

Improving Conveyor Belt Safety Training Through the Use of Virtual Reality

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Abstract

Working around conveyor belts is the cause of numerous accidents each year that are costly to the mining industry. Current safety training practices generally include the use of slide show presentations, lectures, videos, and paper material before sending each worker onto site with an experienced person for on-the-job task training. These training methods are passive in nature and do not allow for an actual realization of consequences resulting from ignoring safety practices during interaction between the employee and the environment. It is with this in mind that virtual reality (VR) is being proposed as an added effective method of safety training.

In order to prove this hypothesis, a working VR prototype application of a mining environment has been developed. The application is designed in two modules. The first consists of an instructional based module, where the user is given all relevant information based on background research dealing with safety issues, hazard awareness, conveyor maintenance, and conveyor components and assemblies. The second module is a task-based training session that then tracks the user's performance as they complete assigned tasks.

An evaluation scheme was performed on the prototype to determine the usability and usefulness and identify areas in need of improvement. First, industry professionals were presented the application in an informal setting where the types of information and overall concept were examined and perceived usefulness was discussed. Secondly, users, both novice and industry professionals, were asked to go through the prototype training application and rate their agreement with statements based on the user interface and usability of the application. Finally, subjective interviews were performed to record perceived benefits of the virtual reality application over typical training material. This final stage consists of using both industry professionals and novice experience individuals and documenting their perceptions of benefits and challenges of using both typical methods of training and the designed prototype.

This document consists of an explanation of the research steps and papers that are published (or in press) detailing certain areas of the research, compiled findings, conclusions, and future research suggestions.

Thesis was formulated using paper format and 3 papers.

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1. Introduction

1.1. Background

Between 1995 and 2007, there were 50 conveyor belt related fatalities reported to the Mine Safety and Health Administration (MSHA) (Lucas et.al., 2007). Another analysis classified 459 conveyor belt related accidents reported between 1996 & 2000 for metallic/non-metallic surface mines (Goldbeck, 2003). These accidents cost the industry millions of dollars, with each fatality costing an estimated \$1.9 million. A rate calculated by estimating the value of lost time due to investigations and reports, payments to families for compensation, insurance, and lower production rates following each incident (Lucas and Thabet, 2007).

Current training methods fulfill regulations set forth by MSHA's Code of Federal Regulations (CFR) Title 30 that require that new miners participate in 24 hours of training. Four hours of training is required before the miner starts any work with remaining 20 hours occurring within 60 days of starting work. There are also requirements within Title 30 for task training of miners when they are assigned a new job task as well as miners transfer to a different mining operation. Every miner is also required to participate in eight hours of refreshment training courses annually and the facilities are required to alert them to new and temporary hazards that exist with the area of operation (CFR, 2008).

Three mining companies located within Virginia were consulted on how they meet the MSHA training requirements. In all three visited facilities slide show presentations are used accompanied by various training videos and literature handouts to meet the basic training requirements. Weekly or semi-weekly "tailgate" meetings are held to inform workers of near misses at their site and other safety issues that recently appeared through the industry. Training professionals often take this time to remind the workers of a particular safety practice (i.e. seatbelt use, lock-out & tag-out, etc) and to inform the workers of new hazards or temporary maintenance that will occur in the near future at the site.

MSHA's requirements with Title 30 cover safety training for the entire mine operation and are not specific to conveyor belt operation and maintenance. Individuals working with or around conveyor belts would participate in the 24 hours of training required by MSHA and then have task training for their specific job. Within the industry the task training often occurs while working with an experienced miner. This on-the-job training has value if the experienced miner can transfer the knowledge to improve the new miner's knowledge base. There are methods of tracking such knowledge base improvements (Gunderson, 1973) but they are often tedious and not utilized. There is also need to ensure that individuals participating in training new miners through on-the-job training have the adequate knowledge and are sufficiently trained themselves. With planned on-the-job training learning is often accelerated. With poor on-the-job training a new employee can be inhibited from properly performing tasks and cause injuries to rise (Wiehagen et al, 2002). Besides tracking effectiveness of on-the-job training and ensuring adequate trainers, the task-related nature of this training method makes it difficult to transfer knowledge to other companies and facilities that have different machinery that require different processes (Kowalski et al, 2001). This leads to issues of the ability to adequately train new and old miners efficiently. Complicating the issue further, a hiring boom through the 1970's and a reduction of new hires over the next decades has left mining facilities with the need of effectively and quickly training large numbers of newer, younger miners (Kowalski and Vaught, 2002). Trends within the mining industry are moving from specific on-the-job training to training methods that are more transferable from job to job.

1.2. Problem Statement

Problem 1: Belt conveyors are inherently dangerous and statistics show that they continue to pose a risk to anyone working around their use.

Belt conveyors run continuously without loss of time for the loading and unloading, scheduling, and dispatching that haul trucks and other equipment require. They typically run at 600 feet per minute and only need to be stopped for maintenance. Belt conveyors also often offer the lowest transport, maintenance, power, and labor cost per ton of material moved with a larger capacity to operation time ratio than other material moving equipment (Swinderman 2002). Belt conveyors have become “part of the landscape; they are not seen as hazards, but rather as a fact of life” (Goldbeck, 2003). It is 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.

Problem 2: Passive training methods (typically used within the mining industry) are not the most effective method of training adult learners.

Current methods of using videos and slide-show presentations methods are passive in nature with no first person interaction and no prescribed method of assessing the retention of knowledge gained. Kowalski et al (2001) and Kowalski and Vaught (2002) summarize issues of different generations training needs for learning abilities. A younger generation, more computer literate, may receive more benefit from a multimedia based training that they can explore and interact with while the older generations, less likely to be computer literate, often learn better from a more direct and structured approach but all adults often learn best from an active and experience based approach. Current training practices are not set up to accommodate this variety of styles of learning popular among various individuals.

1.3. Hypothesis

Methods of training are needed throughout the mining industry and for conveyor belts to rapidly and effectively train a nearing surge of hires and younger miners. Virtual reality (VR) has been a valuable training tool for other sectors of the mining industry and in other industries in the past when used as a safety training application (Lucas et.al., 2007). It is believed that Virtual Reality can offer an active and interactive method of training for conveyor belts safety. It is with the past success of VR in other fields and the need of a more effective and interactive training that has lead to the following research.

The research hypothesis consists of two areas. The first is considered and proven within the conducted research, the second is a basis for this research and future research is set up to prove its validity.

1. VR can potentially be a useful and effective method of safety training for conveyor belts.
2. With younger miners, who are more likely to be computer literate, needing training, the interactive VR training concept proposed will be successful to augment current training methods and reduce the number of accidents and fatalities.

1.4. Objective

Training for surface conveyors need to be improved to save lives. The main focus of the research is to define and test an evaluation scheme evaluating the use of VR in safety training. The evaluation scheme evaluates the effectiveness and perceived benefits and shortcomings of using VR for safety training on surface conveyor systems as compared to typical training methods used within the mining industry. This

scheme consists of a multi-phase process that will identify feasibility of the prototype, usability issues, and potential usefulness of a developed VR prototype.

1.5. Research Methodology

In accomplishing the set forth objective an evaluation scheme is developed. The phases of this scheme include both qualitative and quantitative studies as well as subjective and objective comparisons (Figure 1-1).

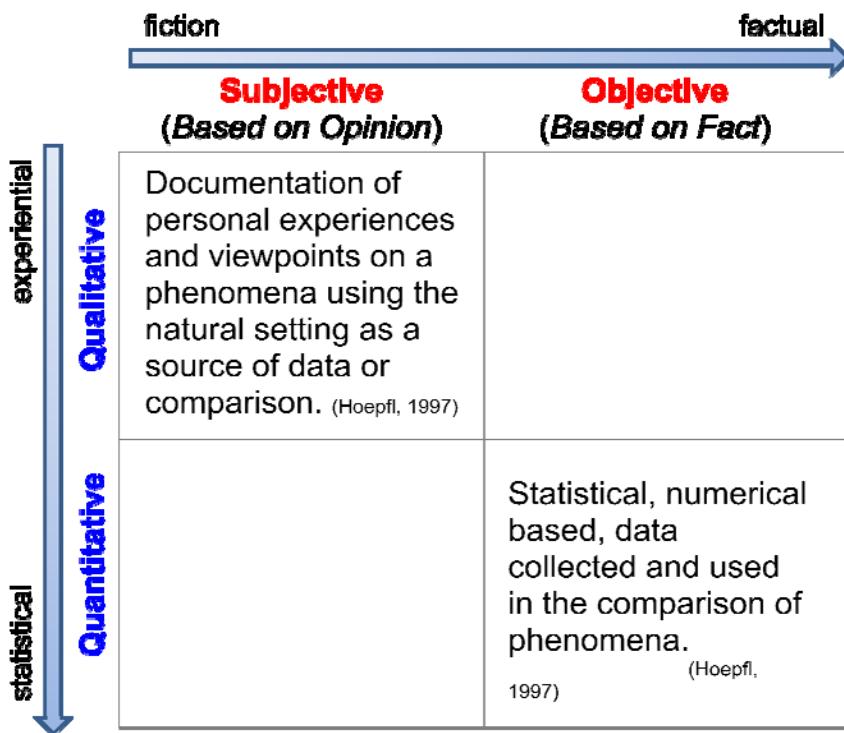


Figure 1-1: Qualitative/Quantitative and Subjective/Objective Comparisons

As defined by Creswell (1994, pg. 1-2), a qualitative study is designed as an inquiry process to gain understanding of a social or human problem by forming a complex, holistic picture with words and detail views of informants. A quantitative study is also an inquiry into a social or human problem, but is based on testing a theory composed of variables, measured with numbers, and analyzed with statistical procedures to determine the results of the study.

A subjective analysis is typically more of opinion and observation while an objective analysis is based on factual information that can be confirmed (Hoepfl, 1997).

The evaluation scheme is developed with three phases; the first two phases are completed within this research while phase three is future research (Figure 1-2). Phase 1 consists of usability evaluations which will record industry evaluation and feedback of concepts and potential use of the application (phase 1.1) as well as an interface evaluation for user controls, graphics, etc (phase 1.2). Phase 2 of the evaluation scheme will consist of a usefulness study. Phase 3 which is not included in this research will consist of a performance-based evaluation.

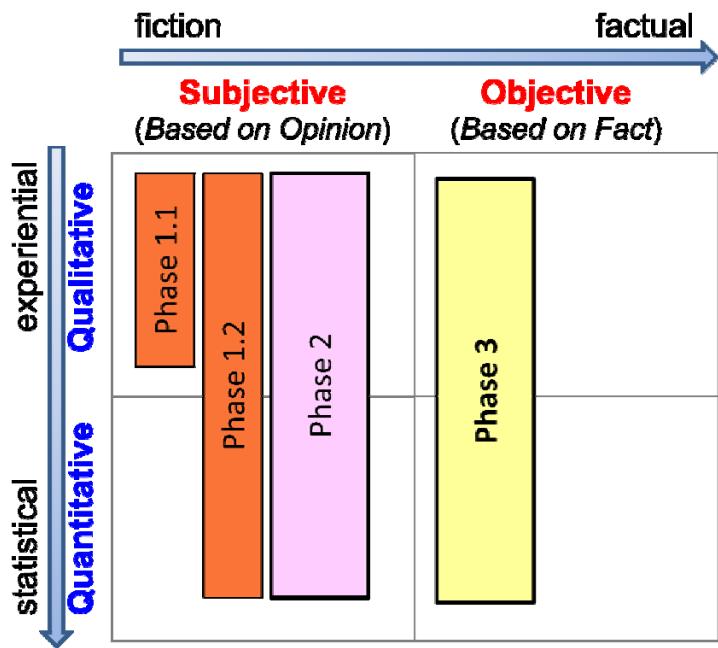


Figure 1-2: Evaluation phases

Each of the studies that are conducted as part of this research are considered verification studies. The participants all fall within the “younger” miner age range. They all have experience with the computer and most have experience with first person video games. A validation study will be conducted as part of future research and phase 3 during the performance based evaluation.

1.6. Research Steps

In order to accomplish the set forth objectives a four step process is used to develop a prototype application that is useable and useful in fitting the industry’s needs (Figure 1-3). The four steps consist of: (1) data analysis and structuring, (2) define components of training areas, (3) VR prototype implementation, and (4) evaluation and feedback.

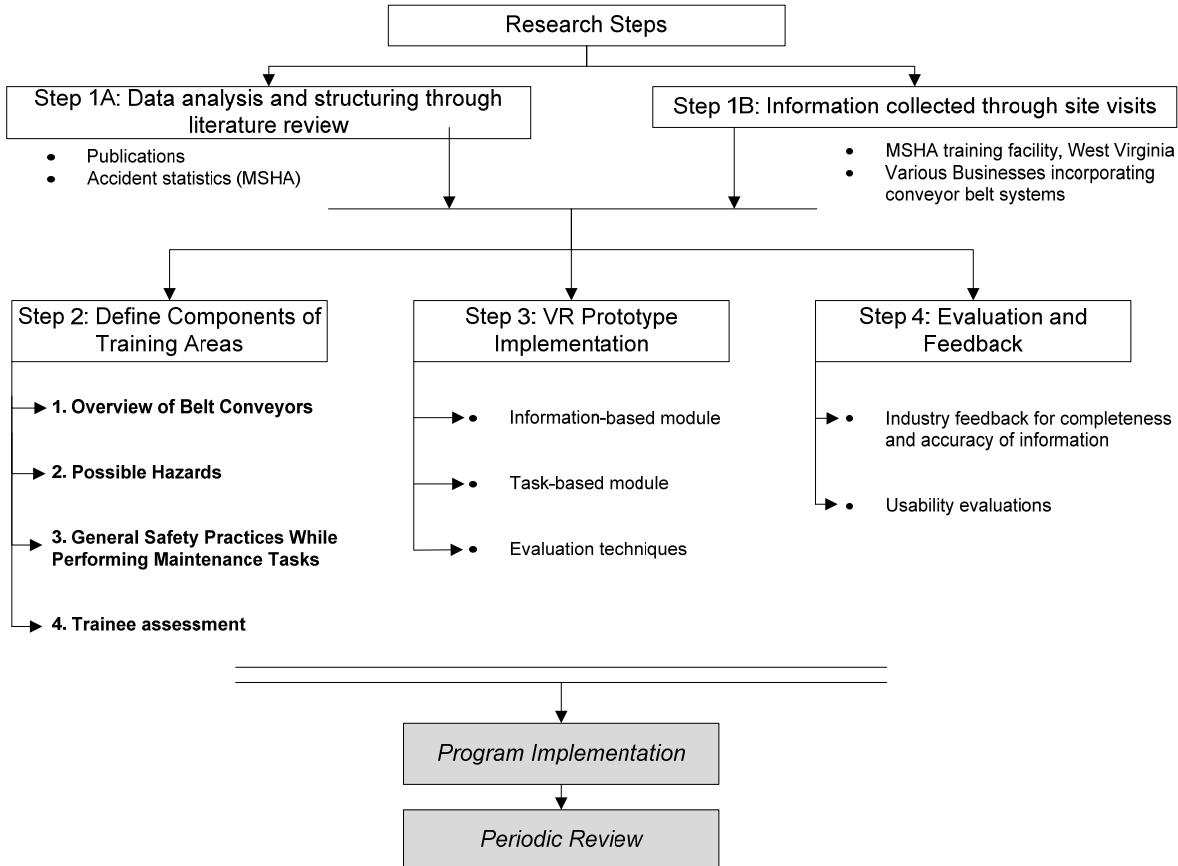


Figure 1-3: Research Process

If the application is further developed two additional steps are needed (1) including implementation into the industry and (2) periodic review of information. The periodic review would all editing outdated information for changes in regulations, procedures, and common accidents and problems.

1.6.1. Data Analysis and Structuring

The data analysis and structuring step is divided into two stages. The first stage is data analysis through literature review of various publications, federal regulations, and reported accident statistics. This stage includes the structuring of this information to be helpful through the research. The second stage deals with information received through site visits. A series of informal meetings and tours were conducted of facilities that incorporate the use of surface conveyor belts within their processing operations. During the same stage of data collection, informal interviews were held with several mining professionals that deal with the day to day operations, maintenance, and safety of the facilities. These individuals aided in determining what types of information to include within the prototype. The information received included common problem areas with safety and maintenance that are often overlooked, their perceptions on what information to highlight within a training program, and their opinions on information to include in the training scenarios.

The information compiled through literature review was combined with the thoughts and concerns of mining professionals to form a databank of information to present within the prototype application. In order to ensure that all bases were covered, further literature review was conducted to aid in what should be included in a conveyor belt safety training program. After the data collection was completed, the

information needed to be tracked and formed into categories to make sure that all areas of interest were adequately covered.

1.6.2. Define Components of Training Areas

The information that was collected through the data collection phase was placed into categories consisting of:

1. *Overview of belt conveyors* – consists of information pertaining to components and assemblies of the conveyor belt, the purpose of each component and assembly, and what defects might appear with certain components and assemblies.
2. *Possible hazards* – consists of hazards to be aware of while working on or in the vicinity of a conveyor belt system. Identifying hazards was considered by mining professionals a significant part of safe conveyor belt operation.
3. *General safety practices* – contains information dealing with safe operating and maintenance procedures. Included within this category of information is safety apparel required for working around conveyors, proper start-up procedures for conveyor belts, and guarding requirements.
4. *Trainee assessment* – consists of creating scenarios from suggestions of industry professionals at interviews or recurring situations from review of accident reports.

The information from each of the categories 1-3 were used in defining the information to present to the user in the first module of the application. The trainee assessment categories include scenarios used within the second module of the application. Once the information was placed in categories the individual topics were listed with related captions. These captions were then transplanted to the prototype application during implementation and presented to the user.

1.6.3. VR Prototype Implementation

The basic application consists of two modules, an instructional-based module that disseminates the information to the user and a task-based module that tests the user's ability to complete tasks based on the information they reviewed in module 1. The 3D model for the application is developed using photos from site visits and other user and maintenance manuals collected through the data collection. Autodesk's AutoCAD (Autodesk, 2008) is used in developing the preliminary model graphical objects. The model is then imported to Autodesk's 3D Studio MAX (Autodesk, 2008) where materials and other properties are mapped to the objects. Finally the model, with material mappings, is imported into Right Hemisphere's Deep Creator™ (Right Hemisphere, 2008), a rapid application development (RAD) program that allows for creation of interactive applications with direct review of how the prototype will operate. Deep Creator was used for development because it offers an easy to learn environment that can model basic shapes and animations as well as a built in LISP Editor for programming of advanced interactions.

