Haul truck safety and virtual environments training

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Abstract

On average, there are approximately 10 fatal haul truck accidents per year. The most common causes for haul truck accidents include mechanical problems, inadequate training and insufficient road/berm maintenance. Due to the frequency and magnitude of haul truck accidents, new training methods are being investigated. With the widespread availability of computers and new technology becoming more reasonably priced, the ability to incorporate computer-based training for miners is becoming more possible. It has been shown that computer-based training is just as effective in knowledge acquisition as traditional lectures, and computer-based training can lead to a significant increase in the retention of material (Williams and Zahed, 1996). Studies have also shown that more engaging training methods lead to more effective knowledge acquisition (Burke et al., 2006). A supplemental system for current and new miner training to address the common causes of fatal accidents was developed. The training system is a virtual preshift inspection of a haul truck, and it can train new haul truck operators to identify parts that look defective. The training will increase an operator's ability to recognize problematic parts and correctly identify the corrective action needed. Increasing the quality of training by providing an engaging, simulated hands-on environment will lead to safer behaviors by trainees, which will ultimately lead to fewer accidents and fatalities.

Introduction

Haul trucks are among the most common pieces of equipment found at any mining site. The primary purpose of haul trucks is to transport material from the working face to a processing facility. To optimize productivity and safety, it is necessary for miners to be sufficiently trained to operate haul trucks. It is also important that miners who do not operate haul trucks be aware of the safety hazards that haul trucks impose. Because haul trucks are a common piece of equipment at mine sites, numerous accidents involving haul trucks occur. There were more than 100 haul truck fatalities between 1995 and 2005.

To reduce the number of fatal haul truck accidents, additional training can be implemented. This work focuses on the preshift inspection of a haul truck. Identifying problems in the truck before operation helps to reduce the number of fatal accidents. An increased understanding of haul truck problems will also contribute to increased safety. In addition to the preshift inspection, exposing new operators to the consequences of unchecked problems will increase the likelihood that the preshift will be performed properly. This work utilizes virtual environments (VEs) in the training application. This is done in immersive and non-immersive VEs.

Background

Haul trucks are large, with lengths, widths and heights ranging up to 15, 10 and 7 m (48, 33 and 23 ft), respectively. One concern is that such vehicles have large blind spots. Another concern is that fully loaded haul trucks have added weight that requires longer stopping distances. The capacities of haul trucks can be up to of 345 t (380 st). All miners who work around haul trucks should be aware of the capabilities and limitations of their equipment for their own safety.

Transporting material from the working face to a processing facility usually results in short repetitive trips. Haul trucks often interact with other mobile equipment and stationary dumping stations. The mobile equipment often includes shovels, front-end loaders and pickup trucks. Because they are large, shovels and loaders can easily be seen, but pickup trucks might be hidden in a blind spot when the vehicles are too close to each other.

It is necessary for miners to be sufficiently trained to operate haul trucks. It is also important that miners who do not operate haul trucks be aware of the safety hazards that they impose. In the United States, miner training for surface operations is outlined in the Code of Federal Regulations as 30 CFR Part 48 Subpart B. The maintenance and upkeep of haul trucks is important for their safe use. All equipment should be checked prior to use to ensure the machine is in good working order. Required maintenance should only be performed by qualified persons.

To determine the most common problems with haul trucks, the fatal accident reports and fatalgrams from the U.S. Mine Safety and Health Administration (MSHA) were considered for every fatality involving haul trucks since 1995. It became apparent that mechanical failures, inadequate training, seatbelt misuse and insufficient berms were the four most common problems:

- Mechanical failures were defined as accidents where there was a mechanical problem with the haul truck.
- Inadequate training was specified for accidents where either the operator or another employee involved in the accident was not sufficiently trained to operate or be around mobile equipment.
- Seatbelt misuse was chosen for accidents where the driver was not wearing a seatbelt.

