

# Virtual Environment Training for Preshift Inspections of Haul Trucks to Improve Mining Safety

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## ABSTRACT

With the goal of reducing injuries and fatalities related to haul truck accidents, this research investigates technologies and intervention strategies for improving worker training using a virtual environment (VE). Funded by the National Institute for Occupational Safety and Health (NIOSH), this research specifically focuses on training workers in preshift inspections of haul trucks to avoid preventable defects from causing worker injuries and expensive equipment damage. Improved training in these inspections is expected to increase uptime.

The VE developed to train workers for preshift inspections consists of three phases: the virtual tour, the virtual inspection and the shift simulation. The virtual tour introduces information necessary to conduct a preshift inspection by guiding the worker around a haul truck, identifying parts to be inspected and explaining defects to look for. The virtual inspection assesses retention as the worker navigates around a haul truck and identifies defects. During the shift simulation, the worker is shown a simulation of the work shift, which animates severe consequences of any overlooked defects to emphasise the importance of preshift inspections.

To provide multiple training platforms, desktop and CAVE™ versions of the training VE were created. Flux Studio was used to model the environment and to produce Virtual Reality Modelling Language (VRML) files for the desktop version. DIVERSE, an application programming interface, was then used to implement a more realistic version of the VE in a CAVE™, a room-sized visualisation system.

Initial feedback from mining colleagues indicates that the training VE may replace normal classroom training for preshift inspections in the future. As opposed to PowerPoint presentations and instructional videos, the training VE provides better spatial understanding of the location of parts and incorporates interactive features to actively engage drivers in the learning process, which may result in better retention. Initial feedback also indicates that minor improvements can be made to the virtual tour and virtual inspection phases.

## INTRODUCTION

Haul truck accidents have resulted in at least 118 fatalities since 1995, according to the Mining Safety and Health Administration (MSHA) (2008). Improper maintenance and inspection, insufficient road and site conditions, inadequate training and incorrect operational procedures commonly cause these accidents. This research, funded by the National Institute for Occupational Safety and Health (NIOSH), addresses two of these causes, inadequate training and improper maintenance and inspection.

In mining, ignorance of an action's consequences may lead to unsafe work practices and injuries. Based on the fatal investigation reports of MSHA (2008), inadequate or insufficient

training is a major cause of such injuries. Another major cause of many worker injuries is improper maintenance and inspection of equipment. Mechanical problems not detected during maintenance and preshift inspections can lead to costly mechanical failures and worker injuries (Miller, 2007). By improving worker training in conducting preshift inspections, these failures and injuries can be reduced.

Traditional miner training includes the use of videotapes, training sessions and apprenticeships. According to research conducted by Kowalski and Vaught (2002), these methods are often inadequate for teaching adults, since most adult learners are 'task-centred and problem-centred' and therefore 'solution-driven'. In addition, traditional training methods are often not engaging. Studies have shown that more engaging training methods lead to more effective knowledge acquisition and retention of material (Burke *et al*, 2006).

One training method that has been successful is the use of virtual reality (VR), also called virtual environments (VE). A VE is a synthetic, spatial world seen from a first-person point of view that is under the real-time control of the user (Bowman *et al*, 2005). Companies such as Immersive Technologies and Fifth Dimension Technologies (5DT) provide simulators as commercial VR solutions to mine training. These simulators train workers to operate equipment, such as haul trucks and bulldozers, by using a cockpit with real controls and interacting with a screen displaying a virtual world. These simulators are effective for training workers to operate different types of equipment (Immersive Technologies, 2008).

This research investigates technologies and intervention strategies for creating an engaging VE training solution to improve haul truck preshift inspection training. By focusing on training workers to conduct proper preshift inspections, this research intends to help workers avoid preventable defects that can cause injuries and damages to expensive equipment. The VE training is divided into three phases: the virtual tour, the virtual assessment and the shift simulation. The three phases are responsible for effectively conveying all pertinent inspection information to the trainee, assessing the trainee's retention of the content and reinforcing the importance of preshift inspections for the trainee. By using a VE, improved training is expected. Hence, haul truck accidents should decrease with training and operating uptimes should increase.

