USING VIRTUAL REALITY (VR) TO IMPROVE CONVEYOR BELT SAFETY IN SURFACE MINING

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ABSTRACT: Each year there are numerous injuries, serious and fatal, that occur around conveyor belts because of inadequate training and untrained personnel. Current safety training programs for conveyor belts are not defined but generalized under safety training practices required by ANSI and OSHA. With the high rate of injury, it is important to research a safe and efficient form of training that is specific for conveyor belts. It is with this in mind that virtual reality is being investigated as a viable form of this safety training.

Virtual reality has been used in the construction and mining industries for accident recreation, fabrication training, and safety training, but has not been used with conveyor belts. A research program is being developed at Virginia Tech to investigate the effectiveness of VR for training of personnel working around conveyor belts in the surface mining industry. The program involves developing a series of instructional-based and task-based VR modules that are intended to assist the user in understanding the components and assemblies of the conveyor belt, explain the different hazards and safety issues associated with moving belt components when performing maintenance, and test the user's ability on resolving problems while performing a required set of pre-defined tasks in the VR environment. This paper explores and discusses the framework and implementation of the instructional-based module. Development of the task-based module and evaluation of the VR program are not covered under the scope of this paper.

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KEYWORDS: virtual reality, conveyor belt, safety, training, surface mining.

1 INTRODUCTION

The demand of mining and processing materials for construction requires equipment capable of transporting materials through different stages of mining operations. Conveyor belts, haul trucks, wheel barrows, and other mechanized material movers are used in the transporting of materials through different mine processing stages; the most cost effective and reliable of which is conveyor belts. (Swinderman 2002).

The nature of the mining industry's high production rate causes the mining industry to be inherently dangerous. A study by the National Institute for occupational Safety and Health (NIOSH) on occupational deaths between 1980 and 1989 indicated that mining industry has the highest average annual fatality rate (31.9 per 100,000 mine workers) of any industry in the United States (Orr In Press). From 1995 to 2006 there have been 510 equipment related accidents accounted for in the United States, 48 of which are conveyor belt related (MSHA 2007). It is with the high rate of accidents that there is now an emphasis on improving safety training and virtual reality is being proposed as an alternate that allows for a cost effective method to provide training for an accident plagued industry.

Virtual reality (VR) offers the opportunity to develop virtual training environments to immerse the user into a computer-generated reality which is too dangerous, difficult, or expensive to play in real life (Haller et al 1999). Various training scenarios can be simulated that allows the users to navigate through and interact with objects and test what-if situations. The cost benefits of VR training come from a few sources. First, in developing programs with RAD (Rapid Application Development) software that gives the designer the ability for real time feedback of environment interaction with minimum programming (Cope 2001). Cost cuts also exist due to cuts in on the job training or expensive real life simulation where full scale mock-ups would have to be used to accomplish what VR allows for on a personal computer (Kizil, in press).

VR has been investigated for training and safety in a wide variety of applications in the mining industry. One such example was conducted by the mining technology unit (HATCH) in collaboration with MIRARCO of Laurentian University , both of Sudbury Ontario, Canada, who are investigating the application of VR for improved safety including equipment design review for specific work environments, accident re-creation, and operator visibility improvement when driving mobile equipment in underground mines (Delabbio et al 2007).

Research work at the School of Mining Engineering at the University of New South Wales, Australia is investigating the use of virtual simulation to replicate the mining work environment and present the users with problem-based learning exercises through the use of a VR training tool (Stothard et al 2007).

Schafrik, et. al. (2003) investigated VR for accident recreation of haulage truck incidents in surface mining to help learn and subsequently teach what the causes of the accidents were by replicated consequences of actions taken.

Work at the National Institute for Occupation Safety and Health (NIOSH), Spokane Research Laboratory, involved developing a VR training tool to educate mine workers on the hazards of mining as well as to train miners on evacuation routes and evacuation procedures (Orr , In press).