- Insufficient berms were identified for accidents where the haul truck came into contact with berms that were improperly constructed or did not meet MSHA standards. The improper road/berm designation was also given to accidents in which haul trucks drove over a highwall where no berm was present.

A spreadsheet was created with each accident classified into the four categories. Other factors were listed, but none of these "other" causes contributed to more than five fatal accidents. All data were collected from the National Institute of Occupational Safety and Health (NIOSH) and MSHA (NIOSH, 2004).

From 1995 through 2005, there were 103 haul truck accidents that resulted in fatalities. Each accident report was investigated to find the underlying causes (the results are illustrated in Fig. 1). Mechanical problems were present more frequently than all other problems.

The data indicate that there were 66 accidents in metal/nonmetal mines resulting in fatalities. The distribution of the common haul truck problems can be seen in Fig. 2. Unrelated causes were more prevalent than any of the most common problems. The accidents that were classified as "other" resulted from lack of communication, alcohol and drug use, improper use of parking breaks and chocking tires, and visibility/blind spots. Lack of communication was listed for four of the accidents, making it the most prevalent problem listed under the "other" classification. Aside from the "other" classification, inadequate training had the greatest impact on haul truck fatalities in metal/nonmetal mining.

The majority of fatal accidents involving haul trucks can be reduced by simply supplying adequate training, keeping the haul truck in good mechanical order and having a sufficient berm. Improving training systems can also improve some of the mechanical and seatbelt factors in fatal accidents. While none of the accidents were caused by a driver not wearing a seatbelt, the severity of the sustained injuries could have been lessened if one had been worn.

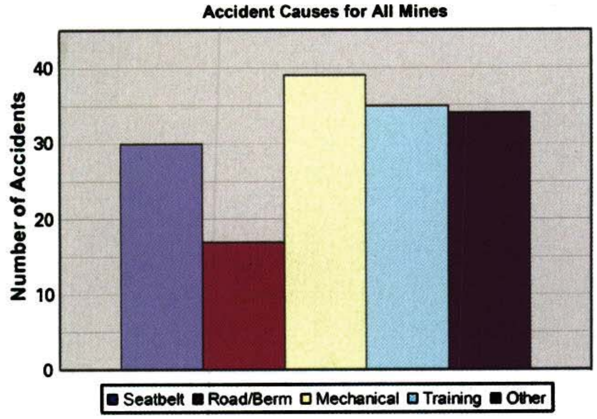
Significance of virtual environments

Current techniques are in place to reduce the occurrence of haul truck accidents. Current safety techniques focus mainly on driver training, dump point proximity alerts, collision avoidance systems and braking systems. The primary goal of all techniques is to reduce the number of haul truck accidents.

MSHA requires that all new miners must complete no less than 24 hours of training for surface operations. The basic new miner training is outlined in 30 CFR Part 48.25. Experienced miners must receive at least eight hours of training when hired or transferred, which is detailed in 30 CFR Part 48.26. Additional task-specific training is required for miners who operate mobile equipment. The additional training is required for a supervised operation and to cover safe operating procedures during production and nonproduction times. Task training is outlined in 30 CFR Part 48.27. Every mine worker must also have eight hours of annual refresher training. The purpose of refresher training is to keep all employees aware of safety hazards in the mine. Training is also interdependent with all other systems implemented. To be effectively used, the drivers and operators of mobile equipment must be adequately trained to use the safety measures put in place.

FIGURE 1

Common haul truck problems for all mines.



Braking systems are critical components in all mobile equipment. There are three main types of braking systems common to all haul trucks: the service brake, the secondary (emergency) brake and the parking brake. The service brake serves as the main braking system used to stop the machine and hold it stationary. It acts much in the same way as the brakes in a car. The secondary (emergency) brake works as a backup in the event that the service brake does not work. Secondary brake systems often have less braking capacity than the service brake and should only be used in an emergency. The parking brake is only intended to hold a stopped machine. In the event that the parking brake is used to stop a machine, it must be tested for parking capacity before the machine is used again. Some machines may come equipped with a retarder brake. The retarder brake is used only to control the vehicle's speed while traveling downgrades. All manufacturers provide detailed instructions on the proper maintenance and inspection of braking systems. Should a problem in the braking system be found, only qualified and trained personnel can perform maintenance (MSHA, 2005a).