The instructional-based module consists of an automated tour of the virtual mining environment that consists of three conveyor belt assemblies, one at ground level, an elevated belt system, and a sloped belt system. This offers all of the potential hazards that can exist while working around conveyor belt systems. All of the information that existed within categories 1 through 3 of "1.6.2 Define Components of Training Areas" is presented in this first module. The automated tour navigates the user to six different station, or stops, within the environment. These stations contain a series of hot-points that are connected

to the collected information. The information presented at each station is grouped to what is common to that area of the belt.

The process of developing the instructional-based module is explained in detail in chapter 2 “Using Virtual Reality to Improve Conveyor Belt Safety in Surface Mining” (Lucas et.al. 2008a).

Once the instruction-based module is completed, the task-based module is developed. The task-based module gives the user tasks that they need to complete. While completing these tasks, the application tracks the user’s progress and actions and records them to a file that prints out at the end of the session and can be reviewed by the training professional to help determine further training for an employee. The user is given points based on their performance which then can be used by the administering safety trainer to determine if they have learned the information that was presented and what they will need to review more before starting work.

The first step of implementation of module 2 was to create a scenario from the data collection. Information from accident statistics and fatality reports as well as input from mining professionals was used in creating the scenario. The objective is presented to the user as they enter the environment and is similar to what would occur at the beginning of the work day for a miner. This includes, checking the belt for hazards, following proper start-up procedures, and then ensuring the belt is running properly. In order to implement this scenario into the prototype flow-charts were created of what the user would encounter while working in the virtual environment. These flow-charts were then used to implement the scenario.

The user self navigates through the environment by using the mouse and the keyboard and is first presented with needing to find three hazards that exist. When the user clicks on these hazards the user is presented with questions about the hazard and how to fix the hazard. If the user answers correctly, the system scores them the appropriate points, however, if the user answer incorrectly, they are given an explanation of why it is the wrong answer and an animation of the consequences if they went about fixing it the wrong way or not at all is shown. The wrong answers are also recorded by the system so the user can be trained on his/her errors by the safety training professional. Once the hazards are found, the user then needs to go through the process of turning on the belt by following the correct procedures. Finally the user has to check the environment and fix a broken return idler. In doing this they are tested on their ability to lock-out the system correctly and given points for completing each step in a similar method to that of when they turned the belt on.

The LISP programming features of Deep Creator were used with the addition of system variables, loops, if-then statements, and other lines of code in order to track user’s performance. This allowed for the application to check the conditions of the environment so the proper response is given to any action taken. Some instances of this are that the belt cannot turn on if the breaker is turned off and if the user did not sound the alarm before the belt was turned on.

The process and details of developing the task-based module are explained in chapter 3 “Implementation and Evaluation of a VR Task-Based Training Tool for Conveyor Belt Safety Training” (Lucas and Thabet, 2008).

1.6.4. Evaluation and Feedback:

The final step in conducting the research consists of making sure the application is in line with the training needs of the industry, ensuring that the interface is usable and identifying usability issues, and evaluating the effectiveness of using VR as a training tool for safety training on conveyor belts as opposed to typical training methods.

The developed evaluation scheme consists of three phases (Figure 1-4): Phase 1 is usability evaluations, Phase 2 subjective analysis, and Phase 3 performance based comparison. The first two phases were completed as part of the research with the third being future work.

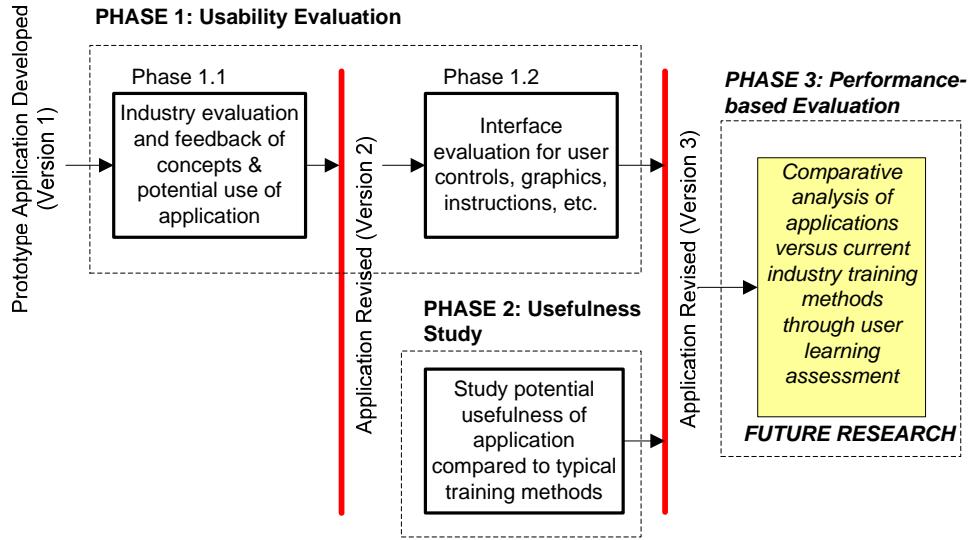


Figure 1-4: Three phase evaluation scheme

Phase 1, the usability evaluation, includes two parts, (1) an unstructured industry feedback where the information presented within the application was reviewed for accuracy and completeness as well as for general comments and (2) an interface evaluation to help identify usability issues and programming bugs. The industry feedback was conducted through a series of meetings where members of the mining industry were given a presentation of the proposed application and their thoughts and comments on application design, usefulness, and presented information was recorded and used to revise the application. The interface evaluations were conducted with both novice user groups and expert user groups. Each participant tested the application and then was asked to complete a survey rating their agreement with statements on instructions, navigation, clarity of presented information, and ease of completing tasks. Programming bugs and issues with the graphical user interface (GUI) were also identified during the usability evaluation.

Phase 2 consists of a potential usefulness study which documented perceptions of industry professionals and novices users on the usefulness, benefits, shortcomings, and preferences of the proposed training application compared to typical training methods. The subjective analysis study was conducted to document users' perceptions of the benefits, shortcomings, and preferences of using the proposed application as compared to typical training methods. Novice users were given a presentation of typical training material commonly used through the industry and then allowed to test the proposed application. They were then asked to complete a survey questionnaire dealing with their perceptions on the benefits

and shortcomings of each training method as well as which they preferred. Professionals from the mining industry were allowed to test the application and then asked to complete the survey questionnaire to document their opinions.

The proposed Phase 3 to be conducted as part of future work would be a performance based comparison. This would involve having new miners, with no prior training experience, participate in a fully implemented and functional VR training application and then complete a test in the field. Another group of new miners would participate in typical training sessions and complete the same test in the field. The results of the two groups would then be compared. The use of a prototype application for this type of test is not practical because of usability issues that were identified in the prototype application.

The evaluation scheme and findings for each stage are summarized in chapter 4, “An Evaluation Scheme for Two Safety Training Applications” (Lucas et.al., 2008) and complete findings listed in the conclusion of this document.

1.7. Thesis Organization

The following chapters consist of papers that document specific steps of the development and evaluation process in detail. They have either been published, accepted for publication, accepted with comments, or had the abstract accepted for publication.

Chapter 2: “A VR-Based Training Program for Conveyor Belt Safety” (Lucas et.al., 2008A) has been published to ITcon (Journal of Information Technology in Construction). This paper discusses the research steps taken in developing the training program, current training practices and what to include in a training program, and literature review of successful VR application in mining. The process of developing the instructional-based module and how industry feedback was used to modify the module is also discussed.

Chapter 3: “Virtual Reality as a Task-Based Training Tool” (Lucas and Thabet, 2008) has been published to ITcon special issue “Virtual and Augmented reality in Design and Construction.” This paper discusses in detail the implementation, challenges, and methods of tracking user performance of the task-based module. The evaluation process for the task-based method is discussed with detailed results of the feedback and evaluation.

Chapter 4: “An Evaluation Scheme for Two Safety Training Applications” (Lucas et.al., 2008B) has been presented at and published in the proceedings for the CIB W78 conference in Chile. This paper discusses the details of the evaluation scheme and gives a summary of the preliminary results.

Chapter 5: “Limitations and Findings” contains details of the findings of the evaluation structure as well as noted limitations to each study.

Chapter 6: “Future Work and Conclusions” contains suggestions for future work as well as the conclusions made from the study.

2. A VR-Based Training Program for Conveyor Belt Safety

“A VR-Based Training Program for Conveyor Belt Safety”

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SUMMARY: The mining industry is characterized by the need for high volume of production which has forced its adoption of large and fast moving equipment for transporting bulk material. Belt conveyors have attained a dominant position in transferring material due to such inherent advantages as their economy of operation, reliability, versatility, and practically unlimited range of capabilities. With all of these factors comes an inherent danger. From 1995 to 2007 there have been a total of 534 equipment related fatal accidents in the United States as recorded by the Mine Safety and Health Administration, 50 of which are conveyor belt related. Most accidents around belt conveyors are caused by human error, improper maintenance procedures, lack of effective training or lack of awareness of possible hazards.

To counteract this high number of accidents, virtual reality (VR) is being looked at as an alternative to current safety training programs. The structure and program being proposed consists of 4 steps in creating a two phased program. This paper discusses the step by step structure of creating a safety training program for belt conveyors and the first phase of implantation of the program. The first phase includes an instructional-based phase that allows for the presentation of the information compiled for the areas of training that were determined within the structure of the program. This paper will discuss the framework used in developing the VR safety training application, the first phase of the prototype development, how the data has been retrieved and organized, and how industry feedback was gathered and used to develop the application.

KEYWORDS: *virtual reality, safety training, conveyor belts*

2.1. Introduction

The mining industry is characterized by the need for high volume of production which has forced its adoption of large and fast moving equipment for transporting bulk material. Belt conveyors have attained a dominant position in transferring material due to such inherent advantages as their economy of operation, reliability, versatility, and practically unlimited range of capabilities.

Belt conveyors come in various configurations; however, the basic components of the conveyors are the same. They can be level or inclined and are usually set up in a series of multiple conveyor runs. With the

basic operation of a belt conveyor, the material is loaded onto the belt near a tail pulley and unloaded near a head pulley (or drive end). Between the head and tail pulleys are a series of idlers and pulleys to keep the tension and alignment of the belt and to help prevent excessive wear (Figure 2-1). Belt conveyors run continuously without loss of time for the loading and unloading, scheduling, and dispatching that haul trucks and other equipment require. They typically run at 600 feet per minute and only need to be stopped for maintenance. Belt conveyors also often offer the lowest transport, maintenance, power, and labor cost per ton of material moved with a larger capacity to operation time ratio than other material moving equipment (Swinderman 2002).

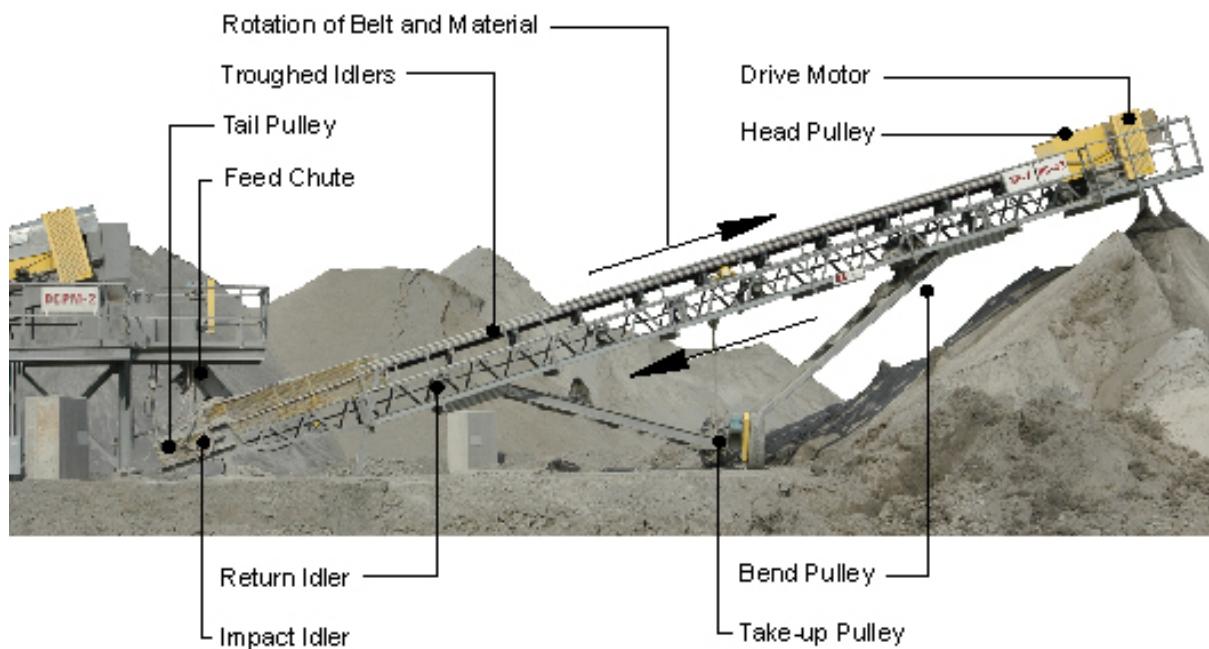


Figure 2-1: Conveyor Belt Components

By their very nature, belt conveyors are inherently dangerous as a work environment. Due to the continuous moving parts and high rate of materials transported, the forces applied by conveyor belts are significant and potentially dangerous. Conveyors also feature many “pinch” points with large amounts of mechanical energy. As the name suggests, pinch points form areas between the moving conveyor parts (e.g. cylinders) and belt where miners can get entangled or pulled during performing maintenance tasks. As a result, they have a high rate of injury. Nevertheless, belt conveyors have become “part of the landscape; they are not seen as hazards, but rather as a fact of life” (Goldbeck, 2003). It is 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.

Most of the accidents around belt conveyors are caused by human error, improper maintenance procedures, lack of effective training or lack of awareness of possible hazards. In the Code of Federal Regulations (CFR) Part 46 and 48, the Mine Safety and Health Administration of the United States Department of Labor (MSHA) require training for all miners (Goldbeck, 2003). Newly trained workers must receive 24 hrs of specified training. An additional 8 hrs of refresher training is specified each 12 months. No specific training on belt conveyors is mentioned. Based on the number of conveyor related

accidents and fatalities (MSHA 2007), it is evident that current required training that are based on standard audio-visual methods, are not achieving their goal. More rigorous and structured training programs oriented towards identifying conveyor belts' problems and hazards need to be devised and implemented. Virtual reality (VR) provides the opportunity to develop interactive virtual training applications that are comparable to real life simulations but could be more cost effective. Interactive VR applications designed for safety training can provide better cognitive learning tools by allowing trainees to actively participate and experience in near-reality sense the hazards associated with working around conveyor belts and to virtually practice performing tasks without the dangers of a working belt. A large amount of scholarly work investigating the use of VR for safety training exists (Delabbio, et. al. 2007, Ruff, 2001, Stothard, et. al., 2004, Orr, et. al., in press, Schafrik, et. al., 2003, Hollands, et. al., 2002, and Dezelic, et. al., 2005). However, no published work was found that explores the benefits of VR to improve safety training of conveyor belts.

A VR-based training program is proposed for safety training around belt conveyors. The proposed program comprises of two interactive phases; an instructional-based phase, and a task-based phase. The instructional-based phase is a guided walkthrough simulation intended 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 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. Quantifying the trainee's ability to identify and remedy risks will allow for enhancing the cognitive learning process of users and help track the effectiveness of the training program. The goals of the research is to offer a VR application that train the user at their own pace through first person interactions while tracking their process and performance while giving them direct consequences to actions taken and finally to offer an aid to the industry that they would view as a valuable supplement to current training material.

This paper discusses the requirements of the proposed training program and presents in detail the steps that are being suggested to use in order to develop a comprehensive training program as well as the developed instructional-based phase of the prototype. Needed data on belt components, maintenance and safety issues were acquired through site visits, examination of documented case studies, and literature on current training practices. A digital 3D model of a conveyor belt is created from images taken during various site visits and from manufacturers' catalogues. The 3D model was developed using Autodesk's AutoCADTM and 3D Studio MAXTM. The model was imported into Right Hemisphere's Deep CreatorTM and linked to safety training data to develop the instructional-based prototype. Interviews with industry professionals involved in the operation and maintenance of belt conveyors is used to provide feedback on the prototype development and to revise the prototype for its completeness and accuracy. The limitations of this research are recognized as a VR program can only offer a supplement for advanced training before on-the-job training and that it cannot fully replace the experience gained through one-on-one interaction with an expert who works within the real environment day in and day out. The intention of this research is to not replace all other training, but to add a valuable aid to supplement current training practices.

2.2. Existing Conditions

2.2.1. Conveyor Belt Accident Analysis

Between 1995-2007 there have been a total of 534 fatal accidents in the surface mining industry that are equipment related, out of which 50 cases were associated with conveyor belts (MSHA, 2007). We analyzed the 50 cases to identify the reasons for the accidents, and determine the type of maintenance tasks performed and their location around the belt when the accident occurred. A summary review of our analysis is provided in appendix A. The 50 reported injuries were grouped into four categories based on the cause of the accident; entanglement, collapse of structure, belt components or loose material (suffocating or crushing the victim), falling from heights, and miscellaneous. Within each accident category, we identified the type of maintenance task that was being performed when the accident occurred, and the belt assembly that contributed to the fatal injury. Figure 2-2 provides a summary statistical analysis of the 50 cases showing distribution by accident category, by maintenance task category being performed while the accident occurred, by critical belt assembly contributing to the accident, and by year the accident occurred.

