Virtual Environments for Surface Mining Powered Haulage Training

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ABSTRACT: This project investigated technologies and intervention strategies for reducing injuries and fatalities from powered haulage equipment in the metal/non-metal mining industry through improved worker training using virtual environments (VEs). The investigation focused on two primary equipments: haul trucks and conveyor systems. The research team developed VE applications to improve worker training for each type of equipment. The effectiveness and cost-benefit ratio of these VE training tools were empirically evaluated. Based on the results, the VE training tools were found beneficial for training pre-shift inspections of haul trucks and for training safety and operational procedures for conveyor systems.

INTRODUCTION

The integration of personnel and machines to transport tons of material over long distances is a dangerous formula, with haulage trucks and conveyor systems being key components. Haul trucks are widely used in the majority of large open pit mines and some large tunnel underground mines, moving material from the working face to processing operations. The operators of these vehicles must be highly aware of any hazards that may exist in their surroundings. Conveyor systems are large, energy-intensive pieces of equipment, generally used to move materials from one point to another within a mine site that is not constantly changing. Conveyors at mine sites are highly regulated and covered under parts 46 to 48 of the Mine Health and Safety law enforced by the Mine Safety and Health Administration (MSHA). Haul truck and conveyor accidents, with other powered haulage accidents, accounted for 37.2 percent of surface mining fatalities and 24.5 percent of underground mining fatalities between 2001 and 2005, in the United States (NIOSH 2008).

Based on the analysis of the fatal investigation reports of MSHA from 1995 through 2007 (2008), inadequate or insufficient training was considered the precursor to many of the causes identified in powered haulage accidents. In a mining operation, ignorance of the full consequences of an action may lead to unsafe work practices and in turn to accidents. While the mining industry has been advancing machine technology to improve health and safety, these advances do not take the individual worker and potentially insufficient training into account.

Typically the training requirements outlined by MSHA are met through classroom training, with information presented via videotapes and PowerPoint presentations by a training professional. Oral, written, and practical tests are used to demonstrate training completion, but these methods are passive in nature as the trainees observe more than participate. According to Burke *et al.* (2006), engaging training methods are the most effective for knowledge acquisition and retention of material. Kowalski and Vaught (2002) have also found that adult learners, such as new miners, are “task-centered” and “solution-driven.” Hence, the traditional methods for training new miners may not be the most effective training solutions; however, alternative methods of training are available.

One alternative to traditional methods of training miners is to use virtual reality (VR) or virtual environments (VEs). Virtual environments are synthetic three-dimensional spaces, which are seen from a first-person point of view, and which are under the real-time control of a user (Bowman *et al.* 2005). Given this definition, many different types of systems can be considered VEs, including 3D computer games, desktop animations, and web-based 3D communities. Particular VEs that create the illusion that the virtual world surrounds the user spatially are referred to as immersive virtual environments. Immersive VEs can lead to the sensation of presence, the feeling of "being there," where the virtual world replaces the physical world as the user's reality.

Outside of mining, VEs have already been used successfully for phobia training (Rothbaum *et al.* 1995), military training (Durlach and Mavor 1995), and medical training (Gutiérrez *et al.* 2007). In the mining field, VEs in the form of simulators (see Figure 1) have also been successfully used for training. Immersive Technologies and Fifth Dimension Technologies both commercially offer simulators for training operators of equipment such as haul trucks, bulldozers, and shovels. In addition to commercial simulators, other forms of VEs have been investigated for improving safety through accident simulation (Delabbio *et al.* 2007), helping identify hazards (Ruff 2001; Orr *et al.* 2003), and simulating health and safety activities (Stothard *et al.* 2004). The AIMS Research Unit has also developed SafeVR, a revolutionary tool that may be used to create VE training applications quickly (AIMS Research 2008).