MSHA regulates the requirements for vehicle braking system in 30 CFR part 56.1401 (for surface metal/nonmetal). Detailed instructions for the testing of brake systems, along with tables of brake requirements are included.

Currently, driver training and braking system regulation are the only MSHA required techniques to increase truck haulage safety. The implementation and use of all

FIGURE 2

Common haul truck problems for metal/nonmetal mines.

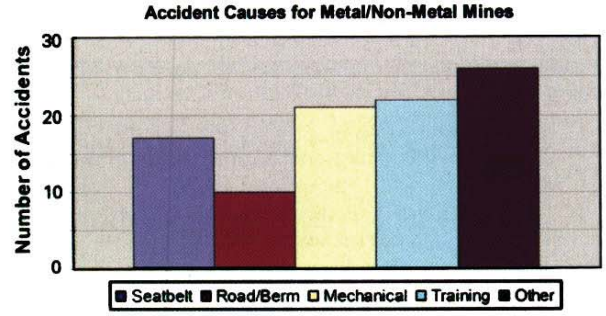


FIGURE 3

Hydraulic tank during the virtual tour.

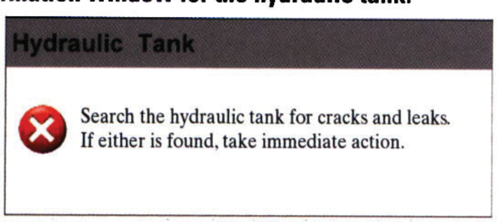
other technologies is solely dependent on the mine operator. The use of collision avoidance and proximity detection systems are increasing as mine operators become aware of the cost effectiveness of prevention systems versus the cost of haul truck accidents. While it is common for new technology to be used in accident avoidance, there is little technology available for driver training.

Virtual environments (VE) provide the user with a fully immersed interface. While inside the virtual environment, the user can travel and examine at any object freely. This ability to move around in the environment and closely look at objects is desirable for increasing truck haulage safety. Virtual environments have the capability to be very beneficial to aid in training.

One key area that can benefit from VE is inspection of mechanical systems. The inspection of mechanical systems can benefit trainers who teach miners proper preshift inspection techniques. A virtual environment can provide a clear view of mechanical systems that are in need of repair or that are ready to fail. The key components to check for in a VE inspection of the mechanical system of a haul truck are the brake systems, hydraulic lines and tires. These three components are needed for the safe operation of a haul truck, and VE can provide added training to ensure that haul trucks are not driven with damaged components. Users in a VE can walk around, look under and closely inspect all components of haul trucks. VE systems also provide the user with the clear difference between acceptable and unacceptable equipment components. VE systems have been used in haul truck safety and working directly with metal/nonmetal mining activities (Schofield, 1997). These applications mostly work with proprietary viewing applications. Commercial applications for driver training are available internationally, with the major applications being immersive driver training. This project focuses on the preshift inspection because this offers an opportunity to compare the usefulness of immersion while producing a useful tool without repeating work that is commercially available.

FIGURE 4

Information window for the hydraulic tank.



Description of the training system

The training system was developed in X3D, the next generation VRML, and can be implemented over the Internet or as a standalone application. The complete system contains three major parts: a virtual tour, a preshift inspection and the results. This application is tested immersively and non-immersively for the purpose of comparing the two experiences. To complete the program from start to finish, the user can expect to spend roughly 30 minutes.

The virtual tour will take the user on a guided preshift inspection. The inspection points are shown and the corrective action is given. There is the opportunity, within the tour, to go back and revisit parts that may have been unclear. The total tour lasts approximately 10 minutes and, at the end, the user has the ability to freely move around and look at the haul truck. The virtual tour will only show the correct working parts. It is in this part of the program where the user learns about the key components and what to inspect. Figure 3 shows the hydraulic tank during the virtual tour. There is also a window displaying text (which is accompanied by a voiceover reading the same text) of what to look for and what actions to take. The window for the hydraulic tank is shown as Fig. 4.