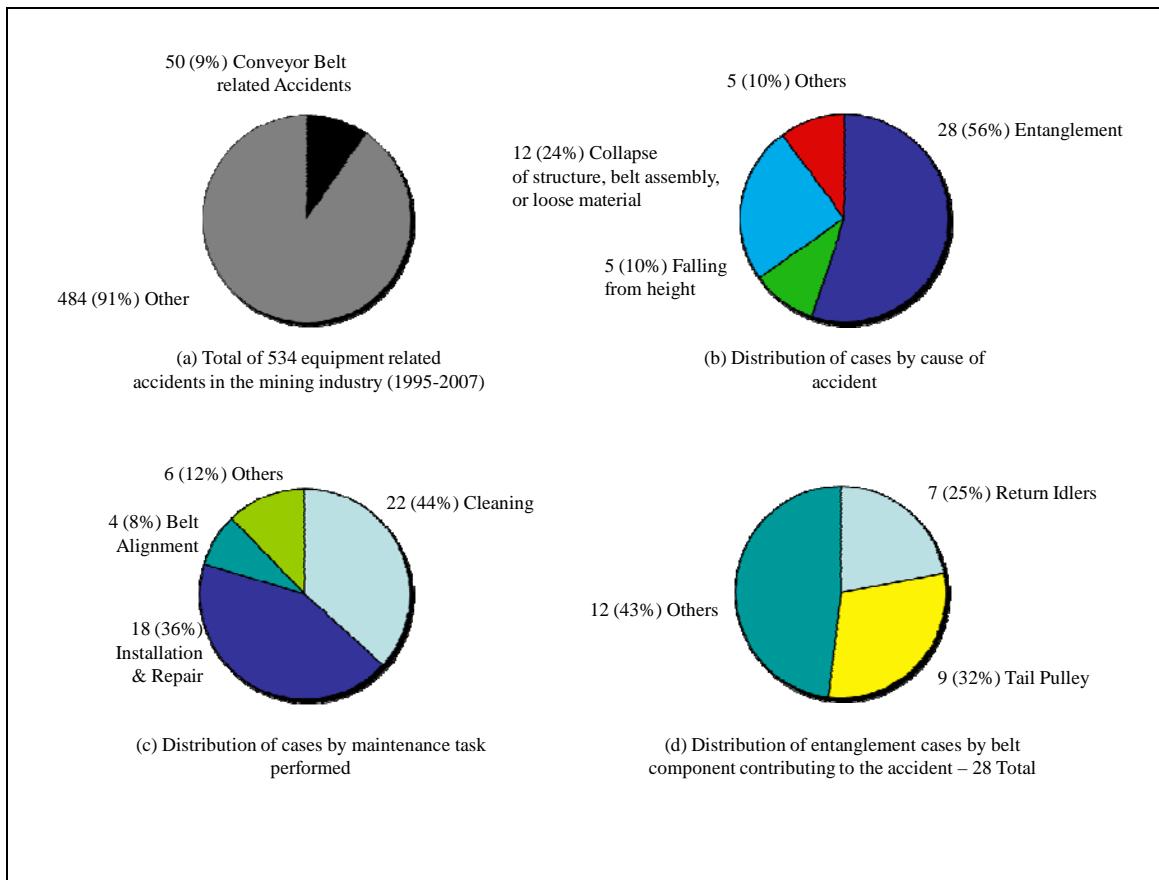


Figure 2-2: Statistical analysis of belt-related fatal accidents reported by MSHA between 1995-2007

Analysis results by accident category (Figure 2-2b) show that the most common reported cause of accident around conveyors is due to entanglement between the victim's body parts, or his tools (e.g. shovels) and the conveyor assembly. This accounted for 28 (56%) of the 50 fatalities reported. Few of the entanglement incidents occurred due ignoring proper work attire. A second critical cause of fatal

accidents included collapse of structures, belt assembly, or loose material falling off the conveyor, either crushing, or suffocating the victim. This contributed to a total of 12 fatalities (24%). Falling from height mainly off the elevated structures along the conveyor, or while crossing the conveyor where there is no crosswalk, resulted into 5 fatalities (10%). Other various reasons contributed to 5 fatalities (10%). These included burning, run over by service equipment and victim being crushed by belt assembly.

Four categories of maintenance tasks were identified from the cases:

Cleaning. Cleaning around and under the belt and equipment to remove spilled debris accumulated on belt components or built-up on the floor under the belt. Cleaning was frequently done using small tools (e.g. shovel) or sometimes by hand.

Installation and repair. This involved maintenance work for installing new or repair existing parts of the belt assembly (e.g. replace broken chain for belt drive motor) or the surrounding structure.

Belt alignment

Other. This included miscellaneous maintenance tasks such as inspection work, maintenance of large service equipment (e.g. loader) near the belt, and material sampling.

Distribution of accidents by maintenance task category (Figure 2-2c) indicated that cleaning of spillage and debris on and around the energized belt was the highest reported work performed when the accident occurred – 22 of the 50 accidents reported or 44%. Of these 22 accidents, 14 (73%) were a result of entanglement, and 7 (27%) occurred due to falling loose material and components crushing or suffocating the victim. Maintenance work involving installation and repair of the belt assembly or the surrounding structure contributed to 18 of 49 fatal accidents (36%). Four accidents (8%) occurred during maintenance work involving belt alignment. The remaining 6 out of 49 accidents (12%) occurred during performing other miscellaneous tasks.

Fatal accidents due to entanglement were analyzed to determine critical belt component contributing to the accident. Figure 2-2d shows distribution of accident by belt component involved. It is realized that the most critical parts of the conveyor assembly contributing to accidents by entanglement are return idlers, tail pulleys, and the conveyor belt itself. In total, 28 fatalities have occurred due to entanglement. 14 of these accidents were a result of getting entangled between an unguarded tail pulley (8 cases or 29%) or an unguarded return idler (6 cases or 22%) and the energized belt. An additional 14 accidents (48%) occurred as a result various other belt components and assemblies including head pulleys, drive pulleys, bend pulleys, take-up pulleys, power rollers and drive motor rollers. Most of these accidents could have been avoided by de-energizing of the belt and proper lock-out and tag-out procedures.

Figure 2-3 shows the distribution of accident categories by year from 1995 to 2007. Except for 2003, the average number of fatalities per year reported was 4-5 accidents. The lowest number of accidents occurring per year was 3, and the highest was 8.

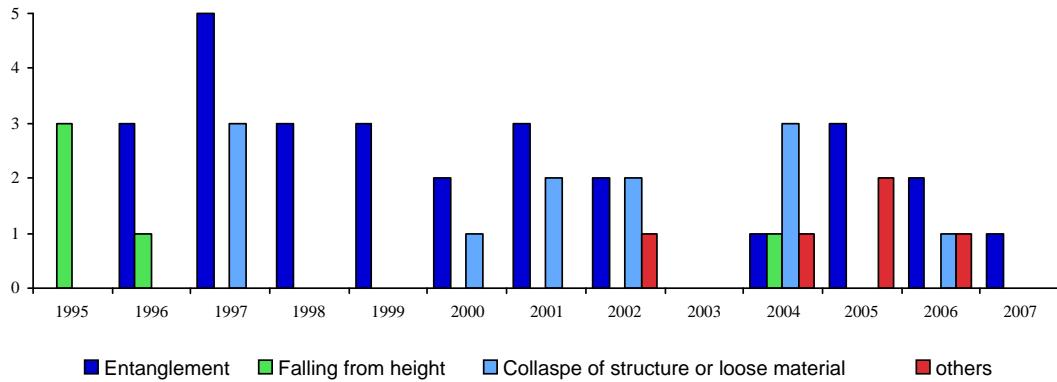


Figure 2-3: Distribution of belt-related fatal accidents by year

Conveyor belt injuries were also reported by Goldbeck (2003) in surface areas of metallic/non-metallic mines in the use. He reported that between 1996 and 2000 there were 459 reported injuries ranging from fatalities to injuries with restricted work activities. 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 the moving conveyor belt and a pulley (Goldbeck 2003).

2.2.2. Need for a Safety Training Program for Belt Conveyors

The average cost of a fatality in a mine is estimated \$1.02 million (figure originally published in 1986, would equal \$1.94 million in 2007 according to the U.S. Bureau of Labor Statistics inflation value (U.S. Bureau of Labor Statistics, 2007) and was calculated by considering medical expenses, worker's compensation, accident investigation, loss of family income, and lost production value. Permanent disability accidents of less severity were estimated at \$237,000 and each lost-time accident resulted in an average of \$5,000 (Goldbeck, 2003). A well structured training program that covers areas of proper maintenance, proper working habits, proper work attire, and hazards and safety recognition can save on injuries and fatalities. The cost for developing the program is a small price to pay compared to the cost of preventable accidents and the loss of human life.

Recognizing the need for conveyor safety standards during the 1940s, the American Society of Mechanical Engineers (ASME) issued safety standards through the American National Standards Institute (ANSI) for conveyors and related equipment (Schultz, 2003.). This was later modified to B20 in 1972 (a specification-based standard) and then to B20.1 in 1976 (a performance-based standard). The Occupational Safety and Health Administration within the United States Department of Labor (OSHA) was founded in the 1970's and started preparation of its own conveyor safety standards (20CFR, Part 1910.186). To date, OSHA has not adopted any conveyor safety standards and seldom become involved with conveyor safety inspections which remain MSHA's responsibility.

According to Schultz (2003), conveyor safety operations and training are not adequately addressed by the ANSI standards or OSHA regulations. They place responsibility on the owner to limit job assignments to "certified," "competent," and "qualified" employees. When it comes to conveyor belt safety training,

training materials as videos or text information is minimal as prepared by ANSI Conveyor Safety Standards, OSHA, or by any of the safety engineering professional associations. These associations have some general safety guidelines, but do not place requirements or suggest a training program structure or specific training guidelines (Schultz, 2002 and Schultz, 2003), leaving the responsibility of developing a successful training program to the owner/operator of belt conveyor.

MSHA requires 24 hours of training in part 46 and 48 of the Code of Federal Regulations (CFR). MSHA requires that the first 4 hours of training be given before the new employee starts work with the remaining twenty hours performed within the first sixty days of work (Goldbeck, 2003). Since it is up to the operator of the conveyor belt system to structure their training programs, there are some essential elements that should be included. These essential elements include establishing learning objectives, preparing a course outline, allocating proper time, recognizing the level of training required (knowing who your audience is), documenting the training that take places, and evaluating the class/session effectiveness and making proper modifications (Shultz, 2003).

In order to help reduce accidents with a comprehensive safety training program, it is important to include certain areas of training. Goldbeck (2003) proposed four categorizes of training areas: general safety practices, guidance for performing maintenance and inspection, information about conveyor and belt conditions, and procedures for belt tracking. General safety practices include using the proper safety equipment, hardhats and glasses, to wear proper clothing and hair that is not loose or too long, and making sure that the each employee is aware of emergency stop button or cord locations. Guidance for performing maintenance and inspections includes making sure the conveyor is properly locked out and tagged out when performing maintenance tasks, performing maintenance tasks properly, and making sure any connected equipment is properly placed out of service and blocking, if necessary, is used. The employee also needs to be trained on belt conditions and be able to recognize impact and heat damage, belt cupping and cambering, or damage to belt splices. The training also needs to include general conveyor system conditions, such as to make sure idlers are properly working and having the ability to recognize spillage sources. Lastly, Goldbeck explains belt tracking as a science of manipulating conveyor belt components to get the belt to run on the center of the structure. The improper adjustment of components when tracking the belt can lead to serious injury (Goldbeck, 2003).

Similar training program goals are described by Schultz (2003) who states that traditional safety hierach priorities are eliminating the hazard or risk, applying safeguarding technology, using warning signs, training and instruction on a regular basis, and prescribing personal protection. Out of these safety priorities the training and instruction on a regular basis and the prescribing personal protection are the primary responsibility of the owner/operator. The training method that Schultz describes includes three steps. The first step is to set safety standards which include establishing performance standards for equipment, systems, personal, and operations and maintenance. It also includes that the design and manufacturing of the conveyor system has to perform to the safety standards when it comes to warning systems and safety factors. The second step is to set training requirements, meaning establish basic training procedures for all employees, and then developing procedures for training of new employees who are statistically involved in more accidents then the more experienced workers. The last step is to have management participation, periodic review, and continued training. This can be accomplished by keeping management involved and advised on all safety training programs and when they are scheduled, the use of monthly operational and maintenance safety review meetings, quarterly operations and maintenance

conveyor belt safety review meetings to identify problems or changes which include identification and training of new equipment that can compromise safety and training part-time employees, and lastly keep a permanent record of all safety and health training that takes place by group or individual (Schultz, 2003).

Currently, most training that is taking place is within the MSHA guidelines for training and falls under general training, with very little of the training specifically directed at conveyor belts and conveyor belt safety. Within the industry, the training that focuses on conveyor belts and conveyor belt safety is usually conducted with slideshows and videos. This type of training is very passive and is hard to quantify the amount of knowledge that the employee is gaining through such training. The employees are often then placed with an experienced person for on the job training where they learn how to properly operate, repair, and maintain a conveyor belt system. If this training is incomplete it can lead to accidents that could have been prevented with a better training program. VR is offered as a solution to improve the current training practices of the industry.

VR offers a large variety of possibilities for safety training programs that can offer the owner/operator a cost effective training method with the capability of quantifying or testing the users' knowledge gained through the training program. VR offers the ability to simulate real life events in a digital environment that might be too dangerous to simulate otherwise (Haller, et. al., 1999). VR also offers cost savings within development of specialized programs through RAD (Rapid Application Development) software that requires minimal code programming and offers real time feedback to the designers (Cope, et. al., 2001). VR training also offers specialized training on an individual basis that can be run on a personal computer eliminating the need for large training sessions with groups of people and specialized equipment (Kizil and Joy, In Press).

2.2.3. Current Research

VR has been investigated for training and safety in a wide variety of applications in the mining industry. These safety and training programs include general safety training for hazard recognition and escape planning in underground mining, educational programs based on accident recreation for prevention, proper equipment operations training, and safety design reviews for new equipment and processing layouts.

The safety training programs within the mining industry that utilize VR have focused on a large variety of research goals that are organized in Table 2-1. Some of the research utilized VR in visualizing information and accident reconstruction, meaning training was conducted by recreating scenes, processes and accidents with VR. One version of information visualization is combined with the trainee being charged with completing a task and is action-reaction training. This shows direct results of actions and shows the effects of a decision. This often consists of recreating what would be likely to happen if the same chain of actions were taken within the real working environment. This is done more as a passive method to let the user know what would happen if the proper procedures are not followed while working within the environment. Similarly, risk analysis training has been explored by giving options to the user and then they would have to judge the risk of the activity and the proper actions to take. Results would be immediately given to the user and consequences are animated within the program.

Other goals of research were to teach the users of hazard recognition and safety measures by having the user recognize, make note of, or fix hazardous conditions. These often require the user to enter the environment and avoid placing themselves in danger and taking note of the dangerous conditions. Within

recognizing hazards, the users can also be placed through an inspection simulation. This requires the user to examine the equipment and environment used to make sure it is in proper working order. Anything that is wrong with the equipment and environment would then be marked and the user would have to determine the proper action to be taken. Procedure training or training of proper use of equipment and operation of equipment within the working environment has also been done using VR within the mine industry.

More advanced systems have the goal for easily customizable programs. These programs allow for easy adaptation of the physical environment into the digital environment and simulate the actual working environment that the trainee will be working in instead of a generalized typical environment.

| | RESEARCH FOCUS | | | | | RESEARCH GOALS | | | | | | | | | | | |
|--------------------------|-------------------------------------|----------------------------|-------------------------------|--|-------------------------------------|-----------------------------|-------------------------|----------------------|---------------------------|--------------------|--------------------|-----------------|--------------------------|-----------------------------|--------------------------|-----------------------|------------------------|
| | VR Training Tool to Create Programs | VR for Equipment Operation | VR Haul Truck Safety Training | VR Health and Safety Activity Simulation | VR Underground Mine Safety Training | VR to Improve Safety Design | Equipment Design Review | Accident Simulations | Information Visualization | Hazard Recognition | Procedure Training | Safety Measures | Customizable Programming | Replace on the Job Training | Action/Reaction Training | Inspection Simulation | Risk Analysis Training |
| Dellabio, et. al. (2007) | | | | | | | | | | | | | | | | | |
| Ruff (2001) | | | | | | | | | | | | | | | | | |
| Stothard, et. al. (2007) | | | ■ | | | | | | | | | | | | | | |
| Orr (In Press) | | | | ■ | | | | | | | | | | | | | |
| Schafrik, et. al. (2003) | | ■ | | | | | | | | | | | | | ■ | | |
| Kizil (In Press) | ■ | | | | | | | | | | | | | | ■ | | |
| Hollands, et. al. (2002) | ■ | | | | | | | | | | | ■ | | | | | |
| Dezelic (2005) | ■ | ■ | | | | | | | | | | | | | | | |

Table 2-1: Current Research Focus and Goals

The mining technology unit (HATCH) in collaboration with MIRARCO of Laurentian University, both of Sudbury Ontario, Canada is investigating the application of 3D modeling and visualization with 3D CAD through the Virtual Reality Laboratory (VRL) at Laurentian University. The visualizations and VR are being used 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 and are often easily distributed and viewed without the need of high end computer equipment. Through the use of visualization, the projects conducted end with a cost savings for design and improved

safety for the final constructed product that otherwise would be hard to achieve through traditional design methods alone. (Delabbio, et. al. 2007).

The National Institute for Occupational Safety and Health (NIOSH) has developed a safety training software package for new mine employees called Miner Training Simulator (MTS). MTS is a computer based training tool that allows a trainee to enter a simulated mine environment and interact with the surroundings to learn the basic mining concepts, procedures, layouts, and escape routes. The program is customizable through script commands to change the actions in the simulations allowing for various degrees and scenarios of training (Ruff, 2001).

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. The work involved a feasibility study, funded by the New South Wales Joint Coal Board Heath and safety Trust, on the usability of VR as a training tool for personnel in mining. The feasibility study led to more funding produced the simulation of three issues that have high health and safety implications and are dependent on individual's actions: sprain and strain injuries, coal rib hazards, and self escape from underground mining. The main purposes of these simulations are to reduce accidents, create a safer working environment, and reduce operation cost by providing trainers with a powerful tool to create safety training programs and ultimately save lives (Stothard, et. al., 2004).

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. The goals of the project are to create a cost effective and safe training environment for mine personnel by putting them through training tasks and tests in a VR environment (Orr, et.al., In press).

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 through the use of a Computer-Based Training program. The work described in the paper focused on modeling the consequences of abandoning a moving fuel truck with failed brakes and the resulting effects of such actions.

Work by Kizil and Joy (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. Accident reconstruction conducted by the AIMS research unit at the University of Nottingham has been used for training and accident prevention. The same research group also conducted equipment simulation to help drivers become familiarized within common working environments, conditions, and principles of equipment operation.

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 use of VR technologies towards training and other applications. The research work as developed by the AIMS Research Unit invested in developing an application toolkit for the purpose of creating VR-based training tools. The resulting system, SAFE-VR, uses a graphical user interface to combine 3D models into various training

systems, from hazard spotting to equipment operation. The use of this toolkit could dramatically reduce the development time (and therefore cost) of VR training system.

The University of Missouri – Rolla is developing a VR training program for miners that focus on the proper installation of rock bolts using a jackleg drill. Through the use of a VR training program the trainee will be walked through the process of proper handling and operation of the bolting equipment. The main goals of the training are to reduce the chance of injuries that often occur during on the job training and learning (Dezelic, et. al., 2005).

2.3. Proposed Safety Training Structure

The aim of this research is to offer a supplement to current training program. It is the intention of the research to offer a cost effective and convenient training program that teach the user and then quantify the knowledge gained through the training by assigning tasks for the user to complete. Virtual reality is being explored because it offers a realistic first person experience where the user can go through the training at their own pace, experience consequences and actions, and have their performance tracked.