Work by Kizil (In Press) at the Minerals Industry Safety and Health Center (MISHC), Australia, explored the benefits of VR for training and developed a number of VR applications for data visualization, accident reconstructions, simulation applications including haul truck simulation and inspection , risk analysis, and hazard awareness and training.

Hollands et al (2002) recognized that cost of equipment and the difficulties associated with customized development of the software as two leading reasons for restricting the widespread of VR technologies towards training and other applications. The research work invested in developing an application toolkit for the purpose of creating VR-based training tools into applications for a wide variety of uses which could dramatically reduce the development and time (and therefore cost) of VR training systems.

Although there is a significant amount of work investigating the use of VR for training in the mining industry, there seems to be no published work that explores the benefits of VR to improve safety of conveyor belts. The goal of the research being undertaken by VT is to explore VR technologies and develop a cost effective virtual environments to train workers on the hazards of conveyor belt operation. The research investigation is being comprised of two phases. In the first phase, an instructional-based module (guided walkthrough simulation) is being developed to familiarize the trainee with the working environment around a conveyor belt, the conveyor belt components, and to alert the user of the maintenance tasks and related hazards of the moving components. The second phase of the study involves task-based training. Simulations of various problem based scenarios will be developed to test the user's ability on resolving problems while immersed in the VR environment. Information related to the task can be accessed from within the simulation and the trainee's ability to identify and remedy risks can be quantified. Consequences of poor decision-making or risk-taking behaviors while interacting with the environment will be demonstrated to the user. This will allow for enhancing the cognitive learning process of users after both modules are completed.

This paper will address the exploration and investigation work performed under the first phase and the development of the walkthrough simulation prototype. The next section addresses the functionality and assemblies/components of conveyor belts. Hazards and safety concerns involved in working around a conveyor belt and corresponding accident statistics are presented in sections three and four respectively. Section five addresses current traditional training on conveyor belt safety. The framework and prototype development of the proposed walkthrough simulation is described in section six.

2 CONVEYOR BELTS

Conveyor belts have become the foremost transporter of bulk materials due to their dependability, versatility, and ability to handle large material varieties and capacities. They can run continuously, typically at 600 feet per minute, only being stopped for maintenance. The material is loaded on and automatically unloaded off the conveyor while the belt is in continuous motion. This eliminates loss of time for loading and unloading, and the need for scheduling and dispatching multiple trucks. Of all the material handling systems, belt conveyors typically operate with lowest transport cost per ton, the lowest maintenance cost per ton, the lowest power cost per ton, and the lowest labor cost per ton and the largest capacity. (Swinderman 2002).

In order to fully understand the dangers of the conveyor belt and the need for training, it is felt that the reader be informed of the basic components of a conveyor system and where those injuries are most likely to occur. A belt conveyor has six basic components (see figure 1), the belt, the belt support system (idlers), the pulleys, the drive, the structure, and the enclosure. Other parts can be added to these components in order to improve performance and decrease maintenance.

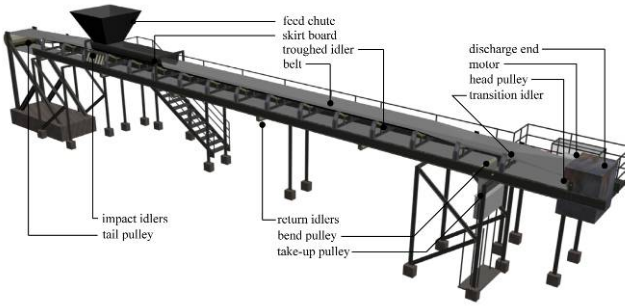

Figure 1. Conveyor belt components.

The conveyor belt stretches between two pulleys, the tail pulley (image 1), typically near where the loading takes place, and the head (or drive) pulley, which powers the belt and is where the material is usually discharged at the enclosure or discharge end (image 2). Loading may take place anywhere along the length of the conveyor belt and discharging is possible along the belts length with the use of plows and trippers.