Icons accompany the text on the windows and are used to identify the severity of the problem. For added convenience, the common Windows icons (Microsoft 2005) for a critical stop and a warning (Fig. 5) are used to identify a problem as needing immediate action or needing action after shift. The use of the common icons will make it easier for the user to learn which parts are more critical.

Once the virtual tour is completed, the user will begin the second phase of the training. During this phase, the user will be presented with a broken haul truck and be asked to perform a preshift inspection. The broken parts will be positioned around the truck in a somewhat random manner. The most common problems (usually involving rocks lodged in tires) will occur more often than the less common problems (such as the bell crank pin bracket failing). There will be no more than two parts broken during one preshift simulation. An example of a broken hydraulic tank is shown in Fig. 6.

To identify the part as needing action immediately, needing action after the shift or needing no action at all, the user will click on the part to see the action window. The action window will allow the user to select the level of action needed. Each part that could fail will show an action window when clicked. It is up to the user to decide what level of action needs to be taken if a problem is found.

After the user completes the preshift inspection, a

FIGURE 5

Windows icons: (a) critical stop icon indicating that the problem needs immediate action and (b) warning icon indicating that the problem needs action after shift.

resulting animation will play. If the user either missed a broken part or identified a critical problem as an after-shift problem, the animation will display that particular part failing. If the user missed more than one item, the animation will show the consequences of missing the more severe part. A computer screen shot from the animation is shown as Fig. 7.

Once the animation completes, the user will be presented with a list of what problems existed on the truck during the preshift inspection and will be shown what the correct course of action would have been. This will also identify any parts that were mistakenly marked as broken or needing immediate action when the parts were not broken or could have waited until after shift to fix. At this point, the user will be given the opportunity to revisit the virtual tour or attempt another preshift inspection.

Testing the effectiveness of the training program

A pilot study using a limited number of participants was conducted to determine if the training program was effective enough to begin testing with a larger population. The pilot group consisted of six participants with varying degrees of experience (from never having seen a haul truck to former haul truck operators) with haul trucks. All participants were presented with the same broken haul truck during the virtual preshift inspection portion of the training and they all completed a post-assessment survey of the training system.

The post-assessment survey's goal was to identify the strengths and weaknesses of the training program. The survey consisted of six simple questions that provided an outlet for the user to describe how effective they observed the training to be. Survey results were separated into each section of the training system and overall observations and comments of the system. The comments obtained from the surveys provided good insight into what needs to be modified and what is appropriate for further testing.

Conclusions

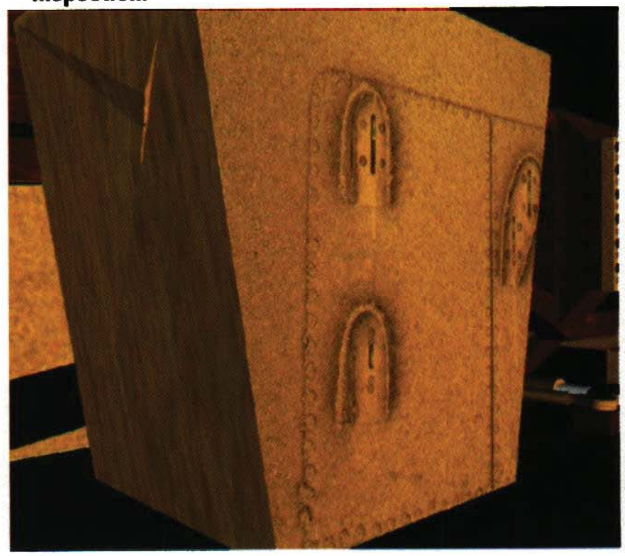
From 1995 through 2006, there were 108 fatal haul truck accidents in the United States. The current measures available for increasing haul truck safety focus more on collision avoidance, rather than prevention. With additional training to address some of the most common factors contributing to fatal accidents, the frequency of fatal haul truck accidents can be reduced.