In order to have a successful and beneficial safety training program, it is important for it to be well thought out with accurate and quality information that fits the needs of the industry. Through this research and as depicted in Figure 2-4, we are proposing a 4-step training program structure that was used during this research to aid in the development of the application:

Step-1: Data Collection.

The first step of developing a safety-training program is collecting and compiling data and information. In the case of the research conducted, this was done through site visits and literature review. The information was tabulated into a series of fact sheets where it was easily organized under categories. The categories were further developed in step 2 where they were placed within different training areas.

Step-2: Define Safety Training Areas

Within this step, the information that was gathered through the literature and site visit was reviewed and categorized into the categories of conveyor belt components and maintenance procedures, safety issues, hazard recognition, and trainee assessment. The categories were used to aid in the development and compilation of information to make sure it is complete and all areas are fully covered. Each category is further sub-divided into information based upon their criticality and frequency of occurrence as analyzed during the literature review. The information as it is structured within this step aides in the development of step 3, the VR prototype implementation.

Step-3: VR Prototype Implementation

The VR Prototype Implementation is developed in two stages. The first stage is to inform the user of the information that was compiled in step 2. The second stage is designed to test the user's ability and capacity of knowledge to determine if the user has gained the proper knowledge through the training. The proposed VR prototype contains two modules, the instructional-based module and the task-based module. The instructional-based module is used to guide the user through the environment where they are familiarized with the conveyor belt and assemblies and the related hazard recognition and safety issues. The task-based module gives the user a task to accomplish and is assessed based on his performance. The

second module is built off of the knowledge that was distributed within the first module as both a test and reinforcement of the knowledge given in the first session.

Step-4: Evaluation and feedback

The final step is to evaluate the developed program before implementation to make sure that the program is successful in reaching its goals of training the employee. Evaluations will be planned for the entire system on three levels. The first level is through industry feedback. This level is used to determine the accuracy and quality of the information that is being presented and will be used to make sure the tasks that the user is assigned in the second phase of the research is realistic to what would be asked in real life. The industry feedback will also be used to determine if the system would fit within their training needs as a supplement to current safety training programs. The second level of evaluation will be conducted using various users of different backgrounds and experience levels. The main purpose of this evaluation will be to test the usability of the system and determine any areas that need to be clarified to improve the understand ability of the application. Lastly, after both sessions are complete and revised through the feedback process, a general knowledge comparative test will be given to two separate test groups. One will be placed through typical training and the other will be given the instructional-based portion of the VR application. Both groups will be given the same general knowledge test. This study will allow for a determination if the VR application is more beneficial to the learning of the material.

It is expected that after the program is initially tested and evaluated, it will be adopted by the industry to allow new employees a good basis of knowledge so they can successfully complete their job safely. It should also allow for experienced employees to go through a ‘refresher’ course to make sure that their training is up to date. It is also important that the program is periodically evaluated and reviewed for completeness. It is also important to update the system as the technology changes in order to make sure all employees are aware of any new procedures for conducting their jobs.

The flexibility and relative ease of creating the virtual environments can allow for customization to a specific companies needs or to a specific plant layout. The information presented will be the similar in nature as the information compiled through the first two steps of the framework but can be presented with a different belt set-up if it proves of value to a specific company. The program can also allow for the addition of more equipment and machinery for plant specific situations if the need arises.

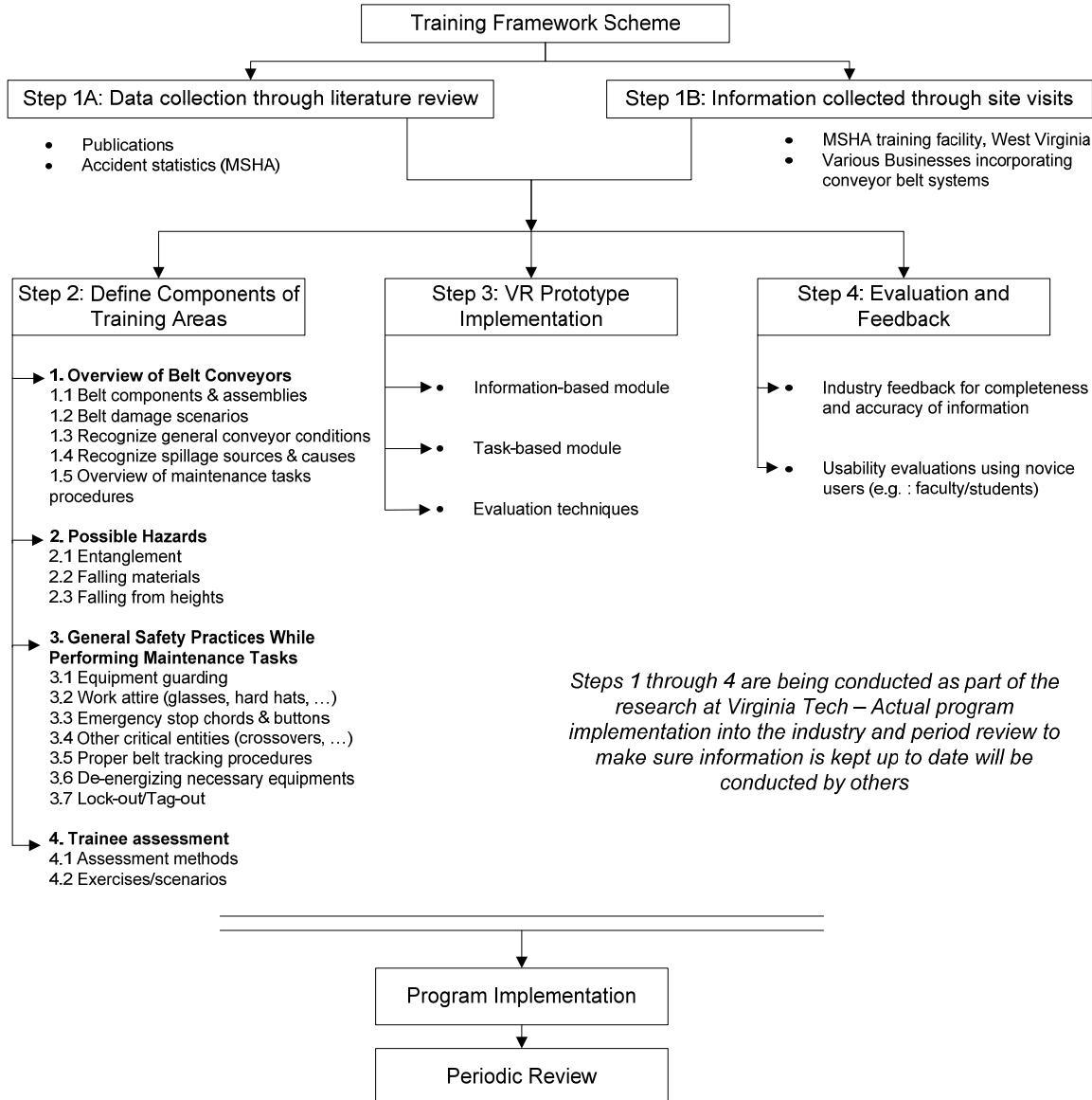


Figure 2-4: Proposed Safety Training Structure

2.4. Instructional Based Phase of Prototype Development

The safety training prototype developed as per the structure described above contains two parts; the first phase is the instructional based research phase, and the second, being conducted in future research, is a task-based phase. This section of the paper focuses on the development of the first phase of research. In order to produce the training program that was developed within the first phase, preliminary research was conducted to see what has been done with VR as well as to determine what current conveyor belt safety practices exist within the industry. After the preliminary research was completed, information was compiled and the development of the VR environment was conducted. The information that was collected through the research was categorized into conveyor belt components, safety issues, hazard recognition and general maintenance practices. This information was then displayed within the virtual environment to train the user. After the development was completed, industrial feedback was used to check for accuracy and completeness and then make appropriate revisions to the program. Table 2-2

shows the structure of the instructional-based phase implementation that matches the categories as described in Figure 2-4 under “Define Components of Training Areas.” The information that is given to the user at each station is also listed.

| Training Areas per fig. 4 | Sub-Category | Station 1 | Station 2 | Station 3 | Station 4 | Station 5 | Station 6 | Color |
|---|--|-----------|-----------|-----------|-----------|-----------|-----------|--------|
| 1 Information about conveyors and belt conditions | Bend pulley | | | | ● | | | Green |
| | Take-up pulley | | | | ● | | | Green |
| | Return idler | ● | | | | | | Green |
| | Impact idler | | | ● | | | | Green |
| | Tail pulley | | | ● | | | | Green |
| | Feed chute | | | ● | | | | Green |
| | Troughed idler | | | ● | | | | Green |
| | Head pulley | | ● | | | | | Green |
| | Drive Motor | | ● | | | | | Green |
| | Recognizing belt damage | ● | | | | | | Yellow |
| | Recognizing gen. condition - structure | | | | ● | | | Blue |
| | Recognizing spillage sources | | | | ● | | | Blue |
| | Grease lines | | | ○ | | | | Green |
| 2 Possible Hazards | Removal of spilled material | | | | ● | | | Blue |
| | Maintenance of belt | ● | | | | | | Blue |
| | Entanglement | ● | | | | | | Orange |
| 3 General Safety Practices | Falling Material | | | | ● | | | Orange |
| | Falling From Heights | | ● | | | | | Orange |
| | Equipment Guarding | ● | | | | | | Red |
| 4 Trainee assessment | Work attire | ● | | | | | | Red |
| | Emergency Stop Cords & buttons | | | ● | | | | Red |
| | Protective Railings | ● | ● | | | | | Red |
| | Proper belt tracking procedures | ● | | | | | | Red |
| | De-energizing necessary equipment | | | | ○ | | | Red |
| | Proper start-up procedures (alarm) | | | | ○ | | | Red |
| | Lock-out & Tag-out | | | | ● | | | Red |
| | Harness when working at heights | ○ | | | | | | Red |
| | Use of Crossovers | | | ○ | | | | Red |
| | Conducted in other research related to Task-Based Session development. | | | | | | | |

● = Original Implementation

○ = Revisions based on Feedback

Table 2-2: Instructional-based phase implementation structure

Each station has been chosen on two accounts, if there is information that relates to one another, they are most likely contained in the same station, and then if there are components that are located close to each other, they are most likely listed at the same station. The majority of the information is presented with a combination of captions and animations within the environment. Information pertaining to safety attire, belt damages, and belt maintenance that is heavy on text and difficult to animate is distributed in menu form with text and images but connected to the environment in an area related to the information.

The preliminary research and literature review was used to help determine examples of current research dealing with VR and determine what type of training needed to be produced. The key issues that were taken into consideration based on success of past projects was that the environment should show enough detail for the user to become familiarized with the conveyor belt configuration and be able to recognize the components and assemblies on any conveyor belt system. The virtual reality session offers an active mode of training to supplement current on-the-job training methodologies where as other training through slides, images, and videos is a more passive method of training. With this in mind, it was important that the experiences of the digital environment be easily transferred to real life situations where the user would be able to recognize hazards and safety complete tasks. After participating within the training, the operator should be able to competently participate in normal work activities around a conveyor belt system.

Once the goals of what the research is to accomplish were compiled a digital model of a conveyor belt system was created by using Autodesk's AutoCAD and 3D Studio Max. The model was developed through photos taken during the site visits and through different operations and design manuals such as *Foundations 3* (Swinderman, et. al., 2002). Mine Safety and Health Administration (MSHA) accident report data was also reviewed to help determine that three different configurations of conveyor belts (Figure 2-5) were needed in order to simulate all inherent dangers. This led to the development of an inclined belt run that is fed by a crusher and dumps material onto a second belt run that is elevated and level. The elevated and level belt run then dumps material to a lower belt run that is at grade. With this chosen configuration all of the hazards can be simulated that are the cause of the major accidents reported by MSHA. The three part configuration also allows for the experience of safety precautions that are required with each piece of the overall plant configuration, some of which are proper guarding, falling materials, and falling hazards.

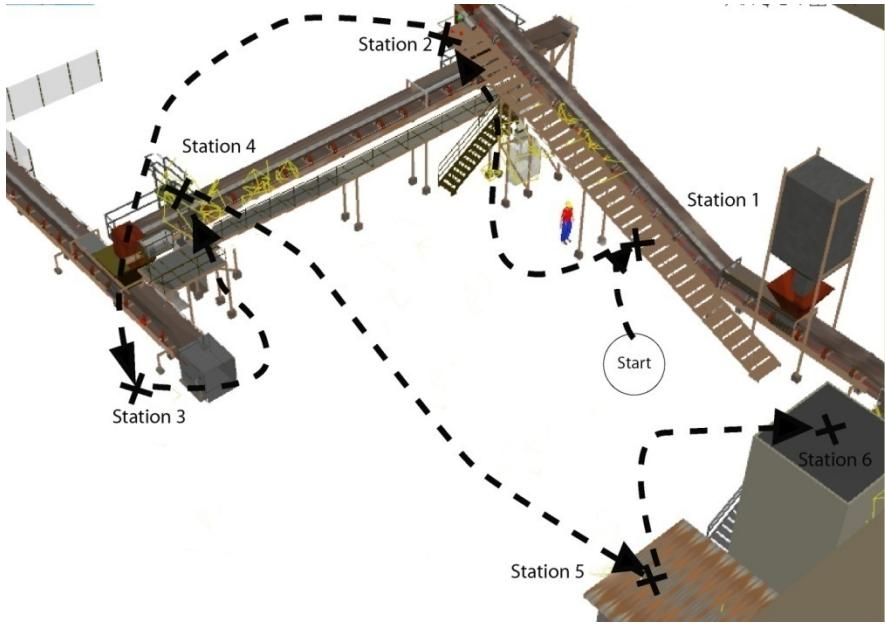


Figure 2-5: DeepCreator belt overview with overlaid station markers and path of travel.

When the digital model of the conveyor belt and basic configuration was completed, the digital model was exported out of 3D Studio MAX and imported into Right Hemisphere's *Deep Creator*. Deep Creator was used because it is a Rapid Application Development (RAD) program with built in features for basic animations and modeling. A RAD program allows for the creation of a virtual environment with little programming needed for the basic functions. Within Deep Creator animations were added to simulate the belt moving. In order to allow for smooth navigation through the environment the poly count (number of surfaces) had to be reduced. This involved using multi-sided shapes instead of spheres and cylinders as well as removing sides of objects that are not visible during navigation and making sure that excess detail was not added to the model. One issue that was inherent through much of the literature review was to make sure that there was enough information to convey what is trying to be shown in order for the user to be able to recognize situations in real life, but to not add excessive detail that make the system slow and tedious to use. One of the goals during the environment development and animation was to make sure that the environment remained user friendly; part of this was to make sure the environment remained easy to navigate.

After the basic animations were added within Deep Creator other information had to be added that is presented to the user during the training. The information list in Table 2-2 provides the information available at each station, detailed information related to each item in Table 2-2 was developed by using a fact sheet. Fact sheets were the method used to document relevant information and keep track of resources. A station is a location at which there are a number of hot-points (objects with connected information) used to organize the information during development of the instructional-based phase. The user is taken on an automatic navigation through each station as shown in Figure 2-5. The user can only advance once they have reviewed the information connected to all the hot-points at one station. There is also an option for the user to jump back to a station and re-examine pieces of information through a navigation map and "jump-to" buttons in the menu. An instruction screen is given at the beginning of the session to inform the user of the navigation process.

When the session is started the user is first taken on a fly through over the conveyor set-up to allow them to become familiarized with the major parts of the environment and then stops at the first station. Within the first station the user is presented with information as listed in Table 2-2. The grouping of the information is based on the close proximity of the components of the belt and groups of information that presented.

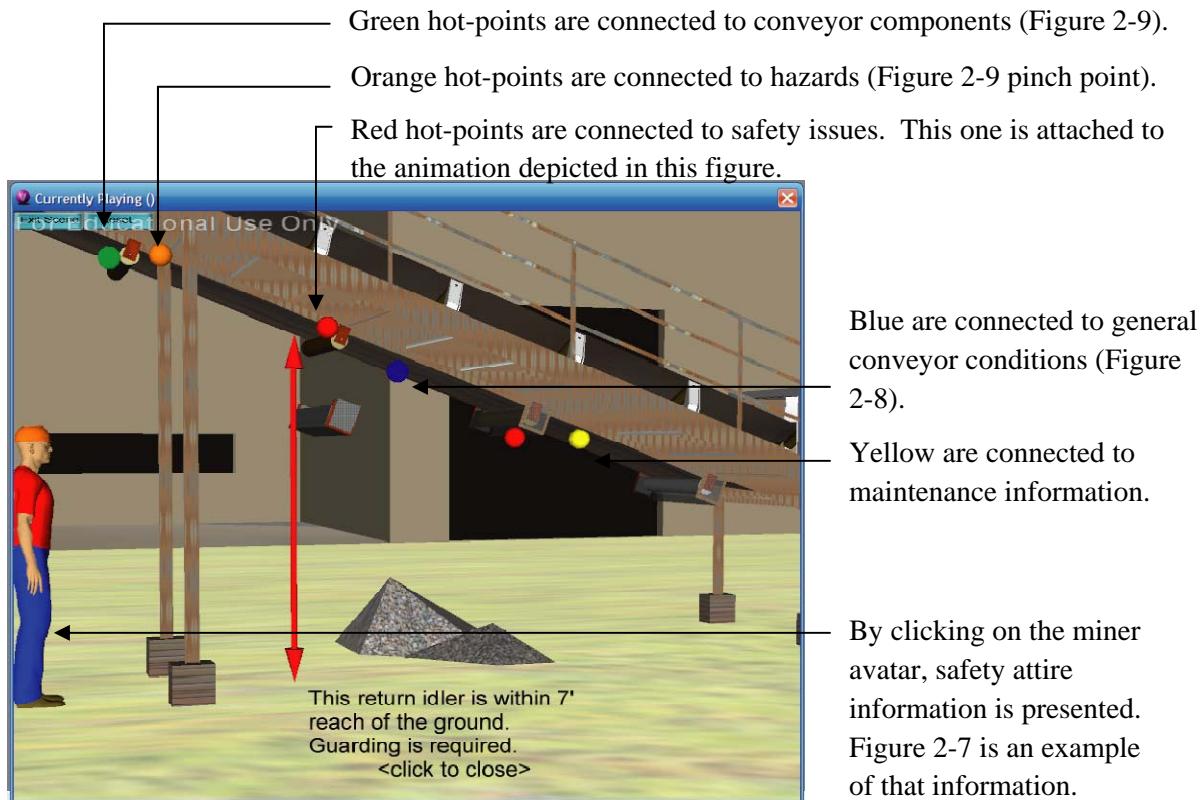
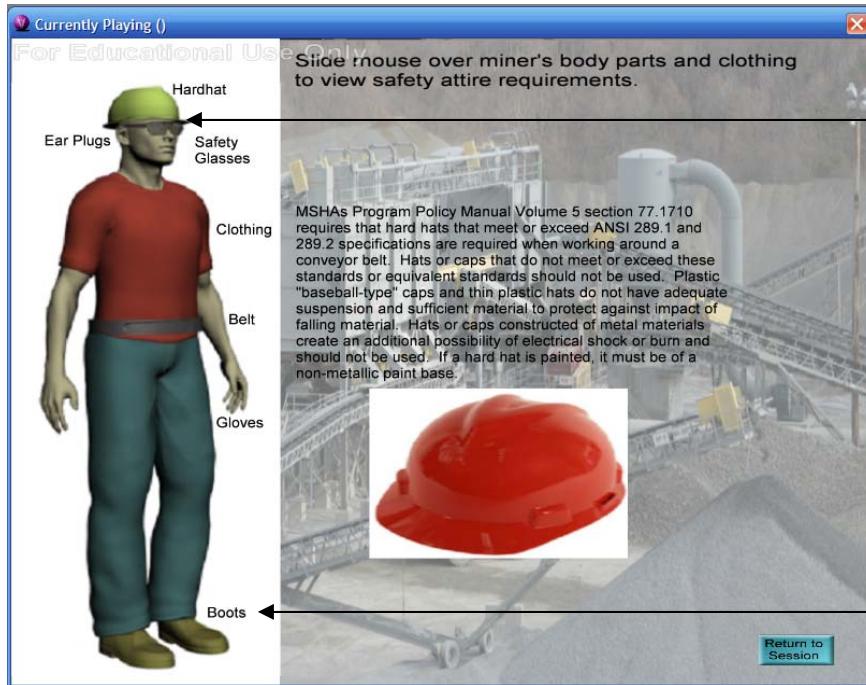


Figure 2-6: Screenshot of station 1

At the first station (Figure 2-6), the user is presented with a few options of information to view. The first one would be Safety Practices of proper work attire. This information is presented to the user as they select the glowing hat on the miner avatar in the scene. When the hard-hat is selected the user is shown an image of a prepared worker, as the user slides the mouse cursor over the different parts of the image, textual and image information is presented with requirements and recommendations for proper safety attire (Figure 2-7). The information is either the MSHA requirements if there is a specific clause within the regulations, or the industry's common best safety practice when a specific federal regulation does not exist. The user is given information when the mouse is rolled over the hard-hat, safety-glasses, ears, hands, belt, clothing, and boots. This information, being considered important for the safety of the conveyor belt operator, is available for review whenever the miner appears on the screen.