Idlers help to shape and support the belt, prevent slippage, and maintain tracking. Impact idlers (image 3) can be used to help absorb the impact and prevent damage to the belt at material loading. To increase the carrying capacity of conveyor belts, troughed idlers (image 4) can be use to angle the sides of the belt, reducing spillage and helping to center the loaded material. On the return side of the belt bend pulleys are commonly used to bend the belt into the take-up pulley (image 5) which ensures proper belt tensioning through the use of counterweights. The structure helps to align the components and supports the weight of the materials being transported.

Image 1. Tail pulley (belt not yet assembled).

Image 2. Discharge end.

Image 3. Impact idler.

Additional equipment, such as scrapers (image 6) for belt cleaning and dust suppression systems, may be added to the conveyor system to help improve performance. More equipment may be need based on the desired outcome of the operation. For instance, if a conveyor system is comprised of multiple belts there will be a need for transfer chutes (Swinderman 2002).

Image 4. Troughed idler.

Image 5: Take-up pulley.

Image 6. V-plough scraper.

3 CONVEYOR BELT HAZARDS

Despite the multiple benefits of a conveyor system, they are an inherent danger in the mining industry. Conveyors can be a source of fire or personal injury due to the quantity of constantly moving parts. Conveyors have safety precautions set forth by the manufacturers as well as the government (Code of Federal Regulations in Title 30, Chapter 1, Subchapter K) (CEMA 2007), and it is when these precautions are not followed or ignored that accidents are most likely to occur. Cutting cost by not including certain safety equipment, or simply not having safety equipment properly in place can be very dangerous for not only the workers, but for the productivity and profitability of the mine. Safety standards make up a small percentage of the overall costs of conveyor systems. Safety measures that are commonly dropped from conveyor systems are pull cords along the conveyor, stop buttons at critical locations, backstops (or roll-back protection); start up warning systems, lockout devices, and guarding around dangerous areas.

Belt conveyors and their transfer points can be dangerous. By their very nature, they form many “pinch” points (figure 2) and rapidly moving objects. These “pinch” points are the main cause for most of the accidents that happen around the moving conveyor belts. As the name suggests they form areas between the moving conveyor parts and belt where miners can get entangled or pulled during performing maintenance tasks. It becomes imperative to be aware of the power of a conveyor while performing operations and maintenance as it has potential to injure or kill an untrained or unaware individual. The conveyor belt related safety/hazard factors are categorized as guarding, lock out/tag out, work attire and other critical entities like emergency cords along the belt, stop buttons at critical locations, start up alarm systems and railings. Guarding seems to be the most crucial safety factor with the conveyor belts and needs to be replaced before performing any maintenance task around the pinch points of the belt. While locking/tagging out the equipment is one of the most important safety precautions in mines. Lockout/Tagout is defined by MSHA as the “specific practices and procedures to safeguard employees from the unexpected energization or startup of machinery and equipment.” Lockout/Tagout procedure allows miners to perform maintenance tasks on the belt by putting lock and tag on energy isolating devices, which also informs other miners that task is being performed on the belt to avoid accidents. Third safety factor is wearing proper work attire while performing activities around the conveyor belt. Taking proper precautions can prevent these accidents and they need to be considered during construction, installation, maintenance, or inspection in the area of the belt. Further precautions should be taken by providing emergency warning signals and emergency stop controls, by de-energizing conveyor before performing any operation, and by providing proper training to the miners (Swinderman 2002).