This research also investigates the use of multiple levels of immersion for mine safety training. Immersion refers to the objective level of sensory fidelity a VR system provides (Slater, 2003). A VR system's level of immersion depends only on the system's rendering software and display technology (Bowman and McMahan, 2007). To use multiple levels of immersion for training, desktop and CAVE™ versions of the training VE were created. A CAVE™ is a room-sized visualisation system with a much higher level of immersion than a desktop system (Cruz-Neira, Sandin and DeFanti, 1993).

This paper analyses the contributing factors of haul truck accidents and examines current methods for training mine workers. The important elements of improved training are then identified, and the development of the VE training tool is discussed. Preliminary evaluations of the tool indicate that the training VE may replace normal classroom training for preshift inspections in the future. The potential impacts of this research are discussed later in the paper.

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## BACKGROUND

### Contributing factors of haul truck accidents

According to NIOSH, powered haulage accidents accounted for 37.2 per cent of surface mining fatalities and 24.5 per cent of underground mining fatalities between 2001 and 2005 (NIOSH, 2008). According to the fatal investigation reports of the MSHA (2008), in the United States, 116 accidents involving haul trucks resulted in 118 fatalities from 1995 through 2007. According to 2006 statistics of the National Safety Council (NSC) (2007), each work-related fatality costs an average of \$1.24 million (USD). Identifying the contributing factors of haul truck accidents is important in order to reduce worker fatalities and the economic impact of these accidents.

Based on analysis of the fatal investigation reports from MSHA involving haul trucks, since 1995, improper maintenance and inspection, insufficient road and site conditions, inadequate training and incorrect operational procedures are the four most common types of cited violations in haul truck accidents. Figure 1 illustrates the categories comprising the 241 violations cited in the 116 haul truck accidents. Improper maintenance and inspection citations include violations of the Code of Federal Regulations (CFR) (2008), Title 30, Sections 56.141XX, 57.141XX, 77.1605, 77.1606, 77.404 and others. Insufficient road and site conditions citations include violations of Sections 56.91XX and 56.93XX. Inadequate training citations include violations of Sections 46 and 48. Citations for incorrect operations procedures include violations of Sections 56.142XX, 57.142XX and 77.1607. Violations related to electricity, firefighting equipment, illumination, safety programs, the notification, investigation and preservation of accidents and other miscellaneous infractions are included in the category 'Other'.

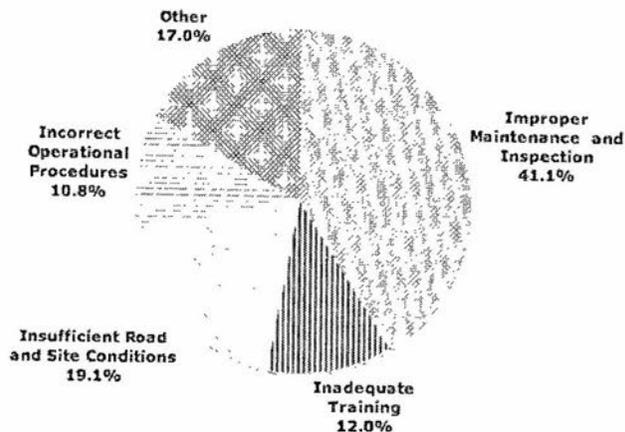


FIG 1 - Categories of cited violations in haul truck accidents.

Most of MSHA's fatalgrams involving haul trucks list 'ensuring [that] adequate pre-operational checks are conducted' as a best practice (MSHA, 2008). This is not surprising considering improper maintenance and inspection citations account for 41.1 per cent of cited violations in the analysed haul truck accidents. In addition, MSHA (2008) often notes that:

*... task training for equipment operators should include a thorough review of the manufacturer's operator's manual and all warnings should be adhered to.*

This suggestion is probably inspired by the 12.0 per cent of cited violations involving inadequate training. Inadequate training often stems from a lack of experience, as the majority of accidents occur when workers have less than two years of job experience (Schaum, 2007). Because inadequate training and

improper maintenance and inspection comprise over 50 per cent of cited violations, it is important to investigate new and more effective methods of training, especially for maintenance and inspection.

### Traditional training for miners

According to Title 30 of the CFR (2008), new miners are required to have 24 hours of training to work at surface mines or 40 hours of training to work in underground mines. For surface mining, four hours of training are required before a new miner starts any work, and the remaining 20 hours are required within 90 days of beginning work at the mine. For underground mining, most training is to be conducted in conditions closely duplicating actual underground conditions, and approximately eight hours of training are given at the mine site. Title 30 of the CFR (2008) also requires task-specific training when a miner is assigned a different job and refresher training annually.

