix D – Legibility Distance

Legibility Distance

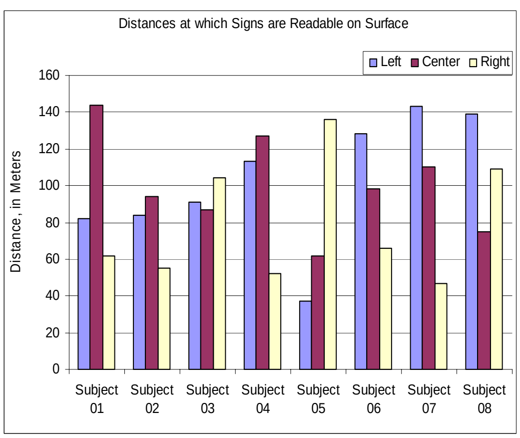
Participants completed a distance legibility task in which they were placed in front, to the left and to the right of a sign, which was not readable from that particular distance. The participant was then driven closer to the sign until it was readable.

Participants

Ten drivers participated. Four were experienced drivers, defined as individuals who had taken training classes and/or currently were employed as ground vehicle operators at MSP participated. Four were inexperienced drivers, defined as individuals who had not previously received training and had never been employed as ground vehicle operators at any airport.

Results

The distances at which signs are visible in the two environments were measured. Participants were placed in front of a gate sign as well as to the left and right of the sign. At the initial starting point in both environments none of the participants were able to distinguish the gate number. As the participant moved closer to the gate, the number became clear. Figure D-1 shows the distance at which signs on the airport surface become distinguishable and illustrates that this distance is greater on the airport surface than in the simulator. The difference in the two environments shows a reduced ability in the simulated environment. In every case, the real-world environment allowed for greater distances to read signs than in the simulated environment. Wide variation in performance was found on the airport surface for the different viewing angles. Performance was more uniform in the simulator.



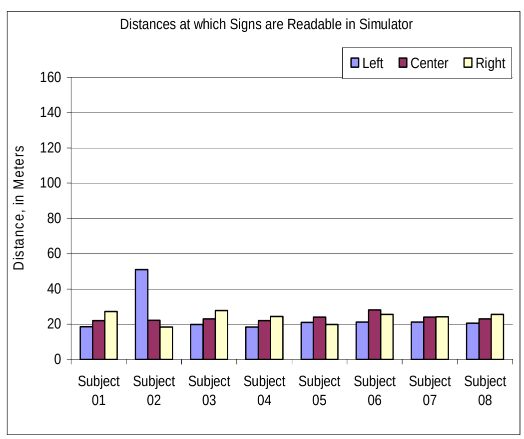


Figure D-1. Results from the distance legibility task are plotted for all participants. The left panel shows results on the airport surface and the right panel results in the simulator.