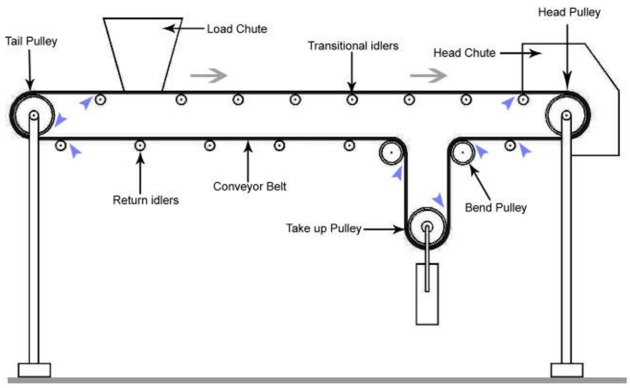

Figure 2. Example pinch point locations on a conveyor belt.

4 ACCIDENT STATISTICS

No matter how innovative, sophisticated, specialized, or foolproof the technology, its long-term performance is governed by the human element. Between 1996 and 2000 there were 459 reported injuries ranging from fatalities to injuries with restricted work activities in surface areas of metal/non-metal mines in the US (MSHA 2007). Of these 459 reported accidents, 13 were fatalities and another 22 were reported as permanent disabilities. 42% of reported accidents occurred when the injured worker was performing direct belt maintenance. Another 39% occurred while the subject was cleaning and shoveling around the conveyors. 290 of the 459 injuries and 10 of 13 fatalities have occurred due to working around moving conveyor belts and due to getting caught between moving conveyor belt and pulley (Goldbeck 2003). Since 1993 there have been 1024 mine fatalities, a frightening statistic that has shown mild signs of slowing since 2001, but still had 57 deaths in 2005 (MSHA 2007). The cause of the reduction of fatalities can be contributed to the recent success of research projects targeted specifically at mines and safety.

Statistics from MSHA indicates that conveyor belts have been the cause of 48 fatalities since 1995 (3 in 2006). Total equipment related accidents accounts for 510 accidents since 1995-2006 out of which 48 are related to conveyor belts (MSHA 2007). The majority of these accidents happened due to performing maintenance tasks and operation around energized conveyor belt. It is also observed that the most accident-prone parts of the conveyor are return idlers, tail pulley, and the conveyor belt itself. Out of these 48 reported accidents 11 fatalities occurred on moving conveyor belt, 9 fatalities occurred due to entanglement between return idlers and moving belt, where as 7 accidents were related to tail pulley. Other notable hazards that caused deaths were materials falling from the conveyor (either crushing, or suffocating the victim), falling off of the actual large structures along the conveyor, crossing the conveyor where there is no crosswalk, and the actual structure of the conveyor itself failing and falling on the victim. Few of these accidents occurred due to not observing proper work attire while working around moving conveyor belt. The fatalities statistics from 1995-2006 depending on the frequency of occurrences and related component of the conveyor belt are summarized in Figure 3.

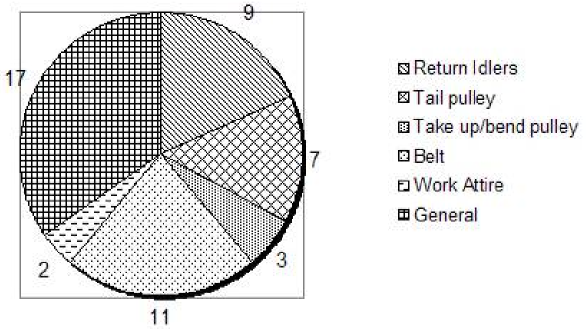

Figure 3. Conveyor belt related fatalities from 1995-2006 (MSHA).

5 CONVEYOR BELT SAFETY TRAINING

In the 1940's, ASME (American Society of Manufacturing Engineers) recognized the need for conveyor safety specification standard and issued ANSI (American National Standards Institute) safety standards for conveyors and related equipment. In the 1970s. OSHA (Occupational Safety and Health Administration) was founded and started preparation of their own conveyor safety standards (Shultz 2002-2003). Because of the "chain of players" involved in the planning, engineering, manufacturing, installation, operation and maintenance of a conveyor or conveyor system, the responsibility for application of the safety standards is often misunderstood, ignored or simply overlooked.