Figure 1. An example of a simulator used for training haul truck operation

Due to the ability to safely simulate real life events in a digital environment that might otherwise be too dangerous or expensive to create, VEs have been used with great success (Haller *et al.* 1999). Using VEs for training offers valuable interactive training environments that allow trainees to take charge of their surroundings and learn at their own pace. Another advantage of using VE technology is that trainees can be placed in virtual situations that range from normal to extraordinary, allowing them to learn from the virtual experience what they have not yet encountered in real life. In consideration of these advantages, the goal of this research was to develop training techniques using VE technology to reduce the dangers of working around haul trucks and conveyor systems.

IDENTIFICATION OF TRAINING NEEDS

In order to develop training VEs for reducing injuries and fatalities from powered haulage equipment through improved worker training, this research began with the identification of training needs pertaining to haul trucks and conveyor systems. These forms of powered haulage were chosen because the manner of their operation and maintenance has high implications for worker safety; they require teaching multiple skills to personnel and the execution of complex tasks. The research team worked with industrial and regulatory partners to identify specific training needs for these equipments that were high priority, based on accident reports, field observations, and interviews. These needs were kept separated, related to haul trucks and conveyor systems, as were the rest of the methodology and procedures.

Haul Truck 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 this type of equipment. Improper maintenance and inspection combined with inadequate training comprised over half of all cited violations in the accidents analyzed involving haul trucks. Problems not detected during maintenance and pre-shift inspections can lead to costly mechanical failures and worker injuries. Inadequate training and ignorance of consequences of actions can lead to unsafe work practices, which result in injuries. Improving pre-shift inspection training was an obvious corrective measure to focus on and was expected to reduce the impacts of poor maintenance and inadequate training.

Haul truck pre-shift 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 pre-shift inspection to avoid missing an inspection point and possible defects. If the operator detects any problems with the haul truck during the pre-shift 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.

Based on training and materials received, specific inspection points and preventable failures were identified for inclusion in developing training VEs for pre-shift inspections of haul trucks. These points, detectable defects, and possible failures can be found in an earlier publication (McMahan *et al.* 2008).

Conveyor System Training Needs

Analysis of the accidents involving conveyor systems showed that additional measures are necessary to ensure the safety of miners working around conveyors. Improper maintenance, improper operational procedures, and unsafe work conditions were the most common causes of accidents around conveyor systems. These causes are directly related to a lack of knowledge of safety procedures and hazardous conditions. Considering these factors, the research team decided to focus on identifying hazards, proper safety procedures, and regulations for conveyor system training needs.

Conveyor system pre-operational checks incorporate both safety procedures and maintenance issues as a precursor to operational tasks. During these inspections, the operator walks around the conveyor system to identify potential hazards and maintenance issues. Once the operator has determined that the conveyor system is free of hazards and obvious mechanical problems, a lockout, tag-out procedure is required to start the system and begin operation. Once operation has begun, the operator is then responsible for identifying any mechanical issues that arise in order to properly shutdown the system to avoid further damage and even potential injuries. These aspects of the tasks required before and during the operation of conveyors were the focus of the research team's efforts to improve miner training. The specifics of these tasks were covered in an earlier publication (Lucas *et al.* 2008).

DESIGN OF VE TRAINING APPLICATIONS

Based on the training needs identified for both haul trucks and conveyor systems, three major considerations were taken into account for using training VEs. The first consideration was the presentation of information and how to effectively present training to the trainee. Because training VEs can simulate unlimited access to expensive or unavailable equipment, the research team decided the best method for presenting training information was to present the information while the trainee was virtually near the relevant equipment. The second consideration was the assessment of the trainee's retention of information while still in the training process. The benefit of using VEs for training in regard to assessment is that the training can be assessed in a simulation of real life situations. The third consideration was the reinforcement of training importance. If the importance of information is explained or demonstrated, the trainee is more likely to remember the information presented, in order to avoid dire consequences. Therefore, the research team decided to use "negative" simulations to emphasize the importance of the training content.