All factors that contribute to fatal haul truck accidents must be considered when developing a new training program. The study from Burke et al. (2006) indicates that the most effective training methods are hands-on training. It was determined by Kowalski and Vaught (2002) that following a checklist of five steps when creating a training program will make the training program more effective:

- Clear goals: The goal of the virtual preshift inspection training is to provide haul truck operators with additional training to successfully complete preshift inspections.
- Content: The information about which parts to inspect and the appropriate corrective action to take comprise the content for the training program.
- Appropriate delivery mechanism: Virtual environments were chosen to convey the content.

FIGURE 6

Crack in the hydraulic tank found during the preshift inspection.



- Assessment: A post-test questionnaire will be given to the trainees to test their knowledge of haul truck parts and their corrective action.
- Remediation: If the assessment or completion of the virtual preshift inspection was unsatisfactory, the trainee must restart the training program.

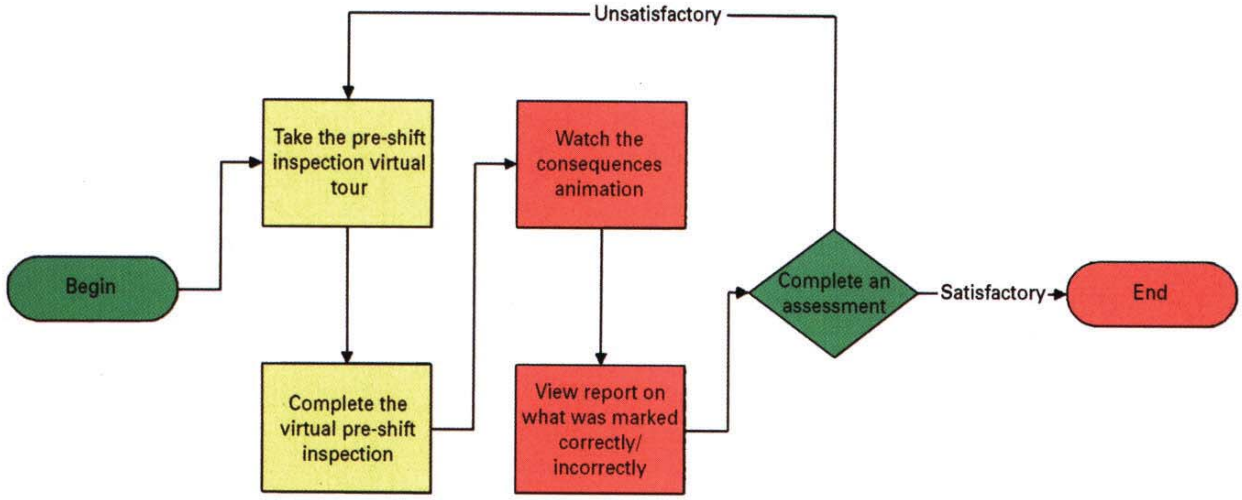
Trainees will begin training by completing the virtual tour of a preshift inspection. They will then complete a preshift inspection on a virtual haul truck. Based on their actions during the virtual preshift inspection, the appropriate consequence animation will play showing a report comparing the trainees' responses to the preshift to the actual parts which needed to be identified. Trainees will then complete an assessment that will test their knowledge of haul trucks and preshift inspections. If the responses are unsatisfactory, the trainees will return to training starting from the virtual tour. If the responses from the user were satisfactory, they will complete the virtual preshift inspection training and continue further

FIGURE 7

Computer screen showing a possible consequence of having a broken hydraulic tank.

FIGURE 8

Process of the virtual preshift inspection training program.



with their standard training. Figure 8 diagrams the training programs process.