Current training in the industry to understand conveyor belts and their safety is mainly the responsibility of the owner/operator of the mining facility. Both OSHA and ANSI classify conveyor belt safety into the general operational and safety training. They place the responsibility of training on the owner to use a certified, qualified and competent person to train the operators. Often times, this leads the owner of the mine to appoint a safety engineer. The common practices of training within the mining industry for conveyor belts are to incorporate the basic safety and awareness into videos and slide-shows that are shown for required general safety training. With the lack of developed training programs, conveyor belt training is left to on the job training where a new employee is placed with experienced personnel to learn the workings of the conveyor belt and proper operations and maintenance. The one downfall for on the job training is that the training cannot be quantified and checked to make sure that the training period is adequate, it also allows for a chance of injury because inexperienced personnel are exposed to the dangers of a conveyor belt system (Shultz 2003).

6 VIRTUAL REALITY FRAMEWORK

In the first phase, an instructional based module prototype is being developed to familiarize the trainee with the working environment around a conveyor belt, the conveyor belt components, and to alert the user of the safety issues and related hazards of the moving components.

Figure 4 illustrates the basic framework for the simulation prototype. A digital 3D model of a belt assembly was created in Autodesk's "Autocad" and Autodesk's "3d Studio Max" (www.autodesk.com). This model was then imported into Right Hemisphere's "Deep CreatorTM" (www.righthemisphere.com) where animations and realistic properties were applied to the model. The first prototype that is being developed under phase-1 of the research is the "Instructional Based Module" which provides either a manual or automated walk-through, to provide the user with textual/digital information on belt assemblies and components, possible hazards, and safety issues. "Deep Creator" was used because it is a RAD (Rapid Application Development) system program that eliminates the need for heavy coding and offers direct results and feedback on user interaction. It also allows for publication of the virtual environments to self-executable files that can then be opened and operated on a "Windows" (www.microsoft.com) platform computer.

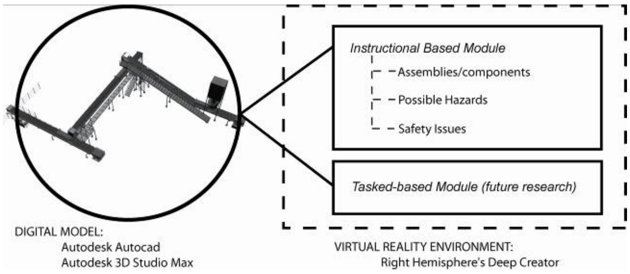

Figure 4. Framework Schematic.

The 3D digital conveyor belt system is designed off of conveyor belt images taken from site visits to a cement production plant in Virginia, US, by referencing Martin Engineering's *Foundations* (Swinderman 2002), and by referencing MSHA's Guide to Equipment Guarding (Chao 2004). The 3D model includes three different conveyor belt systems: an inclined belt, an overhead horizontal run, and a lower horizontal run at grade. This configuration allows for the different inherent dangers that these three conditions create.

When the instructional based module is started the user is given two options for moving around the model in the VR environment; an automated walk-through, or a manual walk-through (Figure-5). The user can toggle between both options during the walkthrough. As the user moves around the 3D model, hot-points (Figure 6), identified by flashing icons and color-coded designating the different type of information provided, allows the user access to textual as well as visual data and information to provide the user an understanding of conveyor belt assemblies and components (Figure 7), possible hazards (Figure 8), and safety issues (i.e. guarding, etc.), (Figure 9) that the user should be aware of while working around conveyor belts.

The instructional based prototype is intended to give the user the needed information, so that he/she would be able to then have an understanding of how a conveyor belt works and what to be aware of when working in a mining environment. It is the goal of this phase of the research to prepare the trainees so he/she would be able to complete tasks safely in the working environment and have the capability to recognize dangers and fix them properly. The information presented will be reviewed by industry professionals and training specialists for completeness and accuracy.