Haul Truck Applications Design

Based on the three major considerations, three correlating phases of training were designed for the haul truck training VEs: 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 an adequate pre-shift inspection of a haul truck 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, information windows are used to identify parts by name and to explain defects to look for with corresponding proper actions to take. Figure 2 shows an example from the virtual tour of a hydraulic hose inspection point and the information window associated with it.

Figure 2. Example hydraulic hose inspection point and associated information window

The second phase of the haul truck training, 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 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. When the trainee finishes virtually inspecting the haul truck, the trainee indicates that the inspection is complete by selecting a completion box located near the haul truck. All of the trainee's actions are graded and reported to the trainee after the virtual inspection to heighten retention levels.

The third phase of training, called the shift simulation, was designed to reinforce the importance of pre-shift inspections of haul trucks. 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 catastrophic consequences of failure. 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 the training.

Conveyor System Applications Design

Similar to the design of the haul truck training VEs, for the conveyor system training VEs, the research team designed an instructional tour to present training information related to conveyor systems and a virtual shift to assess the trainee's retention and to reinforce the importance of training.

The instructional tour was designed to take the trainee around a conveyor system along an automated path. This allows the trainee to become familiar with different areas of the conveyor system without needing to navigate manually. This also ensures the trainee reviews all of the training information provided at designed stops or stations. Each station contains a series of flashing colored spheres, or hot-points, that correlate to information about maintenance problems, safety procedures, hazard awareness, and conveyor components. Figure 3 shows an example of a hot-point related to the lockout, tag-out procedures for turning off the conveyor system. When the trainee has reviewed all of the hot-points at a station, the instructional tour continues to the next station. The research team designed six stations with training points pertaining to the specific training needs identified previously.

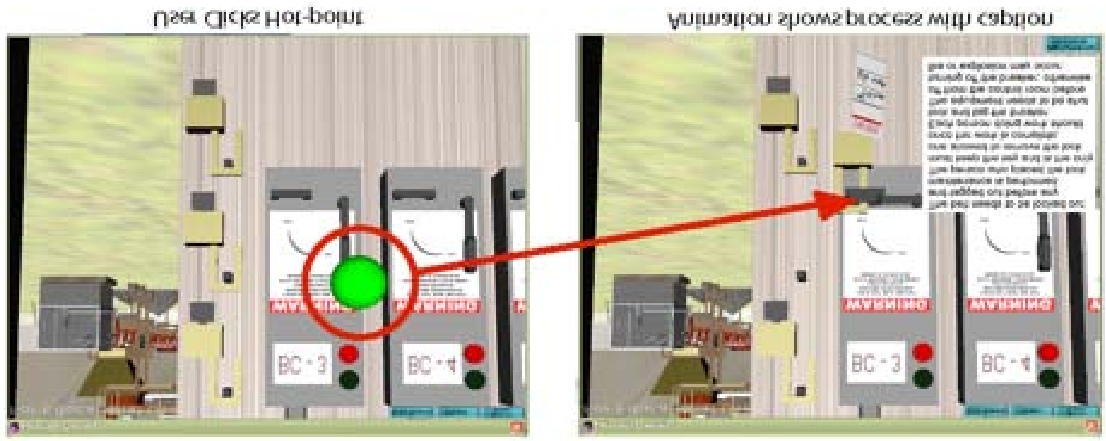

Figure 3. Hot-point example: lockout and tag-out

The virtual shift was designed to assess the trainee's retention of information after the instructional tour and to reinforce the importance of proper safety procedures. During the virtual shift, the trainee is allowed to navigate freely around a conveyor system while completing objectives. The first objective is to complete a pre-operational check to ensure the work area is clear of hazards and that the conveyor runs properly before operation. The second objective is to properly start-up the conveyor system, including turning on breakers, sounding the alarm, and turning the lever on to each conveyor belt. The third objective is to ensure the belts are running properly, which should lead to the discovery that a damaged idler needs to be fixed. The trainee must follow the proper lockout, tag-out procedure in order to initiate the repair and complete the final objective. This sequence of objectives was designed to assess the trainee's retention of information. If the trainee makes a mistake during an objective, a simulation of an accident or failure is used to reinforce the importance of the training.