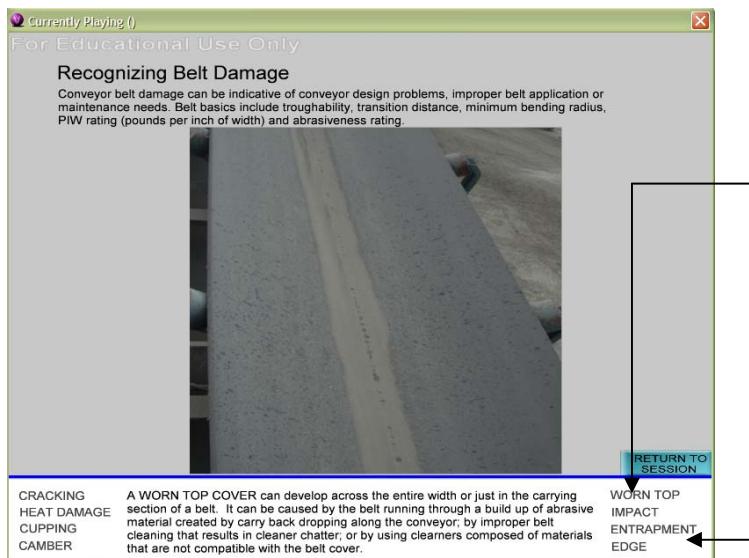


In order to see this screen as shown, the user would mouse over the hardhat or the caption “hardhat.”

By moving the mouse cursor over the different categories, the information in the main window changes.

Figure 2-7: Safety attire information sample with mouse-over at hard-hat

Also at the first station the user is presented with information about the conveyor and how to recognize belt damage such as belt camber and cupping, edge damage, recognizing worn surfaces, top cover cracking, and heat damage (Figure 2-8). This information is presented in a similar method as the safety attire information is presented to the user. Connected to the recognition of damages is also the proper maintenance of the belt which includes proper splicing and patching techniques with diagrams and text shown as a step by step basic instructional. The instructions are generalized tasks as specific training is needed in order to successfully complete these tasks safely and successfully.



This screen appears when the user moves the mouse cursor over “WORN TOP”

The user navigates through the belt damages information by moving the mouse over the categories.

Figure 2-8: Belt conditions information sample with mouse-over at “Worn Top”

Another hot-point at station 1 is connected to the return idler (Figure 2-9). The method of which the return idler is presented is the same as all the components that are listed in Table 2-2. When the hot-point associated with the return idler is selected, the camera view adjusts to the component. The component then flashes a different color while a caption describing what the component does is shown. The purpose of including the components within the instructional-based session is to allow for the users to become familiar with the environment and when assigned a task dealing with a particular component, he or she should be aware of the area they are going to be working on.

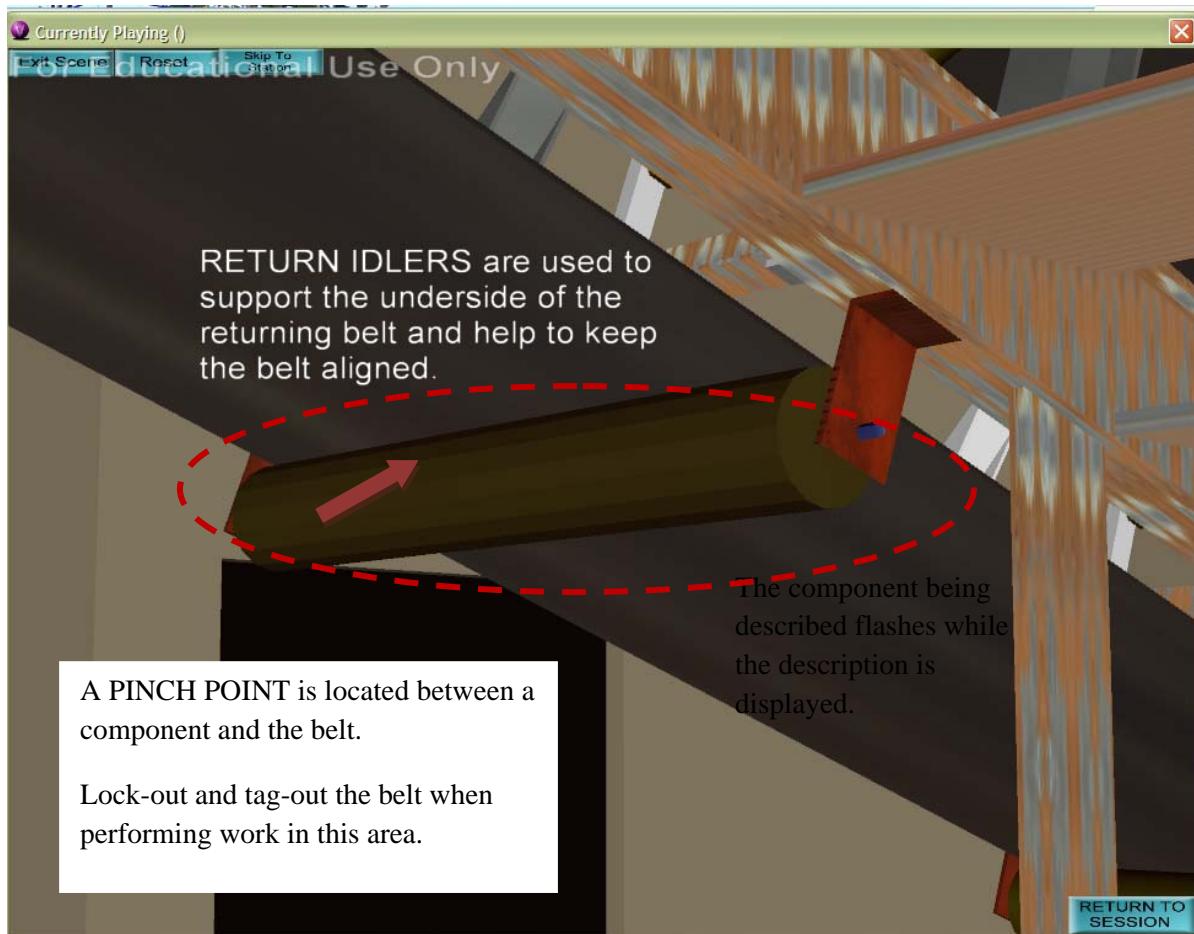


Figure 2-9: Example of Component Information

Another hot-point at the first station that is associated with the return-idler is entanglement and an example of a pinch-point, or a location that entanglement is likely to occur. The method used to introduce the information pertaining to entanglement and the pinch-point is shown in two screens, one to show the definition of entanglement, and the other to give an example of a pinch-point. The example of the pinch-point (Figure 2-9) gives a description of what you are looking at and then animates an arrow pointing out the specific area between the return idler and belt where a pinch-point would exist.

After the user has viewed all of the information associated with the first station the program will take them to each station until the program is completed. Each type of hot-point is displayed in a similar matter as the information that is described for Station 1. Along the path of travel that the user is taken,

there are also markers that bring back some of the safety and hazard information that was mentioned earlier in the session. One example of this is at the first station where there is guarding missing. The system, through animation, replaces the guarding and states why there should be guarding at that location. At the completion of the program the user will have the option of entering the informational-based phase through manual mode or to continue to the task-based phase of the research that is being developed to test their knowledge of the information that has been presented.

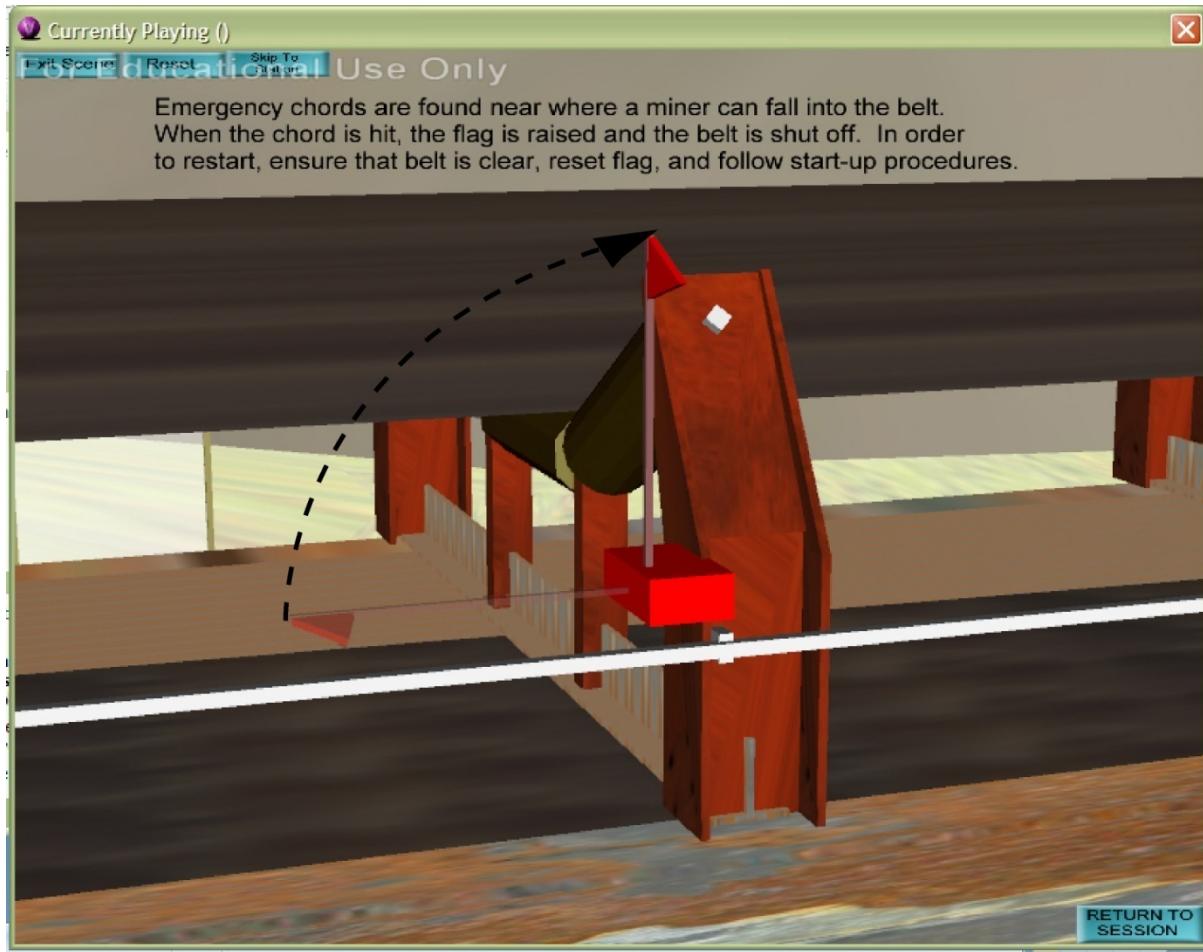


Figure 2-10: Example of Pinch Point location as animated when orange hot-point is selected

Upon reviewing each hot-point at the first station the user is taken to the next station and the process continues through the completion of the session. The information through the remaining stations is presented in a similar manner to that of station 1. There are some situations where actions are described. One such example is located within station 3 and deals with the emergency stop chord (Figure 2-10). In this example, it shows the reaction to the emergency stop chord being pulled. When there is an emergency around the conveyor, the stop chord can be pulled to stop that portion of the belt and the flag rises in order to signal the area where the chord was tripped. The last form of information that is presented are processes, in stations 5 and 6 processes are shown to the user on how to properly and safely turn on and off the conveyor system and lock-out and tag-out the system when performing maintenance

tasks. These procedures use captions to describe the process and animations show the process that needs to be taken. The example of lock-out and tag-out (Figure 2-11) starts while the user is in the breaker room. The hot-point is selected and the sound of the belt stops. The lever on the breaker is then turned from the on position to the off position with a lock being taken from the wall and locked on the breaker. The next step is to remove the key and place a tag, all of which are animated to show the process.



Figure 2-11: Lock-out & Tag-out process animation.

2.5. Industry Feedback

An industry feedback process was adopted following the first implementation phase of the Instructional-based Module. Several visits were conducted with major surface mining companies that utilize conveyor belts in their process plants with the objective of acquiring industry expert's feedback on content and structure of the application. Repeated visits over a process of nine months allowed to record comments, revise content, and structure and receive additional feedback (Figure 2-12). Overall three companies were

visited with a total of eleven industry experts attending the various meetings. Of those eleven individuals that have reviewed the application three are safety professionals, three are involved with safety education processes within the plants and the rest were engineers, foreman, and maintenance personnel.

Overall, the industry's response to the application was very positive. The initial challenge was contacting industry professionals to get the initial meeting scheduled. This was aided with the help of contacts received through the Virginia Center for Coal and Energy Research located at Virginia Tech. Once the initial meetings were conducted to inform the industry members what our intentions were and what the research is about, they were more than willing to continue with follow-up meetings and to give us feedback. Their reasons for this included the potential value they see for using the type of application that has been developed within their training programs. Some comments that were expressed were that they would like to see applications developed to encompass the use of other equipment and pieces of machinery in their quarries, ideas that were documented and will be considered for future research.

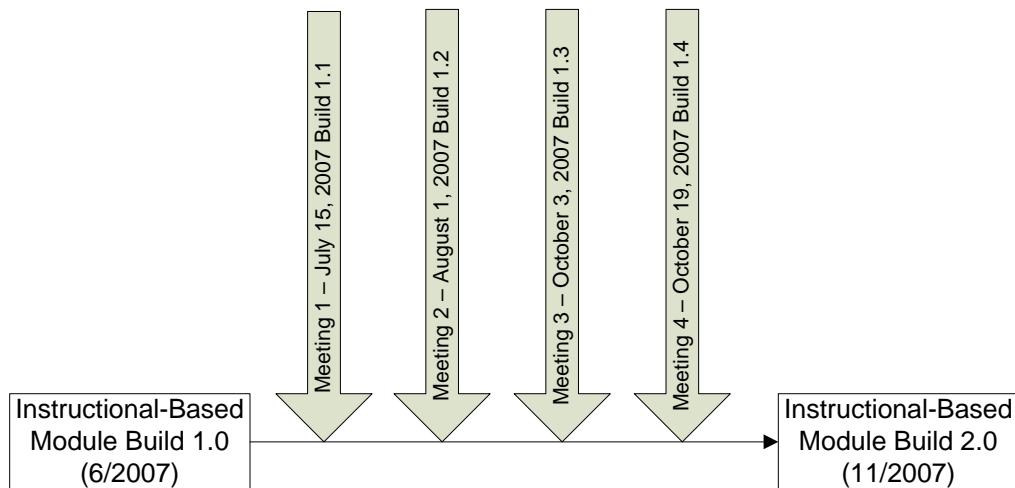


Figure 2-12: Industry Feedback Structure

During the demo of the application, the research team posed specific questions to help center the focus of the discussion. Industry members were also encouraged to ask questions, make comments, and interrupt whenever they saw something that needed to be discussed. The questions that were the basis of the discussion are:

Is the information presented at this station reasonable?

Is there any information that can be added?

Is anything graphically misrepresented?

Was any of the presented information difficult to understand?

Other general questions included:

Would this fit your training needs and how can it be improved to better supplement your training needs?

Can you see a program like this being a valuable addition to your current training program?

The questions were given at the beginning of the meeting; this made the attendees aware of the types of comments that were needed to better improve the application to fit the industries needs. The results of these feedback sessions are documented in Appendix B. Thirty-seven unique comments were received varying from components that were missing to safety procedures. Twelve comments were based on existing information and remaining comments dealt with information that the industry professionals thought would be a good addition to the program. The majority of the comments, twenty, consisted of clarifying and adding safety issues to the application. The remaining comments were split between general conveyor information, components, and hazard recognition. All the comments were reviewed and determined to be relevant to the improvement of the application and were implemented to produce Build 2 of the application.