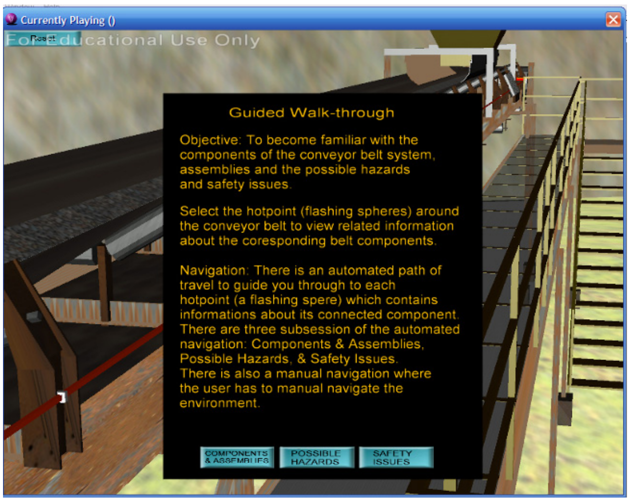

Figure 5. Start-up menu.

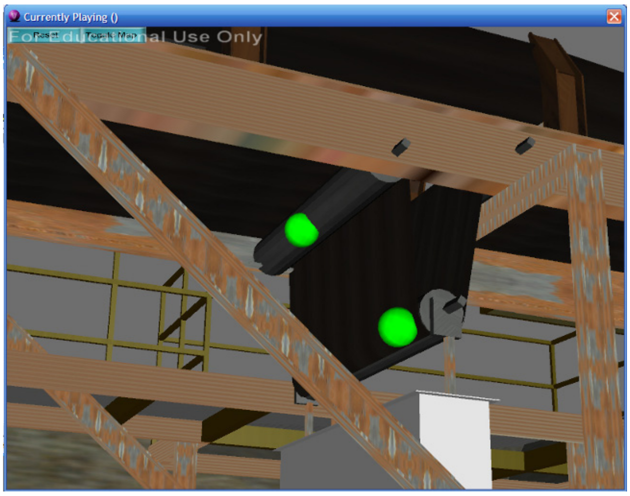

Figure 6. Hot-point.

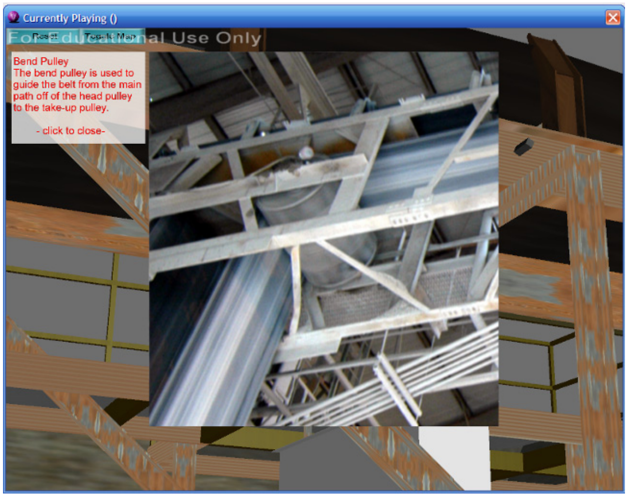

Figure 7. Component data sample.

Once a trainee completes one or more sessions of the information module, their learning ability will be tested in the task-based module sessions. The user will be given a specified task or set of tasks. He/she will then have to complete the steps required in performing that task while recognizing hazards and safety issues that they were informed of in the instructional based module. This work will be developed under the second phase of the research.