DEVELOPMENT OF VE TRAINING APPLICATIONS

With the training VEs designed, the research team decided to utilize two different development processes to provide insight to better approaches for future development of training applications. The models and animations of the haul truck training VEs were created using Studio™. This same modeling and animation program was used to create Virtual Reality Modeling Language (VRML) files to use as desktop versions of the haul truck training VEs. In order to create more immersive versions of the training VEs, DIVERSE (Kelso *et al.* 2002), an application programming interface for VEs, was used to create versions of the training VEs for a CAVE™ (Cruz-Neira *et al.* 1993), a room-sized visualization system. See Figure 4 for an example of these immersive training VEs. For the conveyor system training VEs, the models needed were created using Autodesk® 3ds Max®. Right Hemisphere's Deep Creator™ was then used to create executable desktop versions for Microsoft Windows®. DIVERSE was used again for creating CAVE™ versions of the conveyor system training VEs (see Figure 5).

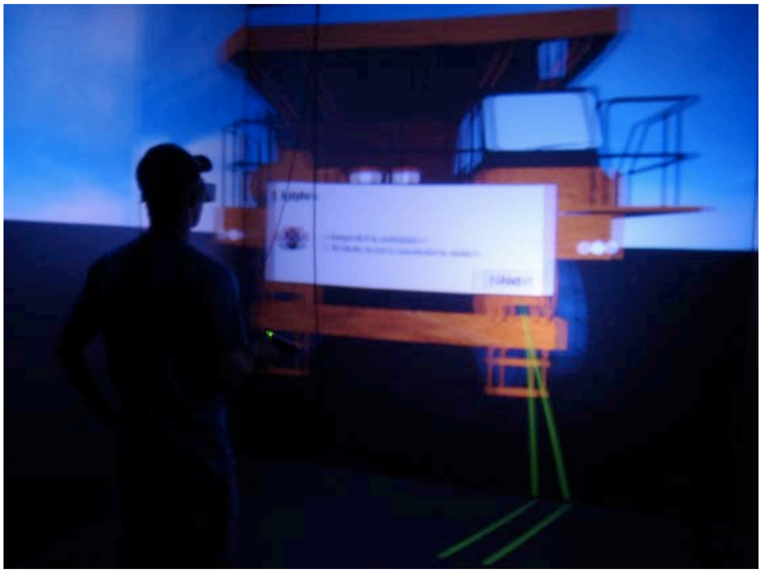

Figure 4. The CAVE version of a virtual environment for training haul truck pre-shift inspections

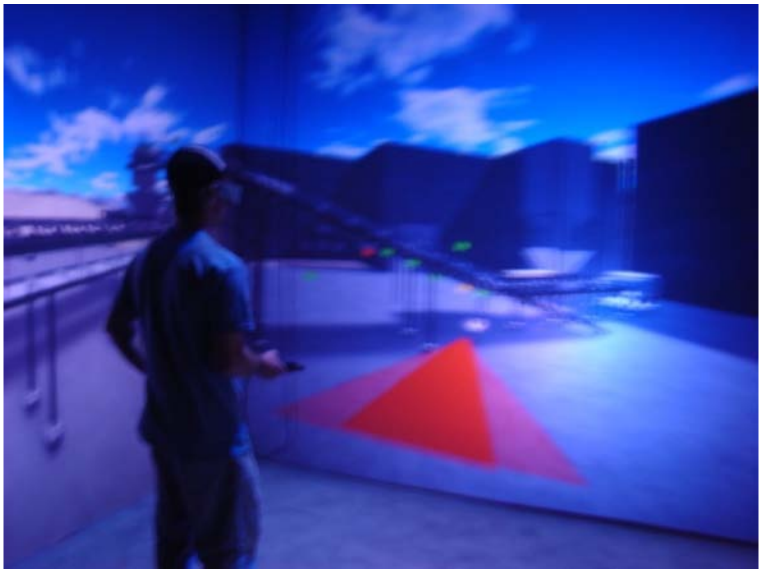

Figure 5. The CAVE version of the instructional tour virtual environment for conveyor systems