In addition to feedback on quality and accuracy of information we asked a questions pertaining to how they thought their industry would accept this type of training application. When asked if they thought this type of application would benefit their training program the overwhelming response was “yes”. Some of the reasons that were given included that the application would allow for self-exploration of the individual under their own pace, and that interaction would enhance the learning by “trying”. From their experience, the training professionals have realized that many employees, especially when going through the required annual training tend to lose focus on slide-show presentations and videos that they see year after year. They believe that if the employee had the interaction and was in control of the environment it would allow them to stay more focused and hopefully learn more. Another benefit of this application that industry recognized was that many of the new employees have used computers their whole life and are technologically inclined. The industry professionals feel that a VR application that represents a video game that many of the employees are familiar with would allow for a unique learning experience that they would be interested in.

2.6. Summary

Virtual reality has been used in different areas of the mining industry and has been proven as a successful and valuable method of training. The technology has not yet been used for conveyor belt safety training. This research is the use of virtual reality for conveyor belt safety training as part of a larger effort for developing a safety training program for belt conveyors. It is believed that virtual reality can offer an interactive and active learning experience for mine employees that work with and around conveyor belt systems that in turn can be more effective than typical video and “Power-Point” presentations that are passive by nature.

Although the first phase, the instructional-based session, uses virtual reality and the virtual environment as a training tool, the second phase, a task-based session that is being developed is taking full advantage of some of the benefits of virtual reality by replicating real life situations and making the user think them through. Cognitive learning and active learning are theories of teaching and training that require the trainee to think out a process through self-explanation and not to just repeat what was taught (Aleven and Koedinger, 2002). The task-based phase of virtual reality being developed which require the user to complete a task and along the way the application will track the movement of the user and the actions taken. The system will then give direct consequences and immediate feedback by tracking and tallying what is needed, taking advantage of some cognitive learning theories and practices. The task-based phase will be put through similar feedback sessions as the instructional-based session where it will be reviewed

by industry professionals for content accuracy and realism of experience to make sure the tasks are realistic to what an employee would have to complete in real life.

Upon completion of the feedback sessions, the entire application will be placed through an evaluation to judge the usability of the system. Test groups of various skill levels will be given the application to explore. Upon completion the users will be given a list of evaluation statements that they will have to rate their agreement with. These statements will deal with navigation, presentation of information, and the digital environment. This information will then be used to make Build 3 of both sessions. Once Build 3 is completed the VR application will go through a comparative analysis to help judge if the traditional method of learning or the VR application offers a better method of training. This will be done by using a test group to go through the VR application and second group to go through traditional training methods of videos and slide-shows followed by a general knowledge test. The test results will then be compared to see if there is any benefit of one training application over another.

Further application of the research will introduce various task-based scenarios of different levels of difficulty and test the virtual reality system against typical training sessions in order to determine if there is a difference of gain of knowledge between the training methods.

When both phases of the prototype are completed, it will offer a comprehensive training program that informs the user and then tests the knowledge of the user. The main goal of the program is to inform the users of safe working procedures around a conveyor belt system and ultimately reduce the number of accidents that occur due to lack of knowledge and skill. It is hoped that this training program will be a valuable asset to the safety training professionals within the industry and prove itself as a useful tool to improve jobsite safety.

2.7. Acknowledgments

This research is being developed with support of a NIOSH Grant # 1 R01 OH008716-01 *Virtual Environment (VE) Applications to Improve Mining Health and Safety Training*. The views expressed in this paper are those of the authors and do not necessarily reflect those of NIOSH.

3. Implementation and Evaluation of a VR Task-Based Training Tool for Conveyor Belt Safety Training

“Implementation and Evaluation of a VR Task-Based Training Tool for Conveyor Belt Safety Training”

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ABSTRACT: Conveyor belts are dangerous to the working environment and the source to many injuries and fatalities that end up costing the industry a lot of money. In order to reduce the injuries that occur on an annual basis better training techniques are examined. Virtual reality is examined as a way to enhance current training practices that consist mainly of slide show presentations and videos. Virtual reality is examined for task-based training where the user can interact with a working environment safely. The user is given tasks to complete within the virtual environment similar to tasks a worker would have to complete on a day to day basis. The purpose of the program is to be a method of rapidly training younger miners while supplementing on-the-job training practices and ultimately reduce accidents. The model was developed using CAD software and then imported into Deep Creator's Right Hemisphere where animations were added and functions were programmed to objects. The user's performance is tracked through the use of LISP programming and scores are tallied to judge user performance. The application was tested for quality of information, usability, and learning potential over other training methods.

This paper is an expansion of the paper presented at the CONVR 2007 conference at Penn State University, State College, PA, USA on October 22-23, 2007 (Lucas and Thabet, 2007).

KEYWORDS: *virtual reality, safety, training, conveyor belt*

3.1. Introduction

The mining industry, as in many other industries, places an emphasis on safety and adequate training for many pieces of machinery. Conveyor belts are one piece of machinery that is the source of many accidents and fatalities each year. Between 1995 and 2007, nearly 10% of all fatalities within the mining industry were related to conveyor belt operation (Lucas, et. al., 2008). Conveyor belts offer many benefits to the mining industry including their ability to run continuously without loss of time for loading and unloading, scheduling, and dispatching and their low transport, maintenance, power, and labor cost per ton of material moved as compared to other material moving equipment (Swinderman, et. al., 2002). With these benefits, conveyor belts are a fact of nature within the mining environment. Only with adequate training can the industry reduce accidents, reduce the amount of downtime due to accident investigation, reduce drops in production rates and lingering effects on productivity after accidents, and create a safer working environment for all employees.

3.2. Accident Statistics

Goldbeck (2003) reported that between 1996-2000 there were 459 injury cases (fatal/non-fatal) due to surface belt conveyors; 13 cases (2.8%) were fatalities and 22 cases (4.8%) were permanent disabilities; 42% of the cases reported (including 10 of the 13 fatalities) occurred while performing belt maintenance and inspection. Goldbeck (2003) also reported that the cost of a fatality in a mine was estimated to be \$1.02 million in 1986; which is equivalent to \$2.0 million in 2008 according to the US Bureau of Labor and Statistics (2008) inflation value. This value was calculated by considering medical expenses, worker's compensation, accident investigation, loss of family income, and lost production value.

Permanent disability accidents of less severity were estimated at \$237,000 and each lost-time accident was also estimated at an average of \$5,000 (Goldbeck, 2003) or a 2008 value of \$464,535 and \$9,800 respectively (USBLS, 2008). Lucas, et. al., (2008a) reviewed and analyzed 50 fatal cases involving the use of conveyor belts that were reported by the Mining Safety and Health Administration (MSHA) between 1995 and 2007. The analysis of the 50 cases involved classifying each fatality to the type of maintenance tasks being performed. Cleaning was performed during 44% of the fatalities while installation and repair was being conducted during 36% of the fatal accidents. Entanglement was also classified as the largest cause of fatalities at 56% with collapse of structure, falling of components, or loose material causing 24% of the fatalities. Based on these statistics, there is a need to explore other means to improve training for safety procedures and properly performing maintenance and inspection tasks to reduce conveyor belt related accidents.

3.3. Training Practices

Within the United States, MSHA's Code of Federal Regulations (CFR) Title 30 part 46 and 48 require 24 hours of training for new hires. MSHA requires that four hours of the training be conducted before the new hire starts work while the remaining 20 hours of training occur within the first 60 days of work. MSHA also requires documented training when a miner is assigned a new work task or transfers to a different facility. Lastly, every miner is required to participate in eight hours of refreshment training annually (CFR, 2008). Training programs are documented and approved by MSHA but guidelines on structure of a program is very limited. Training procedures and guidelines are not adequately addressed by the major professional organizations such as the American National Standards Institute (ANSI) conveyor safety standards, the Occupational Safety and Health Administration (OSHA) regulations, and the safety engineering professional associations and are left to the owner/operator to fulfill MSHA's requirements (Shultz, 2002, 2003).

Several mining facilities were visited to review how they fulfill MSHA's requirements. Typically, videos, lectures with slides, and handouts are used to fulfill the required 24 hours of safety training. Similar methods are used during the required refresher courses each year. Specific task-based training is often done through on-the-job (OTJ) training where a miner assigned to a new task is accompanied by a miner experienced in that task. The inexperienced miner in this situation is to learn from the experienced miner. Beyond the required training, the companies hold weekly or semi-weekly meetings on the site to bring up issues that happened within the industry that miners should be aware of, inform miners of any work on site considered an added hazard, and conduct a quick safety brief. Many of the companies also have incentive programs consisting of quarterly safety bonuses, awards, or group parties for successful inspections and accident free sites. It is felt by the industry that these types of programs act as an incentive for the employees to be safety conscious and help keep safety as part of the industry's culture.

Even with strict regulations set forth by companies to create safety programs that go beyond the required MSHA regulations accidents and fatalities occur.

Current training programs, as discovered through site visits and literature review, are lecture-based and dependent on slides and video presentations to convey safety guidelines and procedures. These training methods are not sufficient for the wide variety of learning styles and education levels that exist within the mining industry. The demographics within mining cover a large number of employees hired during the industry boom from the 1960's and 1970's, very few hires over the following decades, and a current rising need of new, younger miners that will continue to grow in the near future (Kowalski and Vaught, 2002). A younger, more computer literate, generation may receive more benefit from a multimedia based training that they can explore and interact with while the older generations, less likely to be computer literate, often learn better from a more direct and structured approach. All adults often learn best from an active and experience based approach (Kowalski, et. al., 2001; Kowalski and Vaught, 2002). Current training practices do not accommodate this variety of learning styles and are passive in nature.

Knowledge learned from typical training methods, without the trainee actually reflecting upon and experiencing the information presented, may be quickly forgotten and the learning potential of the training lost (Gibbs, 1988). To enhance the learning, the material must be tested in new situations by the trainee to ensure the comprehension of the trained information. Consequences are also inadequately experienced or not experienced at all with current safety training methods. This is because the real environment would not allow the trainee to perform what-if scenarios as safely and cost-effectively as a virtual environment and because real life consequences are often deadly. These same consequences can be simulated within a virtual environment to have a realistic effect on the trainee without the results of an injury.

On-the-job (OTJ) training has value as an active and experienced based approach by placing the miner within the real environment but still does not allow for the experiences of consequences and making mistakes without significant effects of injury or death. OTJ training can be beneficial if well planned and if the individuals doing the training are significantly trained. If OTJ training is poorly planned with inadequately trained individuals it can inhibit the proper performance of tasks and cause a rise in injuries (Wiehagen et. al., 2002). A developed VR application can ensure adequate training and offer the experience of consequences.

Virtual reality (VR) offers a potential for a safety training program to reduce the number of injuries and fatalities through the representation of real-life events in an artificial environment. VR offers a cognitive learning method for trainees to think through actions needed to complete tasks, act them out in a virtual environment, and come in contact with direct consequences to their actions while receiving immediate feedback. With the user having control over the environment and playing out tasks and activities, it is more likely they will be able to perform those tasks safely in real life situations. Testing methods can also track user performance and determine a user's skill level. It is this cognitive learning experience that places interest in the use of VR for task-based training.

Current training methods do not offer an effective way of training a nearing surge of young hires that are needed and will be recruited in the near future. A VR application for task-based training is proposed as a possible solution to effectively train new miners of required safety procedures and hazard recognition information for conveyor belt use and to improve safety within the actual working environment. A four

step VR-based safety training program for conveyor belts is developed (Figure 3-1). Through data collection at site visits and literature review, specific training areas were identified. The training was implemented in a prototype application that consists of two modules, an instructional-based module (Lucas, et. al, 2008a) and a task-based module. The instructional-based module introduces the collected data and the defined training areas to the user and the task-based module tests the knowledge of the user to help determine the user's skill level. Upon completion of the prototype implementation the application was evaluated to ensure it meets industry needs, offers a usable and useful interface, and is perceived as an effective way of learning material. The goal is to create an effective method for safety training professionals to efficiently train new younger miners and ultimately reduce injuries within the industry.

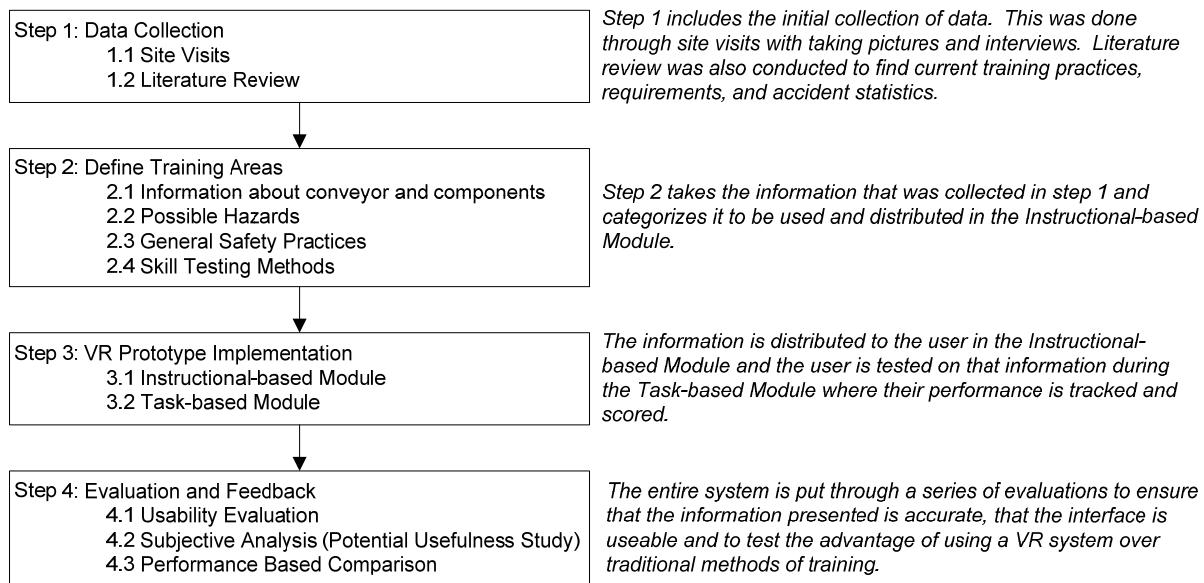


Figure 3-1: Four steps to safety training program structure

In addition to the testing and evaluation of the prototype application using a personal computer, the application has been imported to an immersive CAVE environment. The effectiveness of learning as well as the advantages and disadvantages of the immersive CAVE application versus the non-immersive personal computer applications is being studied (Lucas, et. al., 2008b).

This paper is concerned with the development and evaluation of the second phase of research for the personal computer prototype. Within this phase a prototype implementation for the task-based module (step 3.2) is developed. Current training methods and benefits of VR and cognitive learning and how they can benefit the industry within a safety training program are explored. Current VR task-based training research is presented. The paper discusses in detail the skill testing methods (step 2.4), their implementation in the task-based session, and how the user's actions are tracked and feedback is given to the user. The evaluation scheme (step 4) and select findings are also discussed.

3.4. Cognitive Learning and Virtual Reality in Training

Training has evolved from traditional classroom training to computer-based interactive training in many fields. Classroom training is utilized because of the knowledge that a quality training professional can instill in trainees during classroom sessions, however computer-based training is becoming more popular

in all sectors as it is believed to enhance the cognitive learning of the user. Cognitive learning is a process of acquiring knowledge and understanding through thought, experience, and the senses. The information that is acquired thorough cognitive learning undergoes a process known as cognitive information processing (CIP). CIP is based on the thought process behind the behavior and is used when the trainee plays an active role in seeking ways to understand and process the information received and relating it to what is already known and stored within memory. CIP seeks to explain how learning occurs in a “multistage” theory of memory. In this model of learning, the human mind collects information and moves it around to be associated with other existing related pieces of information and stored in larger files (Driscoll, 1994).

A similar model of cognitive learning is the integration of working memory and long-term memory. Working memory is the “center of cognition and scaffolds all the active thinking activities that occur” (Clark & Mayer, 2003). Working memory deals with the consciousness of our everyday lives (Baddeley & Hitch, 1974) whereas long-term memory is the final stop in the cognitive information-processing path where the information is permanently stored (Shiffrin & Atkinson, 1969). Integration of new knowledge from working memory into long-term memory is called encoding. Later this knowledge from long term memory retrieved into working memory to apply it within a real-life context. Thus the learning progress reaches completion when acquired knowledge is successfully retrieved and applied in multiple contexts (Clark & Mayer, 2003). Meaningful learning ensures that well learned content held in long-term memory is easily brought into working memory. Retrieving and applying the data stored in long-term memory is crucial to solving high level problems involving complex interactivities (Ericsson & Kintsch, 1995).

These theories of cognitive learning can be applied to virtual reality training. Within a VR training environment, the user goes through a series of training (instructional-based session) and rehearsals (task-based training). Unlike with traditional slide show methods and videos, it is an active learning experience where the user is in control. The situations that the user is put into virtually require them to think out proper actions. If improper actions are taken the consequences are immediately shown. These actions and reactions as the user goes through the system are placed in working memory until they are encoded into a larger file of similar information in the long-term memory. When the user comes across a real-life situation the appropriate knowledge is retrieved from long-term memory and applied to the situation (Figure 3-2) where the user would already know of the consequences of mishandling a situation.

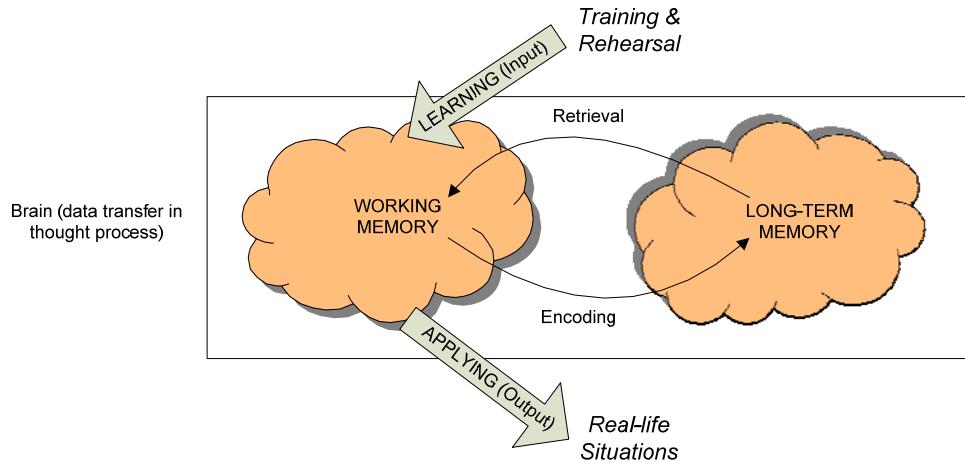


Figure 3-2: A VR application allows for rehearsal of activities, experiences to be stored, and retrieval in real life.