For both surface and underground mines, training usually involves the use of videotapes, training sessions, apprenticeships and oral, written and practical demonstrations of training completion. A study conducted by Kowalski and Vaught (2002) showed that approximately 70 per cent of all training consists of only an instructor and simple demonstrations and that most mine trainers frequently do not teach the way adults learn. Most adult learners are 'task-centred and problem-centred' and therefore 'solution-driven' (Kowalski and Vaught, 2002). Training programs that have been determined to be effective are 'active and experienced-based' (Kowalski and Vaught, 2002), which coincides with the results from a study indicating that hands-on training is the most effective for learning (Burke *et al*, 2006). Regardless, traditional training solutions are sometimes inadequate. New and improved training methods are needed in order to provide more effective training and reduce the number of mining accidents.

### Virtual environment training for miners

Recognising that traditional training is not accommodating to the way adults learn, trainers have investigated other technologies and strategies for improving worker training. One strategy is to use virtual reality and virtual environments.

VR training has already been successful in other fields. It has been effectively used to expose patients to virtual representations of their real world fears and to train patients to cope with their phobias (Rothbaum *et al*, 1995). Immersive VR has been used successfully in military training (Durlach and Mavor, 1995). Training an infantry in urban combat tactics by moving them through a virtual city filled with computer-generated enemies and friendly troops is a good compromise between traditional classroom-based training and real-world training exercises for the military (Bowman and McMahan, 2007). VR has also been used in the medical field to train students on medical procedures (Gutiérrez *et al*, 2007). VR training provides a level of realism not possible in the classroom, as well as higher flexibility and reduced cost compared to real-world exercises (Bowman and McMahan, 2007).

In mining, simulators, one type of VE, are commercially sold for training mine workers. Immersive Technologies offers an advanced equipment (AE) simulator with interchangeable modules called 'Conversion Kits™', that allow training for haul trucks, bulldozers, shovels, excavators, wheeled loaders and draglines (Immersive Technologies, 2008). Figure 2 shows an AE simulator for haul truck training. Similarly, 5DT offers several surface mining simulators for training workers how to use haul trucks, bulldozers, shovels, excavators, wheeled loaders and draglines (5DT, 2008). 5DT also offers underground mining training solutions in the form of a continuous miner simulator, a longwall simulator and a roof bolter simulator (5DT, 2008).

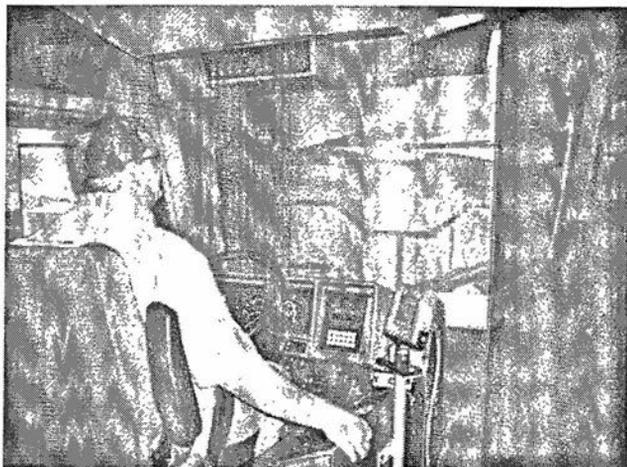


FIG 2 - A haul truck simulator used for training haul truck operation.

In addition to commercial simulators, other forms of VR have been investigated for training mine workers. Dezelic *et al* (2005) have worked on a rock bolter training application that uses the Half-life game engine and head-mounted display (HMD) technology to provide a cheaper alternative to 5DT's rock bolter simulator. Haller *et al* (1999) have prototyped a VR application that allows users to navigate through and interact with refinery scenes in order to simulate 'what-if' scenarios. Stothard, Galvin and Fowler (2004) have created a VR theatre composed of a large screen for group interaction, a touch screen for trainee interaction, real machine controls, and a joystick for manoeuvring around a simulated environment for health and safety training. Another VR training application that has been developed is NIOSH's Miner Training Simulator (MTS), a computer-based tool that allows a trainee to enter a simulated mine and interact with the environment in order to learn basic mining concepts (Ruff, 2001). The AIMS Research Unit has developed SafeVR, a revolutionary tool that may be used to create training applications quickly and simply on a PC (AIMS Research, 2008). Kizil and Joy (2001) have also identified several applications of VR in the mineral industry, including data visualisation, accident reconstructions, simulation applications, risk analysis, hazard awareness applications and training.