EVALUATION OF TRAINING VIRTUAL ENVIRONMENTS

After designing and developing the haul truck and conveyor training VEs, the research team set out to evaluate the effectiveness of these training tools to determine any potential benefits of using immersive technologies and to help determine the cost-benefit ratio of developing desktop and immersive versions of such training tools. In order to determine such benefits, the retention of information by a trainee after using the training VEs would have to be evaluated to determine the effectiveness of each set of VEs. Gutiérrez *et al.* (2007) conducted an experiment with a similar goal by utilizing a learning evaluation method based on Pathfinder-based representations of knowledge to quantify the effectiveness of two versions of a medical training VE.

The learning evaluation method employed by Gutiérrez *et al.* uses a knowledge assessment test consisting of weighting the relatedness of pairs of concepts critical to the training. By administering this related-pairs test before and after the intended training, information on how the trainee correlates critical concepts is established both before and after training. These weighted correlations can then be symbolized by networks, with nodes representing the range of critical concepts and the length of links representing the weight of correlations. A Pathfinder algorithm is then used to prune the network down to a minimal set of links required to keep each node or concept within the network. This pruned network of links is referred to as a knowledge structure. The knowledge structure of the trainee is then compared to the knowledge structure of a predetermined domain expert with a link-by-link comparison. The percentage of links in common is regarded as a measurement of the trainee's knowledge on a scale of 0 to 1. By obtaining a measurement of the trainee's knowledge before and after using the training VEs, the difference between the measurements can be used as an indicator of the retention of information by the trainee and the effectiveness of the training. A more detailed explanation of the Pathfinder-based representations of knowledge is provided by Johnson *et al.* (1994).

An issue of evaluating learning using Pathfinder-based representations of knowledge is that the Pathfinder algorithm necessitates that all of the nodes or concepts be connected to each other by some weighted link. One solution is to ask a relatedness question about every possible pair of concepts, but this requires approximately N^2 questions, where N is the number of concepts. This was obviously not feasible for evaluating the VE training tools developed by the research team due to the number of concepts incorporated into the training VEs.

Another solution to the issue of having connected nodes is to assign the lowest possible weight to links without corresponding relatedness questions. The problem with this solution is that it can be counterproductive to capturing domain knowledge with related-pairs questions. For instance, assume there are two concepts considered "absolutely not related" by the domain expert. In the expert's knowledge network, the link between these concepts would be weighted 7 using the 7-point scale described by Johnson *et al.* (1994). Now assume the same two concepts are rated as "most likely not related" by a trainee. In the trainee's knowledge network, the link between these concepts would be weighted 6. When the Pathfinder algorithm traverses the nodes of the expert's knowledge network, the link between the two unrelated concepts will be removed assuming there is already an indirect path between the two concepts. When the Pathfinder algorithm traverses the nodes of the trainee's knowledge network, the same link will remain since the link's weight of 6 will be greater than any indirect paths weighted 7. Now, the rest of the trainee's knowledge network may change drastically compared to the expert's due to this "most likely not related" link weighing more than links without corresponding relatedness questions. This randomness in the pruning of the network defeats the very purpose of using related-pairs questions to determine knowledge.

The research team decided to avoid these issues by leaving the Pathfinder algorithm step out and modifying the graph similarity computation. Instead of pruning the knowledge networks created from the related-pairs test with the Pathfinder algorithm, the research team modified the graph similarity computation to account for the relative weight of nodes. To demonstrate this modification, consider the following example.