With the use of cognitive learning theory research has shown that computer-based training applications can enhance the training process and give the trainees a better understanding of the material when they are interactive and active in nature. Some work that has been done by using VR and computer-based representations for crisis simulations are: for fire-fighters (Querrec, et. al., 2001), mine safety training (Filigenzi et.al., 2000), security in a refinery (Haller, et. al., 1999), buildings' fire detection systems (Bukowsky, et. al., 1997) and shipboard fire fighting training (Tate, et. al., 1997). Some other examples of VR simulation that replicate an action/reaction scenario and task-based training methods within the mining industry have been conducted by the School of Mining Engineering at the University of New South Wales, Australia with simulated situations of safety in underground mining dependent upon an individual's actions (Stothard, et. al., 2004). Similarly, work at the Spokane Research Center (NIOSH) used VR to test the knowledge gained through training by giving trainees tasks within a VR environment to complete safely (Orr, et. al., 2003).

Other uses of VR within the mining industry include the use of virtual environments to improve safety and design through information visualization and accident simulation (Dellabio et. al., 2007) and accident recreation (Shafrik, et. al., 2003). Virtual environments were also researched for use with underground mine safety training, procedural training, and identifying hazards (Ruff, 2001). Different studies were conducted by Dezelic et al. (2005) and Kizil and Joy (2001) using VR for equipment operation. Stothard, Galbin, and Fowler (2004) used virtual reality applications for health and safety activity simulation.

A VR simulation should replicate the work environment into which a trainee will be placed and then test the trainee with a problem based learning exercise (McAlpine & Stothard 2003). A simulation should also include a method of testing trainee's ability to identify and remedy risk with a method to quantify. In order to enhance the cognitive learning process, the simulation should also demonstrate to the trainee the consequences of poor decision-making and risk taking behavior (Stothard, et. al., 2004). VR applications and the use of virtual environments have been used with great success because of their ability to safely simulate real life events in a digital environment that might otherwise be too dangerous or expensive to create (Haller et al, 1999).

During literature review no research was found that uses VR to target the need for training a high rate of younger employees or train employees on safe operation of conveyor belts, a piece of machinery that is one of the leading causes of injuries and fatalities within surface mining operations. With the models of cognitive learning coupled with the ability of VR to simulate a realistic working environment, a task-based session is researched for safety training with the use of conveyor belts in mining. This prototype replicates a working environment, trains the user of the information that they will be responsible for, and lastly tests the knowledge by assigning a task to be completed. This process is described later in the paper.

3.5. Task-based prototype

3.5.1. Task-based Prototype Development Framework

The task-based prototype uses the model of cognitive theory for the training of new miners and testing their knowledge and skill level of the information distributed to them in the first phase, the instructional-based module. Each exercise is designed by using a five part framework that revolves around instructional design theory and the ADDIE (Analyze, Design, Develop, Implement, and Evaluate) model (Leshin, et. al., 1992). The prototype development also takes advantage of a more advanced instructional design model the Eternal, Synergistic Design and Development Model that revolves around the user's needs and their critique and feedback (Crawford, 2004), by taking advantage of mining industry personnel at various stages of the prototype design and evaluation to ensure it fits industry training needs.

The five part framework for the prototype development and testing (Lucas and Thabet, 2007) consists of (1) determining skills to test, (2) defining training scenarios, (3) determining consequences and reward, (4) animation and programming, and (5) testing for quality assurance. In each exercise it is essential to determine what the user will be tested on by forming a reasonable selection of activities to place within one exercise for the user to complete while in the virtual environment. The environment and scenario then needs clear definition so the user will know what it is they are looking to complete. With an idea of what the user will need to complete within the environment, feedback given to the user and questions asked to the user have to be defined with a tally system to keep track of the user's actions. Once the actions and reactions are defined, they have to be animated and programmed within the system, and lastly the system is put into implementation for testing and quality control.

Flowcharts were used to map the five major tasks and their subtasks that the user needs to complete within the session. Detailed flowcharts were created for complicated tasks that required further definition. With these detailed flowcharts (Figure 3-3) step by step animations were added to correspond with user input.

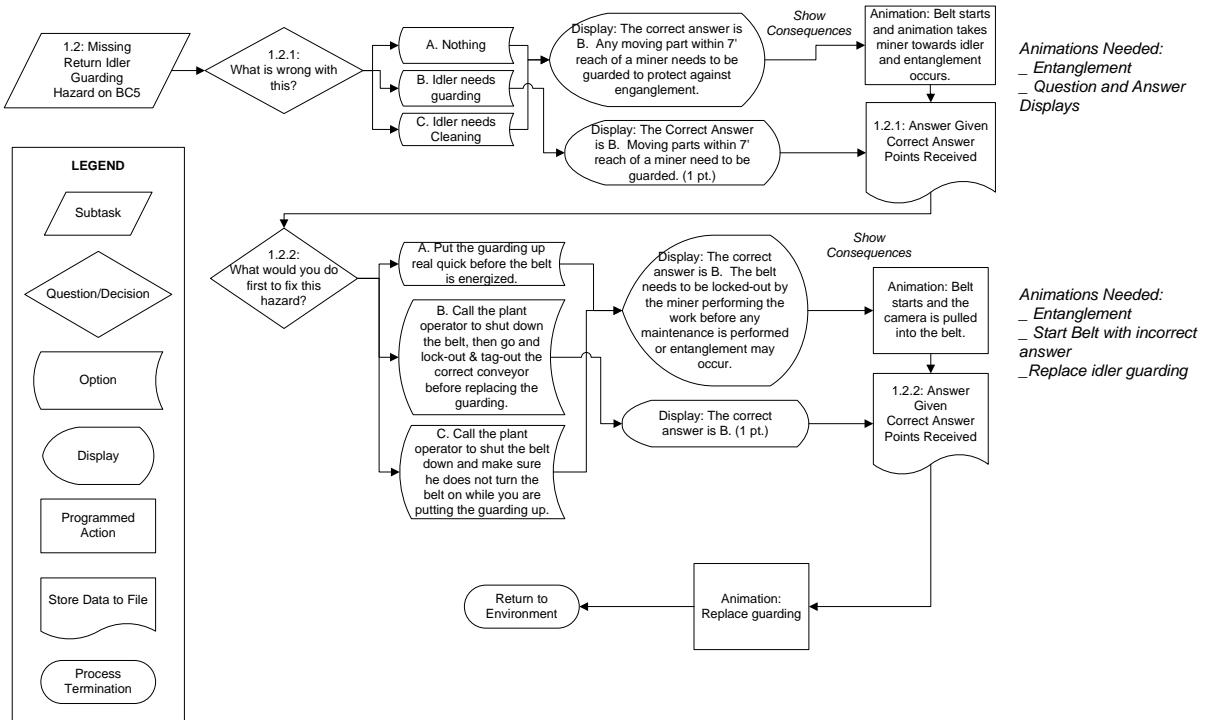


Figure 3-3: Partial scenario flowchart

Figure 3 shows an example of a sub-task where the user is to identify the hazard of a missing idler guard. With each sub-task certain animations were developed. In this example, there were questions that the user is asked during the session. The questions that are displayed with each of the possible answers were put into the flowchart. This aided in the programming to know what information was needed to display with a corresponding user input. Animations and consequences were also added to the flowchart where they would need to be activated within the prototype and shown to the user.

3.5.2. Scenario Implementation

Once the background research to select development topics and define objectives was completed, the virtual environment was programmed to create the training application. This was completed by taking the 3D model that was created in Autodesk's 3DStudio Max for the first module of the application, exporting the model as a .3ds file, and importing it into Right Hemisphere's Deep Creator. Deep Creator offers basic modeling capabilities and basic animation features. Deep Creator also offers a LISP editor where scripts are easily added to each object with the use of trigger controls for controlling animations, system variables with "if/then" statements, and loops, for more advanced animations and interactions.

With the previously completed model, the initial task-based scenario was developed over the course of a few months with approximately 100 man hours that included the learning curve for the application and trial testing before presenting it to the industry. Within this time period the environment was programmed with basic features to make the conveyor belt appear as it is working. After the basic animations were added, the flowcharts were used as a basis for programming the scenario, adding the questions, answers, and consequences, and tracking the user's progress through the prototype.

The basic animations were added to the system with a few different methods. First, materials were added to the different parts of the model. This gives the environment a more realistic appearance. From this, the components that need to be moving when the conveyor system is turned on were programmed. In order to achieve the appearance that the belt is moving the idlers need to rotate and the belt needs to appear that it is moving across the idlers. This was done by adding the basic rotate animation to the idlers, applying the proper axis rotation and designating a rotation speed. Then, the material mapping previously applied to the rubber belt needs to move across the rotating idlers. This was accomplished by assigning the “material move” animation. This animation keeps the object stationary, but makes it appear to be moving by taking the applied mapping and sliding it over the surface of the object. Other noise and bump alterations were added to make the belt appear to vibrate.

Once the animations were applied the ability to turn them off and on was programmed. This can be done through the use of trigger animations and one trigger object but it would require an extremely high number of animation call functions all assigned to one object. The easier method of accomplishing the same task was to write a script using the LISP editor. As the animations were set to “trigger” when they were applied to each idler and the belt in the object tree, they were given the same name with a number suffix (e.g. TI1, TI2, etc. for troughed idlers) (Figure 3-4A) allowing for a loop to be written into the code (Figure 3-4B) and attached to a trigger object, in this case the start and stop buttons that turn the objects’ animations on and off (Figure 3-4C). Once the trigger object is selected when the application is run, the loop calls the name of the component and then runs through all subsequent components that are associated with each piece of the belt.

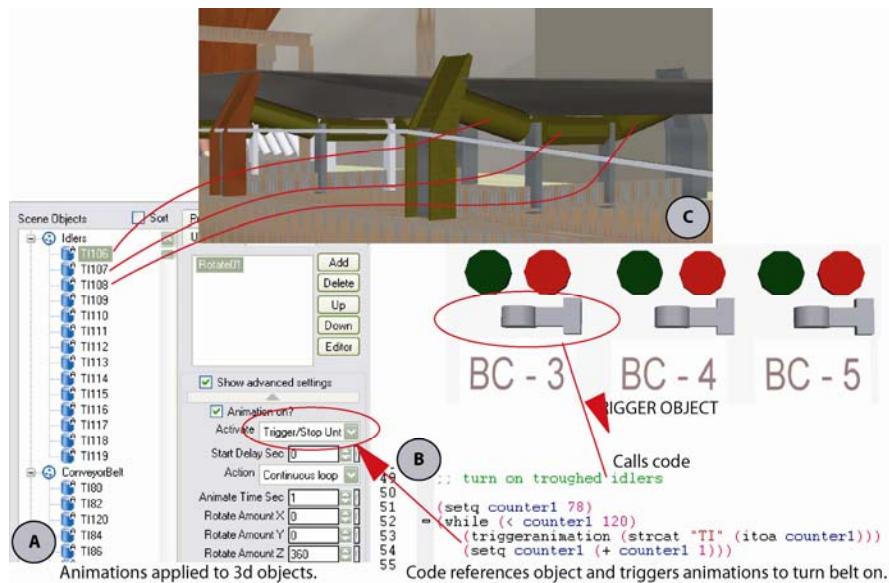


Figure 3-4: Turning on and off the Conveyor Belt

Another layer of information that the start and stop buttons rely on is making sure the breaker is turned on and not in the off position, a factor from the real life environment that needs replication within the virtual environment. This again is done with the use of the LISP editor and the introduction of an “if/then” statement that was added in front of the series of loops that turn the belt and idlers on or off. The “if/then” relies on a system variable called “lever” that returns a 1 or a 0 depending on if the breaker is on

or off (Figure 3-5). As long as the breaker is in the on position it will run the loop and turn the belt on. This process was repeated for each of the three conveyor belt sections.

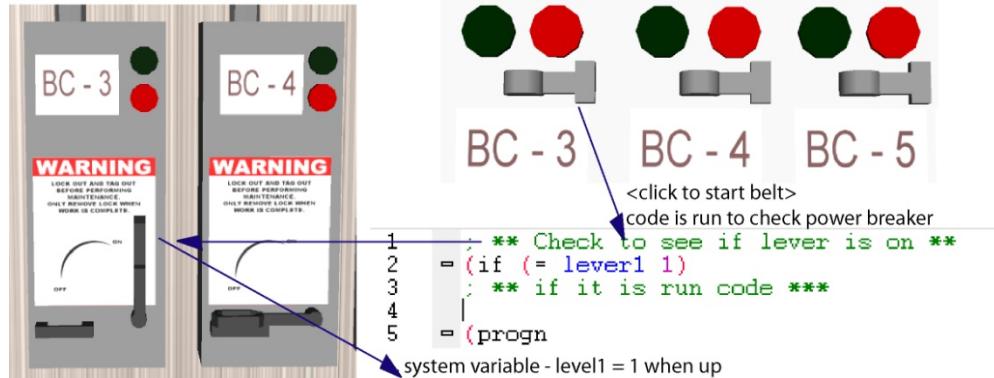


Figure 3-5: System checks to make sure breaker is on

Once the basic features of the environment were programmed, the programming for the specific scenario and tasks was completed. This was done by taking the previously developed flowcharts and following the laid out processes. The first task developed was the “Identify Hazards” task where the user has to navigate through the environment and find three different hazards. In order to program this task, a series of questions and possible answers were added to the environment that the user will be asked. The questions and answered were connected to the hazard in the environment and the application keeps track of which hazard the user identifies first and which answers the user selects. In order to program this, the questions that are associated with each hazard were added to the environment as text blips that appear as message boxes. They were then connected to the trigger object at each hazard. The possible answers were also added to show when the questions appear. The explanations to each answer was then placed as another message box, each of which would appears when the right or wrong answer that it is connected to is selected. Consequences for each wrong answer were animated and are triggered by selecting that wrong answer (Figure 3-6). The code written in the LISP editor controls the message box that appears when each answer is selected by the user. This allows the programmer to easily keep track of and program what appears with each user input. Another reason why the LISP editor was used for this process is that the prototype keeps a tally of how many hazards have been identified by the user so once all hazards are identified the application can instruct the user to move on to the next task. The prototype knows which task message to show based on “if/then” statements and a system variable (Figure 3-7). The prototype also keeps tally of which answers the user selects and prints them out to an output file at the end of the session and tallies the points received by the user to help the trainer keep track of the user’s performance.

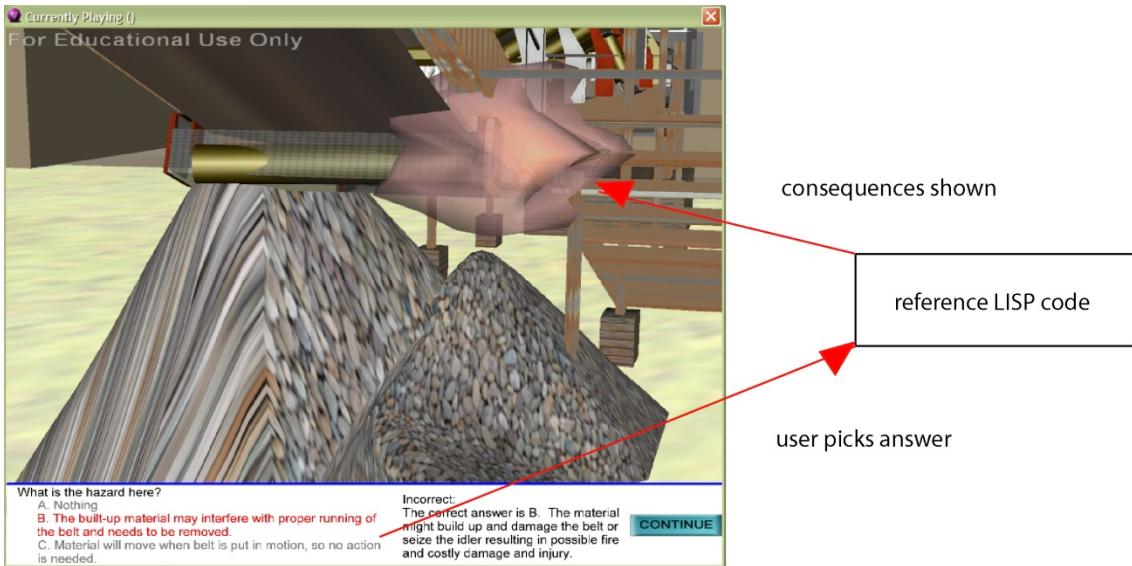


Figure 3-6: Identifying hazards – question/answer example

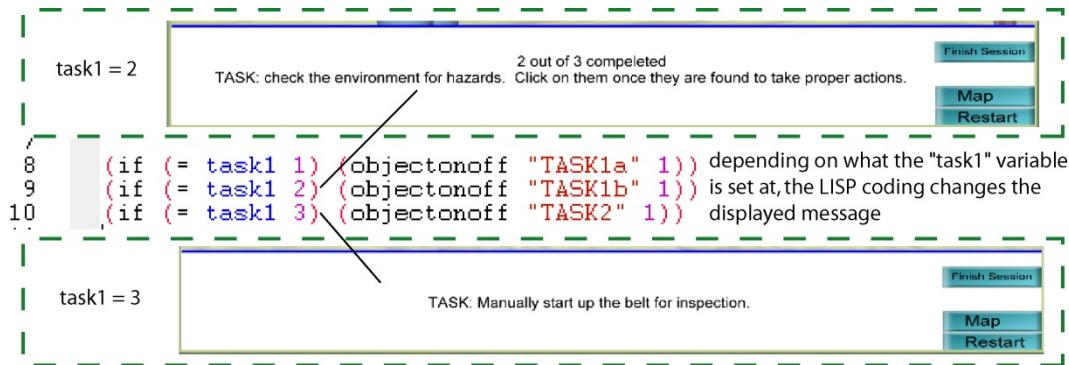


Figure 3-7: Task message example

Another programming feature used for identifying the user location in respect to the hazard to trigger animations, such as the broken rail, is a proximity sensor. Proximity sensors were used and set at the edge of the catwalk where the broken rail is located. If the user navigates too close to the area of the broken rail, animations are triggered that make it appear that the user has fallen from the catwalk. The proximity sensor consists of placing an object, which does not render while the prototype is run, along the catwalk. Another object, that does not render, was tied to the navigation window and follows the user around the environment. Once the two objects collide the animation is triggered.

Once the user identifies the hazards, the next step in the flowchart indicates that Task 2 is to turn on the conveyor belt system. In order to properly do this, the user must make sure that the electricity breakers are in the “on” position, navigate to the control room and sound the alarm, and then start each section of belt. This involves programming that was built off of the initial environment programming that makes the belt look as if it is moving. First, each breaker has a system variable tied to the control switches. As long as this variable is set at “1” the control switch turns the belt on. The control switch also looks for a variable to make sure that the alarm was sound within 30 seconds of the switch being selected through the use of stored times (Figure 3-8). If the alarm was sound longer than 30 seconds before the user tries to

turn on the belt, or was not sound at all, there is a warning message telling the user of the proper procedures. If the user does not follow the proper procedures during their first attempt to turn the belt on they will not receive the points available for completing the task correctly. This process of manually sounding the alarm mimics the basic manual method of turning on a belt in real life. Commonly, computerized systems automatically sound the alarm before starting up the section of belt, but it was felt that programming, and training the user on, the most primitive method that an employee may have to use was important for the success of the application. Once the belts are turned on, the user is charged with the next task of inspecting the belt to make sure it is running properly.