Results from the pilot test of the training program

The results of the survey were separated into each section of the training system and overall observations plus comments of the system. For the virtual tour, the results indicated that some of the on-screen text was difficult to read but very thorough.

The results concerning the virtual preshift inspection focused mainly on movement controls. The responses indicated that the navigation was somewhat difficult and "jumpy." The impressions of the consequence animation once again focused on "jumpiness," but the responses also indicated that an explanation of the failure would greatly increase the effectiveness of this portion.

It was determined that the "jumpiness" of the training program was caused by a lack of computer hardware. The test was completed on a low-end machine, which resulted in the lagging performance. When the program was installed on a mid-range machine, the "jumpiness" was drastically reduced and the movement controls were more responsive. For best performance, the program should be run on a mid- to high-end computer.

Of the six users who tested the training program, all but one missed at least one item of the virtual inspection. Most users missed the mud flap item, which did not require immediate action. The results indicated that the training system in general was adequate to begin further testing with a larger test group.

From the comments obtained during the pilot study, the issues of the text being difficult to read can easily be addressed. Formal testing can then be completed to compare the effectiveness between traditional lecture and the virtual preshift training. ■

References

Burke, M., Sarpy, S.A., et al., 2006, "Relative effectiveness of worker safety and health training methods," *American Journal of Public Health*, Vol. 96, No. 2, p. 315-325.

Kowalski and Vaught, 2002.

Microsoft, 2005, "Microsoft Exchange Server Best Practices Analyzer Tool Readme File," accessed Nov. 11, 2006: <http://download.microsoft.com/download/f/b/a/fba50815-e7a9-420e-a794-90c85d7ca800/readme.htm>.

Mine Safety and Health Administration (MSHA), 2003, "Safety Ideas - "Dump Point Warning Light," accessed Jan. 11, 2006: <http://www.msha.gov/accident_prevention/ideas/dpwarnlight.htm>.

Mine Safety and Health Administration (MSHA), 2005a, "Equipment Safety and Health Concerns - Equipment Related Accidents," Aug. 19, 2005, accessed Jan. 10, 2006: <http://www.msha.gov/equipmentsafety/equipmentaccidents.asp>.

Mine Safety and Health Administration (MSHA), 2005b, "Accident Prevention through the use of New Technologies - Collision Avoidance & Proximity Detection," accessed Jan. 11, 2006: <http://www.msha.gov/accident%5Fprevention/newtechnologies/collision-avoidance/collision%20avoidance.asp >.

National Institute for Occupational Safety and Health (NIOSH), 2004, "Mining: MSHA data file downloads," downloaded Oct. 16, 2005: <http://www.cdc.gov/niosh/mining/data/>

Nieto, A., and Dagdelen, K., 2003, "Development and testing of a vehicle collision avoidance system based on GPS and wireless networks for open-pit mines," presented at APCOM 2003, 31st International Symposium on Application of Computers and Operations Research in the Mineral Industries, Cape Town, South Africa.

Ruff, T.M., 2001, "Application of radar to detect pedestrian workers near mining equipment," *Applied Occupational and Environmental Hygiene,* Vol. 16, No. 8, pp. 798-808, Taylor & Francis, available at <http://taylorandfrancis.metapress.com/link.asp?id=7r3ty38r4vw9j4v4>.

Schofield, D., 1997, "Virtual reality associated with FSVs, quarries and open cast vehicles – training, risk assessment and practical improvements," Workshop on Risks Associated with Free Steered Vehicles, Safety and Health Commission for the Mining and Other Extractive Industries, European Commission, Luxembourg, Germany.

U.S. Government Printing office, 2005, Code of Federal Regulations 30—Mineral Resources, Parts 1 to 199, Washington D.C., Office of Federal Register, National Archives and Records Administration, July 2005.

Williams, T.C., and Zahed, H., 1996, "Computer-based training versus traditional lecture: effect on learning and retention," *Journal of Business and Psychology*, Vol. 11, No. 2, pp. 297-310.