At node A in the expert's knowledge network, there are three links with neighboring nodes B, C, and D. The three links correlate to the three relatedness questions pertaining to the concept of node A. The weight of the links between A and the other nodes are 7, 1, and 1, relative to B, C, and D (i.e. the weight of the link between A and D is 1). In the trainee's knowledge network, at node A the same three links weigh 6, 6, and 4, respectively. Now when graph similarity is computed the relative weight of each node is counted towards similarity. For instance, the expert and trainee share a common link between A and B because 6 is relatively closer to 7 than 1. The expert and trainee do not share a common link between A and C for the same reason. The expert and trainee also do not share a common link between A and D because 4 is relatively as close to 7 as to 1.

With these modifications to the learning evaluation method, the research team was able to account for the relatedness information captured by the knowledge assessment tests without asking thousands of questions to build a knowledge network for the Pathfinder algorithm.

Haul Truck Training Evaluation

For evaluating the effectiveness of both the desktop and immersive versions of the haul truck training VEs, the research team used three types of relatedness questions to compose the knowledge assessment test. The first type of relatedness questions involved the image of a haul truck part to inspect and the name of a haul truck part. If the name matched the part in the image, the two concepts should have been considered highly related. The second type of relatedness questions involved the image of a haul truck part to inspect and the description of a potential defect. If the potential defect described a defect that should be looked for in regard to the pictured part, the two concepts should have been considered highly related. The third type of relatedness questions involved the name of a part and the description of a potential defect. Again if the potential defect described a defect that should be looked for in regard to the named part, the two concepts should have been considered highly related. Otherwise, any pairs of concepts not highly related should have been considered definitely not related.

A total of 29 trainees recruited from around Virginia Tech's campus participated in the evaluation of the haul truck training VEs and a PowerPoint presentation that was evaluated as a traditional tool. Nine of the trainees were given the knowledge assessment test, received training using the desktop VRML versions of the haul truck VEs, and then given the knowledge assessment test for a second time. Ten of the trainees were given the knowledge assessment test, received training using the CAVE™ versions of the haul truck VEs, and finally given a second knowledge assessment test. The other ten trainees were given the knowledge assessment test, allowed to use the PowerPoint presentation for self-paced training, and then given a second knowledge assessment test.

Overall, the training tools and the PowerPoint presentation were found to significantly increase a trainee's knowledge as expected. The desktop versions significantly increased a trainee's knowledge ($p = 0.0041$) by an average of 32.14 percent. The CAVE™ versions significantly increased knowledge ($p = 0.0012$) by an average of 28.57 percent. The traditional PowerPoint presentation also significantly increased a trainee's knowledge ($p = 0.0045$) by an average of 23.04 percent. Because trainees with significant prior knowledge can only improve by a limited number of percentage points, the research team also calculated what percentage of possible new knowledge was retained by dividing the difference between the pre-training and post-training scores by the difference between the pre-training score and a perfect score. Based on these calculations, the desktop versions afforded learning 48.42 percent of possible new knowledge, while the CAVE™ and PowerPoint versions afforded 43.47 percent and 45.31 percent, respectively.

In comparing the desktop, CAVE™, and PowerPoint versions, the research team found that there was not a significant difference between the three versions in regard to the average increase of knowledge ($p = 0.7170$) and in regard to affording learning the most possible new knowledge ($p = 0.8809$). Because there was not a significant difference in the increases of knowledge between the versions, and because the CAVE™ versions were only enabled by immersive technologies costing thousands of dollars, the difference in the cost-benefit ratios of these versions was clear. Based on these facts, the cost-benefit ratio of developing desktop VEs was much more attractive than the cost-benefit ratio of developing immersive CAVE™ versions for these haul truck training tools. A similar difference can be identified in the cost-benefit ratios of the desktop VEs compared to the traditional PowerPoint presentation when the time required to create the 3D models and animations is considered.