**IDENTIFYING TRAINING NEEDS**

Considering the number of accidents involving haul trucks and that haul trucks are a common piece of mining equipment, more safety measures are needed to ensure worker safety around these types of equipment. Improper maintenance and inspection combined with inadequate training comprise over half of all cited violations in accidents involving haul trucks. Problems not detected during maintenance and preshift inspections can lead to costly mechanical failures and worker injuries. Inadequate training and ignorance of consequences of actions lead to unsafe work practices and injuries also. Improving training in conducting preshift inspections is an obvious measure to be taken and should reduce the impacts of poor maintenance and inadequate training.

Preshift inspections include both a safety inspection and a maintenance inspection by the operator before using a haul truck (Miller, 2007). During these pre-operational checks, the operator walks around the vehicle to inspect certain parts of the haul truck and to identify any possible defects or mechanical failures. Ideally, the operator should use a checklist for the preshift inspection to avoid missing an inspection point and a possible defect (Miller, 2007). If the operator detects any problems with

the haul truck during the preshift inspection, the problem is to be reported to one of the mining operation's mechanics. In the case of a reported defect, the operator should be assigned a new haul truck, and the mechanic is responsible for repairing the defect using proper maintenance and safety procedures. These inspections can avert costly mechanical failures and, more importantly, dangerous accidents.

In order to learn more about preshift inspections, the research team conducted a literature review related to pre-operational checks and participated in training sessions focused on the preshift inspection of haul trucks. The first training session was held at the National Mine Health and Safety Academy in Beckley, West Virginia. The research team received classroom training on how to perform a CAT haul truck inspection. In addition, the instructors provided the team with copies of the PowerPoint presentation used for such training at the academy. The second training session was held at the Phelps Dodge mining operation in Morenci, Arizona. The research team received hands-on training on how to perform a preshift inspection of a CAT 793B and obtained several photographs of specific inspection points. Again, the instructor provided the team with copies of the PowerPoint presentation used for such training at the Phelps Dodge Morenci mining operation.

Based on the training and materials collected, specific inspection points and preventable failures were identified for inclusion in developing a new training tool for preshift inspections of haul trucks. These points, detectable defects and possible failures are outlined in Table 1.

**TABLE 1**  
*Identified preshift inspection points, detectable defects and preventable failures.*

Inspection points	Detectable defects	Preventable failures
Bed cylinders	Hydraulic leaks; loose connections	Inability to lift dump bed
Bell crank	Missing pin bracket	Loss of steering
Brake housings	Cracks in housing; missing wheel bolts	Loss of braking
Dog bone	Crack in bone; loose connections	Collapse of rear axel and dump bed
Fuel tank	Crack in tank; fuel leak	Loss of power
Headlights	Broken	Loss of visibility
Hydraulic hoses	Hydraulic leaks	Loss of steering and/or braking
Hydraulic tank	Crack in tank; hydraulic leak	Loss of steering and braking
Mudflaps	Missing flaps	Mud build-up on tanks
Pivot joints	Cracks in joint; missing joint pins	Collapse of rear axel and dump bed
Rear lights	Broken	Loss of visibility and braking signals
Rear struts	Hydraulic leaks; loose connections	Collapse of rear axel and dump bed
Ride cylinders	Hydraulic leaks; missing frame bolts	Collapse of front axel
Rock ejectors	Loose connections	Rocks lodged in tires
Tie rods	Loose connections	Loss of steering
Tires	Cracks in tire wall; rocks lodged in tire tread	Loss of steering
Wheel flanges	Cracks in flange	Loss of steering
Wheels	Missing lug nuts	Loss of steering

## TRAINING APPROACH

As discussed earlier, common training methods do not teach the way most adults learn. There has been success with using VR to train mine workers as this type of training is more engaging than traditional methods. According to Kizil and Joy (2001), there are several benefits of using VR for training. VR training reduces the overall time required for training by decreasing learning time for trainees. VR training can simulate unlimited access to expensive or unavailable equipment and can simulate practice under hazardous conditions. Additionally, VR training enables learners to be dispersed over a wide geographic area. Considering these factors and the leveraging of existing computer investments, VR training ultimately saves money by reducing the costs of traditional training. Considering the benefits of using VR for training, this research focuses on using a VE for training workers in preshift inspections.