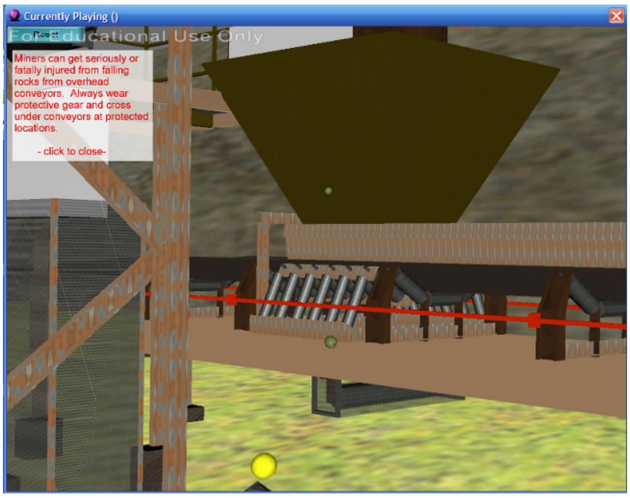

Figure 8. Possible Hazards Sub-session.

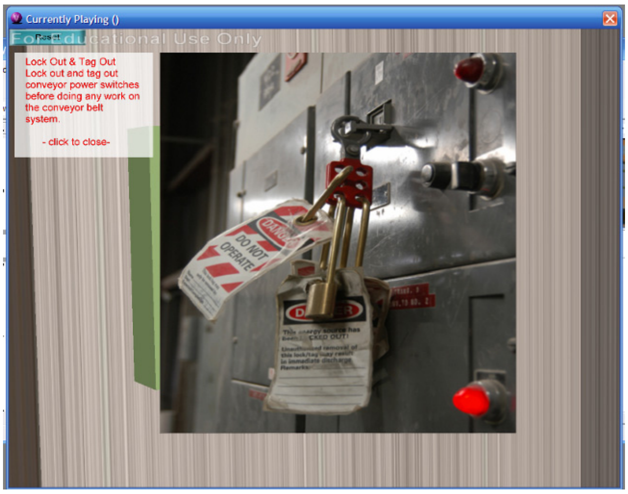

Figure 9. Safety Issues Sub-session screenshot.

7 EVALUATION

There will be two types of evaluation performed on both phases of the proposed safety program (Figure 10). The first evaluation will be an informal evaluation conducted using 2-3 field safety officers within the mining industry. These individuals will be asked to review and give feedback of the instructional-based implementation.

The second form of evaluation will be a formal evaluation using human subjects. One test group (group #1) will sit through a standard safety training session of videos, slides, etc., while a 2nd group of subjects of similar size and background will be informed and trained using the instructional-based module described in this paper. Upon completion, both groups will be tested using a task-based module, yet to be developed. The task-based system will require participants to perform various maintenance tasks and evaluate their performance based on a point system that tracks mistakes they make in the virtual setting. Upon completion, a score is given that can determine the skill level of the user. It is expected that the second test group will receive a higher average score, clarifying the validity of this research as a viable method of safety training for conveyor belt systems.

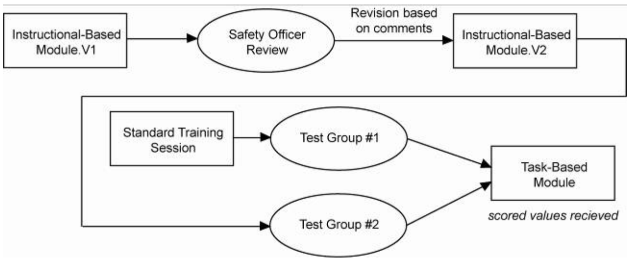

Figure 10. Proposed Evaluation Scheme.

8 CONCLUSION

The proposed investigation of VR for conveyor belt safety is intended to give safety training officials an interactive cost-effective tool with true navigation capabilities where users can control the pace of the exercise/training session. Compared to standard video and PowerPoint-type training presentations, it is hoped, that after the evaluation method described above is completed, this VR-based program will provide better cognitive learning tools that will aid trainees to recognize the hazards associated with working around conveyor belts. It is also a hoped that the training can then be tracked and evaluated which is currently hard to do at times. The main goal of this research is to offer realistic training scenarios that will allow for a safer work environment around conveyor belts and subsequently reduce the number of accidents and fatalities throughout the industry.