Conveyor System Training Evaluation

For evaluating the effectiveness of both the desktop and immersive conveyor system training VEs, the research team again used three types of relatedness questions to compose a knowledge assessment test. The first type of relatedness questions involved the image of protective gear and the name of such protective gear. If the name matched the protective gear in the image, the two concepts should have been considered the same. The second type of questions involved the image of a conveyor system part and the name of a conveyor system part. Again, if the name matched the part in the image, the two concepts should have been considered the same. The third type of questions involved the image of a hazard and the description of a hazard. If the hazard description matched the picture of a hazard, the two concepts should have been considered the same. Otherwise, any pairs of concepts not considered the same should have been considered definitely not the same.

A total of 12 trainees recruited from around Virginia Tech's campus participated in the evaluation of the conveyor system training tools. Six of the trainees were given the conveyor knowledge assessment test prior to training with the Deep Creator versions of the conveyor system training VEs and again afterwards. The other six trainees were given the knowledge assessment test prior to training with the CAVE™ versions of the conveyor VEs and again afterwards.

Overall, the conveyor training VEs were found to significantly increase a trainee's knowledge as expected. The desktop versions significantly increased a trainee's knowledge ($p = 0.0010$) by an average of 35.83 percent. The CAVE™ versions significantly increased knowledge ($p = 0.0194$) by an average of 26.67 percent. Again accounting for trainees with significant prior knowledge, the research team determined what percentage of possible new knowledge was retained by dividing the difference between the pre-training and post-training scores by the difference between the pre-training score and a perfect score. The desktop versions of the conveyor system training

VEs afforded learning 72.43 percent of possible new knowledge, while the CAVE™ versions afforded 41.84 percent.

In comparing the desktop and CAVE™ versions, the research team found that there was not a significant difference between the versions in regard to the average increase of knowledge but there was a trend ($p = 0.1339$). In regard to helping learn the most possible new knowledge, there was a significant difference ($p = 0.0461$) with the desktop versions affording better training than the CAVE™ versions of the training VEs. This shows that the desktop versions provided better training for retaining as much new information as possible. Based on these results, the cost-benefit ratio of the desktop versions of the conveyor system training VEs is better than the cost-benefit ratio of the immersive versions, which use immersive technologies totaling thousands of dollars.

CONCLUSIONS

Based on the results from the empirical evaluations, the training VEs developed for this research are beneficial for training pre-shift inspections of haul trucks and for training safety and operational procedures for working around conveyor systems. The haul truck training VEs significantly increased trainee knowledge by an average 30.26 percent while the conveyor system training VEs significantly increased trainee knowledge by an average 32.08 percent. These results demonstrate the importance of the three major considerations taken during the design process of these tools – presentation of information, assessment of retention, and reinforcement of training importance.

In addition to validating the effectiveness of the training VEs developed, the research team demonstrated that immersive technologies are not necessary to provide effective training. In fact, for the conveyor system training VEs, a trend of the desktop version providing more effective training can be seen, because the desktop version increased training knowledge by an average of 35.83 percent while the immersive version only increased training knowledge by an average of 26.67 percent. These trends show that desktop VEs may have a more attractive cost-benefit ratio for training purposes than expensive immersive VEs, depending on the training content and application.

ACKNOWLEDGEMENTS

The information and developments presented in this paper were funded by a grant from NIOSH. The authors would also like to thank the many companies and research participants that contributed to this study.

REFERENCES

AIMS Research. 2008. AIMS research introduces SafeVR. www.nottingham.ac.uk/aims/VRSite/HTML/SafeVR.html. Accessed May 2008.

Bowman, D.A., Kruijff, E., LaViola, J.J. Jr., and Poupyrev, I. 2005. *3D User Interfaces: Theory and Practice,* Pearson Education.