In addition to deciding on the training medium, other considerations in the training approach include how to effectively present training information to the trainee, how to assess the trainee's retention of information, and how to reinforce the importance of preshift inspections. In order to accomplish these three goals, three phases of training were developed: the virtual tour, the virtual inspection, and the shift simulation.

The first phase of the training approach, the virtual tour, introduces the information required to perform adequate preshift inspections to the trainee. To effectively present this training information, the trainee is guided around a haul truck on a tour of the various inspection points identified in the training needs. At each inspection point, the part is identified by name and the defects to look for are explained using informational windows. Figure 3 shows an example of a hydraulic hose inspection point and the informational window associated with it.

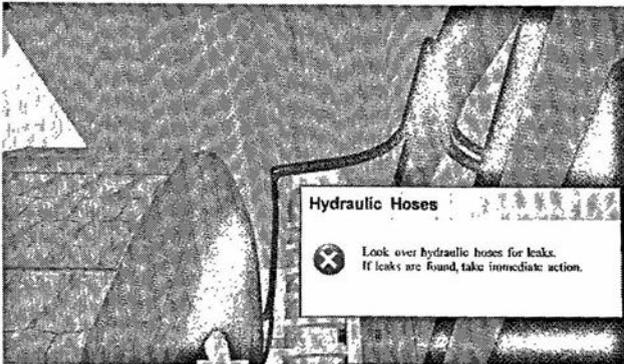


FIG 3 - Example hydraulic hose inspection point and associated informational window.

Because of the number of inspection points and the amount of information presented, the virtual tour is divided into series of inspection points. At the end of each series, the guided tour allows the trainee to decide to continue on to the next series or to repeat the last series of inspection points. Thus, the trainee controls the pace of the virtual tour without needing to explicitly progress through each individual inspection point.

The second phase of the training approach, the virtual inspection, assesses the trainee's retention of the information presented during the virtual tour phase. During this phase of the training, the trainee self-navigates around a haul truck to the various inspection points. At each inspection point, the trainee looks for defects and notifies the training system if a defect is detected. Notification occurs by selecting the defective part and then selecting a corrective action option from a newly activated window. Once the trainee finishes virtually inspecting the haul

truck, the trainee selects a completion box located near the haul truck. All of the information reported by the trainee on defects and corrective actions is assessed for retention levels and stored for use in the third phase of the training approach.

The third phase of the training approach, the shift simulation, reinforces the importance of preshift inspections. During the shift simulation, the trainee is shown a simulation of the work shift following the virtual inspection. If the trainee missed any defects during the virtual inspection, a haul truck accident or mechanical failure related to a missed defect is animated to stress the consequences of not detecting defects during preshift inspections. If the trainee properly detected all defects during the virtual inspection, the shift simulation ends with the worker driving safely home after working. This animation is a positive reinforcement of the importance of preshift inspections.

These three phases, the virtual tour, the virtual inspection and the shift simulation, constitute the approach this research takes for training preshift inspections of haul trucks. These phases effectively present training content to the trainee, assess the trainee's retention of the information and reinforce the importance of inspections. Once a trainee completes all three phases, the training repeats until the trainee completes the virtual inspection satisfactorily by properly identifying all defects and corrective actions. Satisfactory completion ends with the shift simulation of the worker driving safely home after work.

With the training approach established, the development of the VE for training preshift inspections was the next step in the research.

## DEVELOPING A TRAINING VIRTUAL ENVIRONMENT

### Modelling the virtual environment

The first step in creating a VE is to model the objects that will exist in the environment. Since this research is focused on creating a VE for training preshift inspections on haul trucks, a haul truck model with the necessary inspection points included is necessary. The research team decided to model a CAT 777C haul truck because the training sessions received at the Academy and Phelps Dodge involved CAT models, and the 777C model is of intermediate size compared to the gargantuan 793B model and many small models of lower tonnage.