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REFERENCES

Chao, E. and Lauriski, D. (2004) "MSHA's Guide to Equipment Guarding (OT 3)". U.S. Department of Labor: Mine Safety and Health Administration.

CEMA. (2007) "CEMA Safety Page". Conveyor Equipment Manufacture Association.

Cope, M., Gray, M., Denby, B., Hollands, R. & Burton, A. (2001), "Virtual Reality in Mine Safety",29th International Conference of Safety in Mines, Szczyrk, Poland, 8-11 October.

Delabbio, Fred C., et.al. "The application of 3D CAD visualization and virtual reality in the mining & mineral processing industry." HATCH, Mining Technology Unit. http://www.hatch.ca/Mining_Mineral_Processing/Articles/3D_CAD_Visualization_Virtual_Reality_in_MMP.pdf, retrieved February 6, 2007.

Goldbeck, L. (2003) "Conveyor Safety and Education". Aggregates Manager.

Haller, M. G.Kurka, J.Volkert, and R.Wagner, (1999) "omVR – A Safety Training System for a Virtual Refinery." Topical Workshop on Virtual Reality and Advanced Human-Robot Systems, Vol. X, Tokyo, Japan, pp. 291-298, June.

Hollands, R., et al. (2000) "Equipment Operation and Safety Training Using Virtual Reality and SAFE-VR." In Minesafe International 2000. Perth, WA.

Jayaram, S., Connacher, H., and Lyons, K. (1997) "Virtual Assembly Using Virtual Reality Techniques." Computer-aided Design, 29 (8): 575-584.

Kim, S. and Weissmann, D. (2006) "Middleware-based Integration of Multiple CAD and PDM Systems into Virtual Reality Environment." Computer-Aided Design & Applications, 3 (5): 547-556.

Kizil, MS, and Joy, J. "What can Virtual Reality do for Safety?". The University of Queensland, Minerals Industry Safety and Health Centre. In Press.

Mind Safety and Health Administration (MSHA). (2007). www.msha.gov. U.S. Department of Labor.

Oh, H., Yoon, S., and Hawley, J. (2004). "What virtual reality can offer to the furniture industry." Journal of Textile and Apparel. Technology and Management, 4 (1): 1-17.

Orr, T.J., M.T. Fligenzi, and T.M. Ruff, "Desktop Virtual Reality Miner Training Simulator", International Journal of Surface Mining, Reclamation and Environment. In Press.

Shafrik, S.J., Karmis, M., Agioutantis. (2003) "Methodology of Incident Recreation Using Virtual Reality." 2003 SME Annual Meeting, Feb. 24-26, Cincinnati, Ohio.

Schultz, George A. (October 2003). "Training for Conveyor Safety". Material Handling Management, 58(11), 28-29.

Schultz, George A. (2002-2003). "Conveyor Safety and Regulations". Material Handling Management, 57(10), 18-20.

Stothard, P.M., Galvin, J.M., Fowler, J.C.W. (2004) "Development, Demostration and Implementation of a Virtual Reality Simulation Capability for Coal Mining Operations." Proceedings ICCR Conference, Beijing, China.

Stothard, P., J. Galvin, and J. Fowler, "Development, Demonstration and Implementation of a Virtual Reality Simulation Capability for Coal Mining Operations", School of Mine Engineering, University of South Whales. www.mining.unsw.edu.au/Publications/publications_staff/Paper_Fowler_ICCR_2004.pdf, retrieved February 26, 2007.

Swinderman, R., Goldbeck, L., and Marti, A. (2002). "Foundations 3: The Practical Resource for Total Dust & Material Control". Martin Engineering, Neponset, Illinois, U.S.A.