Burke, M.J., Sarpy, S.A., Smith-Crowe, K., Chan-Serafin, S., Salvador, R.O., and Islam, G. 2006. Relative effectiveness of worker safety and health training methods. *American Journal of Public Health*. 96(2):315.

Cruz-Neira, C., Sandin, D.J., and DeFanti, T.A. 1993. Surround-screen projection-based virtual reality: the design and implementation of the CAVE. *Proc of 20th Annual Conference on Computer Graphics and Interactive Techniques*. 135.

Delabbio, F.C., Dunn, P., Iturregui, L., and Hitchcock, S. 2007. The application of 3D CAD visualization and virtual reality in the mining & mineral processing industry. www.hatch.ca/Mining_Mineral_Processing/Articles/3D_CAD_Visualization_Virtual_reality_in_MMP.pdf. Accessed May 2008.

Durlach, N., and Mavor, A. 1995. *Virtual reality: scientific and technological challenges*. National Academy Press.

Gutiérrez, F., Pierce, J., Vergara, V.M., Coulter, R., Saland, L., Caudell, T.P., Goldsmith, T.E., and Alverson, D.C. 2007. The effect of degree of immersion upon learning performance in virtual reality simulations for medical education. *Studies in Health Technology and Informatics.* 125:155.

Haller, M., Kurka, G., Volkert, J., and Wagner, R. 1999. omVR – a safety training system for a virtual refinery. *Topical Workshop on Virtual Reality and Advanced Human-Robot Systems*. 10:291.

Johnson, P.J., Goldsmith, T.E., and Teague, K.W. 1994. Locus of Predictive Advantage in Pathfinder-Based Representations of Classroom Knowledge. *Journal of Educational Psychology*. 86:617.

Kelso, J., Arsenault, L., Satterfield, S., and Kriz, R. 2002. DIVERSE: a framework for building extensible and reconfigurable device independent virtual environments. *Proc of IEEE Virtual Reality*.

Kowalski, K.M., and Vaught, C. 2002. *Principles of adult learning: application for mine trainers*. Strategies for Improving Miners' Training, (ed. R Peters), US Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No 2002-156, Information Circular 9463, 2002 September:3.

Lucas, J., McMahan, R., Engle, R., Bowman, D., Thabet, W., Schafrik, S., and Karmis, M. 2008. Improving Mining Health and Safety through Conveyor System Training in a Virtual Environment, *International Future Mining Conference & Exhibition*. Sydney, Australia. 161.

McMahan, R., Bowman, D., Schafrik, S., and Karmis, M. 2008. Virtual Environment Training for Preshift Inspections of Haul Trucks to Improve Mining Safety, *International Future Mining Conference & Exhibition*, Sydney, Australia. 167.

Miller, T.L. 2007. Making haul truck maintenance routine. *Aggregates Manager.* 12(12):26.

Mine Safety and Health Administration (MSHA). 2008. Fatal alert bulletins, fatalgrams and fatal investigation reports. www.msha.gov/FATALS/FAB.HTM. Accessed May 2008.

National Institute for Occupational Safety and Health (NIOSH). 2008. Mining fatalities. www.cdc.gov/niosh/mining/statistics/fatalities.htm. Accessed May 2008.

Orr, T.J., Fligenzi, M.T., and Ruff, T.M. 2003. *Desktop Virtual Reality Miner Training Simulator*. Center for Disease Control and Prevention.

Rothbaum, B.O., Hodges, L.F., Kooper, R., Opdyke, D., Williford, J.S., and North, M. 1995. Effectiveness of computer-generated (virtual reality) graded exposure in the treatment of acrophobia. *American Journal of Psychiatry*. 152(4):626.

Ruff, T.M. 2001. *Miner training simulator: user's guide and scripting language/documentation*. US Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No 2001-136.

Stothard, P.M., Galvin, J.M., Fowler, J.C.W. 2004. Development, demonstration, and implementation of a virtual reality simulation capability for coal mining operations. *Proc of ICCR Conference*, Beijing, China.