In order to create a CAT 777C haul truck model and the other objects required to create a VE, a modelling application was necessary. In this research, Studio™ (formerly known as Flux Studio) was used to create the CAT 777C model. Studio is a powerful 3D modelling and animation application optimised to create 3D content for delivery in a standard web browser using open internet standards (Media Machines, 2007). Studio supports features such as animation and interactivity, scripting, multi-textures, extrusions, native X3D support, character modelling and animation, a mesh editor, 2D layers, advanced editing features, file imports and exports, integrated internal browser and configurable views and layouts.

Using Studio, the CAT 777C haul truck was modelled, including several parts modelled in detail, in order to support the inspection points identified in the training needs. Defective parts were also modelled in order to provide detectable defects during the virtual inspection phase of the training approach. Most of the textures used in the haul truck model were extracted from pictures taken during the second training session at Phelps Dodge. Figure 4 shows the haul truck modelled for this research. In addition to the CAT 777C haul truck, a mine site with an open pit was modelled to provide an environment in which the training could take place.



FIG 4 - The desktop version of the virtual environment using the Cortona3D plug-in.

### Desktop version of training virtual environment

Since the haul truck was modelled in Studio and Studio supports the Virtual Reality Modelling Language (VRML), it was a natural decision to use VRML to create a desktop version of the proposed training virtual environment. VRML is an interpreted language that incorporates 3D shapes, colours, textures and sounds to produce a virtual world that a user can walk and fly through (HTMLCenter, 2008). VRML was originally an idea that was expressed at the First International Conference of the World Wide Web (HTMLCenter, 2008). Today, VRML plug-ins, such as Octaga Player, Free WRL, OpenVRML and Cortona3D, are available for common web browsers such as Internet Explorer and Mozilla Firefox. These plug-ins allow VRML files to be viewed in web browsers via the internet.

To create the virtual tour phase of the training approach, VRML animations were used to move the trainee's viewpoint around the haul truck model through the series of inspection points. Additionally, VRML touch sensors were used to provide the trainee with buttons for controlling the pace of the virtual tour. For the creation of the virtual inspection phase, the default navigation methods of VRML were utilised to provide the trainee with a method for self-navigation around the haul truck model. VRML touch sensors were used once again to provide the trainee with a method of notifying the training system of defects and corrective actions. For the shift simulation phase, single VRML animations of each type of defect were created to provide feedback on defects missed during the virtual inspection and on their possible consequences.

A major benefit of using VRML to create a desktop version of the training VE is that VRML files can be used on any computer platform with almost any web browser. Additionally, since the VRML files can be shared through the internet, the desktop version of the VE can easily be dispersed to trainers in order to improve mine safety training at more mining operations. Figure 4 illustrates what the desktop version of the training VE looks like.

### CAVE™ version of training virtual environment

In addition to creating a desktop version of the training VE, the research team determined that creating a more immersive version of the VE would provide a different training experience. A major benefit of creating a VE with a high level of immersion is the realistic experiences that can be recreated (Bowman and McMahan, 2007). Higher levels of immersion also provide increased spatial understanding and more depth cues for trainees (Bowman and McMahan, 2007).

In order to facilitate a more immersive experience, the team decided to use a four-sided CAVE™. A CAVE™ is a room-sized visualisation system (Cruz-Neira, Sandin and DeFanti, 1993). The CAVE™ used has three sides (3.0480 m × 2.7432 m) and a floor (3.0480 m × 3.0480 m) and uses projection technology, stereoscopic displays, and head tracking to create a high level of

immersion. The CAVE™ also uses an Intersense IS-900 tracking system with a six-degree-of-freedom (DOF) head tracker and a 6-DOF wand device with four buttons and a 2-DOF joystick.

DIVERSE, an application programming interface, was used to implement the more immersive version of the training VE in the CAVE™. DIVERSE provides a common user interface for interactive graphics and a common programming interface for VE-oriented hardware such as trackers, wands, joysticks and motion bases (Kelso *et al.*, 2002). In order to recreate the VE using DIVERSE, the models for the VE were exported from Studio as objects in Wavefront format. These objects were then loaded into the more immersive VE using DIVERSE. The task of recreating the animations and sensors required for the three training phases was more complicated. Each animation and sensor was programmed into the CAVE™ VE using DIVERSE and basic C++ programming. In order to interact with touch sensors, ray-casting, a type of 3D interaction technique (Bowman *et al.*, 2005), was used with the 6-DOF wand device.

A major benefit of creating a CAVE™ version of the training VE is that it provides a higher level of immersion and creates a more realistic experience. Unfortunately, since the CAVE™ version of the training VE was designed for a specific CAVE™ installation, the more immersive version of the VE is not easily shared with trainers to improve mine safety training. Figure 5 illustrates what the CAVE™ version of the training VE looks like.



FIG 5 - The CAVE™ version of the virtual environment for training preshift inspections.

## EVALUATING THE VIRTUAL ENVIRONMENT

### Expert inspection

To initially evaluate the training VE, an expert inspection was conducted. During this inspection, experts and professionals from the mining industry examined and worked with the training system in an effort to give feedback on their impressions of the system and to detect potential training problems.

The expert inspection resulted in positive feedback. All of the mining experts thought the training VE could replace normal classroom training for preshift inspections in the future. The experts noticed that the training VE provides better spatial understanding of where parts are located than PowerPoint presentations and instructional videos. According to the experts, more interactive features result in increased levels of engagement of trainees, which should result in better retention of the material.

The expert inspection indicated that minor improvements could be made to both the desktop and CAVE™ versions of the training VE. For both versions of the virtual tour, experts

indicated that the pertinent haul truck parts should be highlighted at each inspection point, in order to prevent confusion about which part is being discussed. They also pointed out that some of the informational windows were difficult to read in the CAVE™ version of the virtual tour. This difficulty stems from a combination of using head tracking and the fact that the active stereoscopic glasses create a dimmer view of the VE. For the virtual inspection, experts indicated that navigation in the desktop version, using the standard VRML controls, was extremely difficult to use. The experts did not find the same problem in the CAVE™ version because a 3D travel technique was used for navigation around the virtual haul truck.

### Planned empirical evaluation

In addition to the expert inspection, the research team plans to run experiments to empirically evaluate the effectiveness of the VE. Since the purpose of the VE is to provide training, the retention of information after using the VE will be evaluated. A similar experiment was conducted for a medical training VE (Gutiérrez *et al*, 2007). In that experiment, a learning evaluation method was used to evaluate the effectiveness of the medical training VE by administering a knowledge assessment test before and after using the VE. The knowledge assessment test involved rating the relatedness of pairs of concepts critical to the training. A Pathfinder scaling algorithm and knowledge structures were then used to quantify how much trainees learned using the medical training VE. The same process will be used to evaluate the effectiveness of the VE for training preshift inspections. Additionally, the process will be used to compare the effectiveness of the desktop version to the CAVE™ version.

From the empirical evaluation, significant learning increases are expected from using the training VE. These increases will demonstrate the effectiveness of the VE as a training tool. In addition, the CAVE™ version of the VE is expected to afford a greater increase in learning than the desktop version. Due to the benefits of higher levels of immersion, which include greater spatial understanding and more depth cues, the CAVE™ version should demonstrate an increased effectiveness over the desktop version.

### CONCLUSIONS

Haul truck accidents cause equipment damage and miner injuries each year. The most common causes for these accidents include improper maintenance and inspection, insufficient road and site conditions, inadequate training and incorrect operational procedures. Considering that improper maintenance and inspection combined with inadequate training contribute to the majority of cited violations related to haul truck accidents, improving training for preshift inspections is one obvious method for increasing haul truck safety.

Traditional training methods involve the use of videotapes, training sessions and apprenticeships. Kowalski and Vaught have indicated these methods as inadequate for teaching adults. Hence, more engaging training methods, such as the use of VR, have been investigated. Companies, such as Immersive Technologies and 5DT, have developed several commercial simulators for training mine workers in safety and operation of equipment. Other types of VR training that have been investigated include accident reconstructions, simulation applications, risk analysis and hazard awareness applications.

This research has investigated using a VE to train preshift inspections of haul trucks. By focusing on training workers how to conduct proper preshift inspections, this research helps workers avoid preventable defects from causing injuries and damages to expensive equipment. Two versions of the training VE, each consisting of three phases, were implemented to provide an easily distributable training solution in the form of the

desktop version and to provide a more immersive experience with the CAVE™ version.

Feedback from mining experts indicates that the training VE is engaging and provides better spatial understanding of where parts are located. The consulted experts believe the training VE may eventually replace classroom training for preshift inspections. An empirical evaluation utilising a learning evaluation method is planned in order to verify the positive feedback given by the mining experts. The empirical evaluation will also verify the effectiveness of the developed VE as a training tool.

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