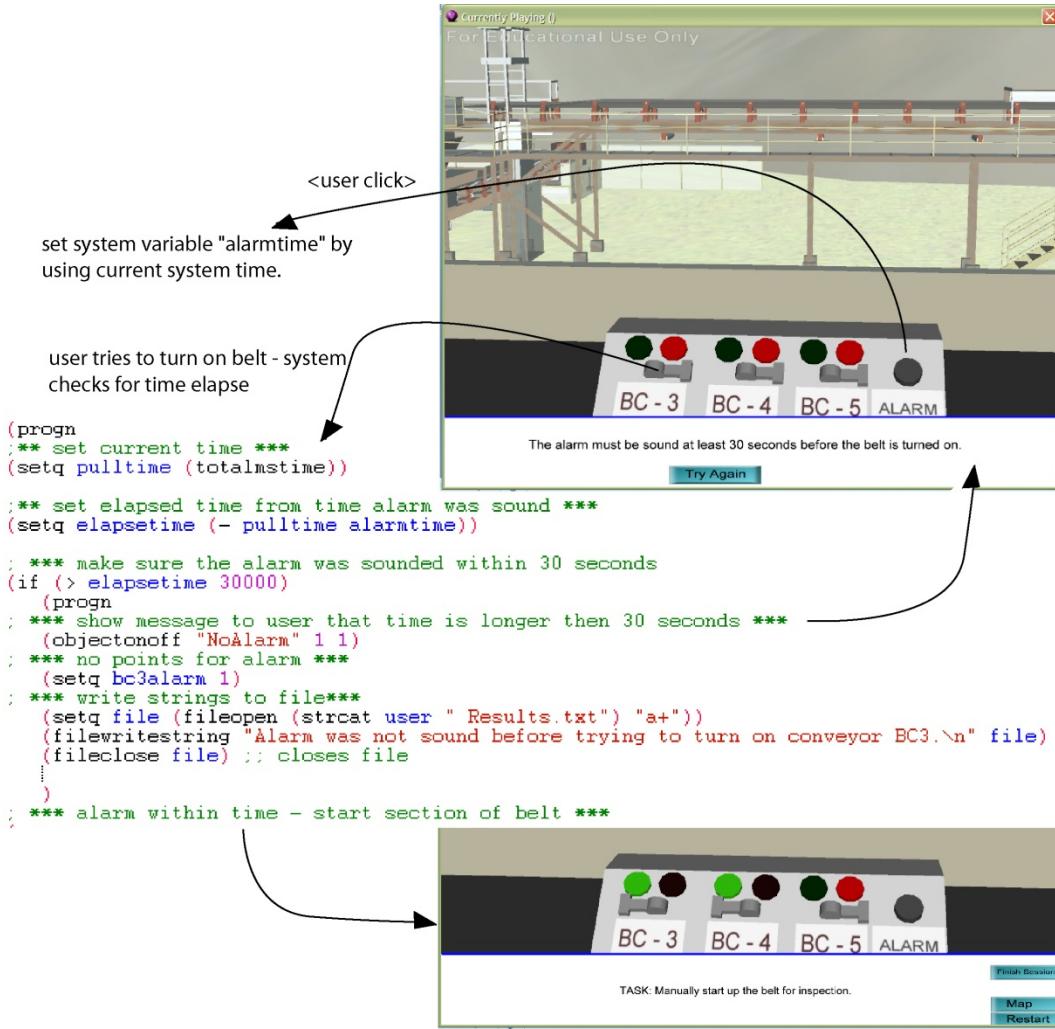


Figure 3-8: Sounding the alarm

The third task that the user has to complete is to inspect the conveyor belt system for any malfunctioning components. There is a smoking idler located along the lower conveyor belt. Once the idler is recognized, the user is able to radio to the control room and have it shut down. After making sure the belt shuts down, the user needs to turn off the breaker and lock and tag it out (task 4), remove the idler guard, fix the idler, replace the guard, unlock and power on the breaker, and start up the belt (task 5). Each one of these steps happens in a specific order to properly complete the task. At certain stages of the process if the user completes something out of order certain consequences can happen. If the user does not shut

down the belt, or lock it out, and removes the guard, it is possible that the employee in real life would be injured. Another possible consequence is if the belt is turned on without the guarding being replaced, a similar situation can occur. One last possibility is if the breaker is pulled before the belt is shut down it is likely to explode. Each of these consequences was programmed in the prototype and is triggered by the use of system variables and “if/then” statements in the LISP editor. If one of the trigger objects is selected, such as the guarding clicked to be removed, the application runs lines of code that check to see if the variables are at the proper value. For the instance of removing guarding, the system checks to ensure the belt is shut down and the breaker is turned off and locked out. If everything clears, the user is notified of “guarding successfully removed” and the guarding is moved away from the idler. If the belt is still on, an animation is triggered and the user is pulled into the conveyor showing the user became entangled into the moving conveyor, which is likely a fatal injury. A message is shown and the event is recorded. The other consequences are programmed in a similar manner.

Once the user completes all tasks that are programmed into the system the application produces an output file as a .txt file (Figure 3-9). This file is created through LISP coding associated with each task the user had to complete. Depending upon what answer is selected depends upon what is written to the file. Also, the coding records each step that the user takes to the file. If a step is missed or the user does not complete the steps in the proper order, it will appear in the text file.

```

Jason Lucas Results
Task-based Session 1: Beginning of shift start-up.

Task: Start the shift by inspecting the belt to ensure all safe guards are in place
and all hazards removed. After energizing the belt, make sure it is running
properly before going on break.

Environment Conditions: Start of shift, the belt is de-energized, unlocked, and
there are no other employees in the work area.

User's Name: Jason Lucas
Order of actions:

ACCUMULATION HAZARD:
Q1. What is the hazard here?
User answered: A. Material will move when the belt is put in motion, so
no action needs to be done. - INCORRECT
Q2. How would you fix this hazard?
User answered: C. As long as guarding is in place, shovel material out of the
way or use a
hose to wash it out. Check for the cause of the accumulation and fix it. -
CORRECT, +1pt.
.....
Alarm was not sound before trying to turn on conveyor BC3.
Belt BC3 successfully turned on.
Belt BC4 successfully turned on.
Belt BC5 successfully turned on.
Belt BC3 turned off by radio call.
Power for breaker BC3 is turned off.
Break BC3 is locked-out.

.....
Session finished.
Total is 11 out of 13.

```

Figure 3-9: Sample from output file created at end of session

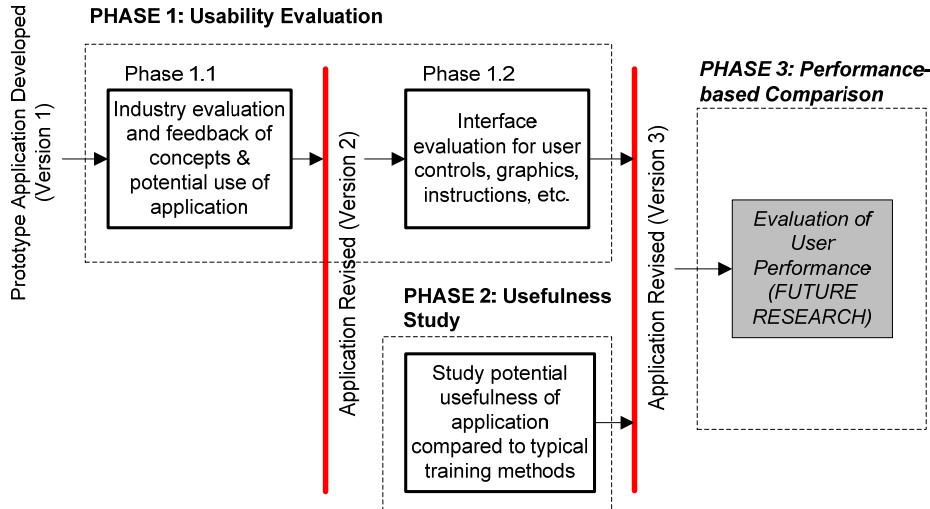
After the programming was completed it was important that the application was tested to make sure that all options the user can take work properly. The process of debugging the application is a repetitive running of the program and completing tasks in different steps to make sure that the proper animations and actions will work in any possible combination when it is used. Deep Creator has a built in “play” function for the environment which aids in viewing the work that has been completed as the user will

interact with the environment. Once a bug is found, the programming code is examined to make sure that the “if/then” statements and system variables are working properly. After all the bugs were removed, the session was exported from Deep Create as a self-executable file (.exe) and placed through the feedback and evaluation process using industry professionals and various other users to check accuracy and completeness of information and usability.

The challenges that exist with the creation of the prototype include the learning curve of the program. Overall, the programs modeling features work similar to that of any other modeling environment. The programming was easy to become familiar with and the help files aided in the understanding of these features as well as the built in animation/alteration functions. Some benefits of using Deep Creator to program the environment was that the built-in features were easy to get used to, and most of what needs to be done can be completed within assigning properties to each object that control animations and trigger events. The LISP editor features of the program aid in a quicker development once controls become complex and only basic knowledge of the programming language was required to program complex processes. Methods of trial and error were used in order to fully understand the limits of features of the program and overcome barriers presented by the basic program functions.

3.6. Feedback and Evaluation Scheme

After initial implementation of the prototype application a series of studies were conducted to ensure that the application would fit the needs of the industry, was usable, and had potential usefulness. The evaluation scheme (Figure 3-10) consists of three phases: (1) a usability evaluation, (2) a usefulness study, and (3) a performance-based comparison (future research). The evaluation process is an iterative process where a study is performed to collect information that is then used to improve the prototype application. Phases 1 and 2 consisted of qualitative subjective studies dealing with personal perceptions. These subjective studies documented participant perceptions of usability and usefulness of the application through the use of questionnaires. Phase 3 (future research) will involve an objective comparison of user performance and will allow a comparison based on participants’ performance in a scored evaluation.



| Phase | Purpose | Participants | Study Type |
|-------|--|-------------------------------------|------------|
| 1.1 | Industry review of information, concepts, and potential of application | Industry Experts | Subjective |
| 1.2 | Evaluation of user controls, navigation and interaction with environment | Expert & Novice Users | Subjective |
| 2 | Perceived advantages and shortcomings of proposed application vs. typical training methods to determine prototype usefulness | Expert & Novice Users | Subjective |
| 3 | Evaluation performance of new trainees after they complete training with application or typical methods. Results compared. | Novice Users (Inexperienced Miners) | Objective |

Figure 3-10: Evaluation scheme for prototype application

3.6.1. Phase 1 – Usability Evaluation

Phase 1, the usability evaluation was broken into two sub-phases, an industry review of presented information and comments and an interface evaluation. The industry review sessions were used as an indicator for industry interest in the prototype application. The interface evaluations were conducted to identify bugs within the application, identify weaknesses in usability, navigation controls, instructions, graphic representation of information, and ability to complete tasks.

Phase 1.1 was conducted through unstructured feedback sessions. In each of the sessions the meeting attendees were presented with a concept overview of the application prototype and then a demonstration of the prototype. During the demonstration the attendees were encouraged to make comments about what they were presented and interrupt at will to discuss any issues, questions, or comments they may have. Overall four meetings with three companies were conducted with a total of 11 professionals in attendance. All consulted companies are based or have operations within Virginia, USA, are aggregate processing plants, and have extensive use of surface conveyors within their operations. The industry professionals consisted of three individuals involved with safety programs at their facilities, two training professionals, and the remainder was superintendents, foreman, maintenance personnel, and engineers. After each meeting the feedback received was used to revise the information creating an iterative review process (Figure 3-11). When all meetings were conducted a second version of the prototype application was created for the next phase of evaluations.

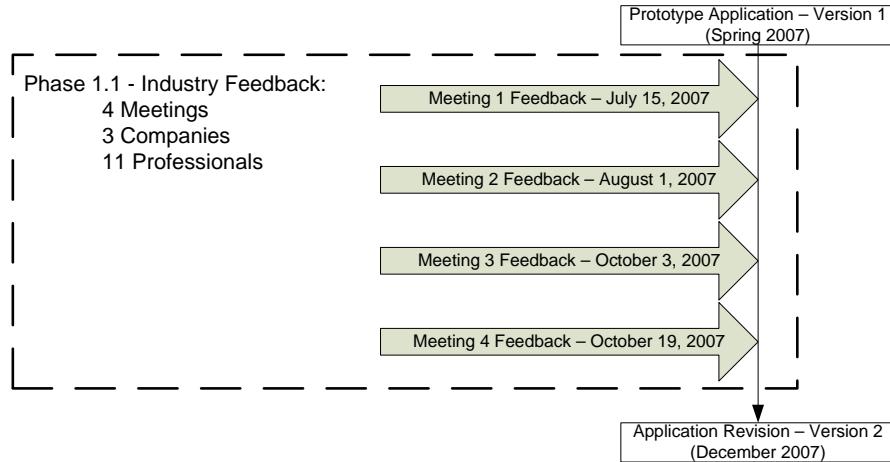


Figure 3-11: Phase 1.1 of evaluation process

From the review sessions 28 unique comments were documented, of these 28 comments 13 were dealing with revisions to existing information while the remaining 15 were suggestions for improvement or suggestions for future scenarios that can be developed. All the received comments were reviewed and the application revised.

The secondary purpose of the industry sessions besides review of information was to judge the level of industry interest in using a personal computer based virtual reality program for training. The following reasons were given during the meetings in support of developing such an application:

The application gives a sense of interaction, especially to the younger generation used to working with the computer and playing video games.

It offers an interaction and practicing of procedures in a close to life environment.

Different people learn different ways and this would offer a better method of teaching to some who do not do so well with other methods of classroom type training.

A complete list of revision comments compiled during industry feedback is documented in Appendix C.

Phase 1.2 consisted of both novice and expert knowledge level participants. Each participant was given a description of application and presented with the purpose of the research. They were then asked to complete the training application by reviewing both modules of the prototype. Once they reviewed the modules and participated in the task-based training, each participant was asked to fill out a questionnaire and rate their agreement, on a one to five scale, to statements on the questionnaire from strongly disagree (1) to strongly agree (5). The statements that were used are classified under five categories: 1.) clarity of instructions, 2.) ease of navigation, 3.) clarity of objectives, 4.) understand ability of information, and 5.) ease of completing tasks.

12 individuals participated in the interface usability study. 10 were students and 2 were mining professionals. 10 were male and 2 were female (both females were students). The average age of the participants was 28 years of age with a range from 20 – 40. One of the mining professionals was in charge of safety training at the time of participation; the other was in charge of a training program earlier

in his career. 11 of the participants (9 students & 2 professionals) have had experience with first person video games before participating in the training. 9 of the 11 had experience using mouse and keyboard controls similar to that of the task-based module of the prototype application. All expressed their rate of play of these types of games as “not often” or “less than 5 hours per week”.

The average agreement for the interface evaluation survey statements are listed in Figure 3-12 (survey statements are listed in Appendix E).

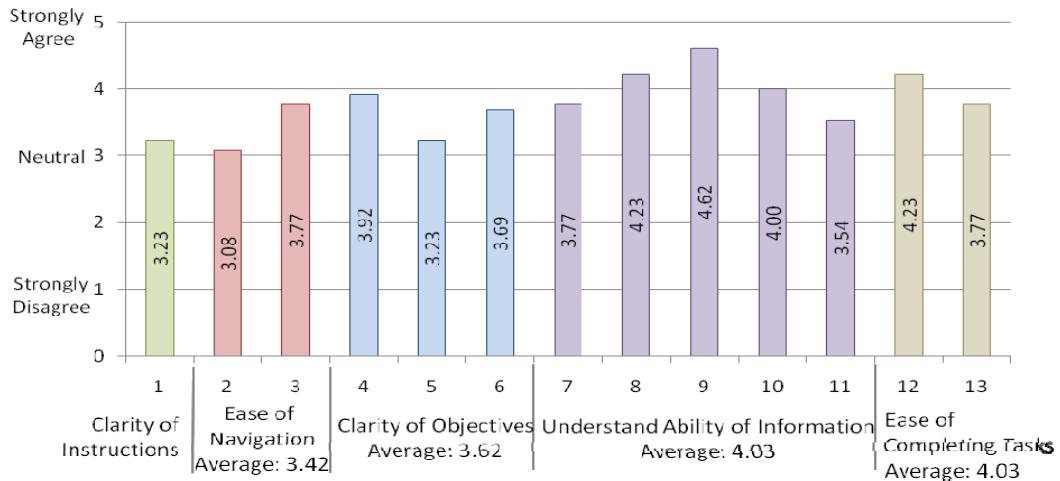


Figure 3-12: Average agreement for Phase 1.2 Interface Evaluation survey statements

Upon examination of the findings some key issues were identified. The instructions were given at the beginning of the session, however since there are several stages to the session they were difficult to remember. Some individuals had difficulty understanding some of the instructions. These issues were resolved by editing the way in which the instructions were written as well as giving the user reminders of the tasks they are to complete as the continue through the session. The same issues existed with the clarity of the objectives. The individuals who disagreed with the statements about clarity of objectives gave suggestions on how some of their confusion could be resolved. Lastly, navigation proved to be the largest issue to most of the participants. Some participants were able to overcome any challenges and familiarized themselves quickly with the navigational controls while other participants found the navigational controls a major issue and were easily disorientated within the environment. If the application were implemented into the industry, additional studies would need to be conducted to see which navigational control methods are favored by the most individuals. Some controls to include in this study are game console controllers, joysticks, touch screens, or the use of keyboard and mouse navigation with different settings and methods for use. No matter which method is found the easiest for the most individuals cues can be added to aid in navigations. One example of a navigational cue is if the user navigates to the doorway of the breaker room within the environment the application would automatically re-orientate them to the breakers on the wall where they would interact with the environment while completing their task.

A full list of statements and their average rates of agreement and distribution is listed in Appendix D.

3.6.2. Phase 2 – Usefulness Study

This study was conducted with the use of a subjective survey designed to capture participants' perceptions of the advantages and shortcomings to learning with a VR application as opposed to traditional training methods. Both novice and expert knowledge level participants participated in this study. Novice knowledge level participants were given a presentation of typical training material as used within the industry and a demonstration of the prototype application, participants were allowed to navigate through the environment and experience the training method. The typical industry training material included several PowerPoint slideshows received from industry contacts, training videos available through MSHA and other organizations for the purpose of training at mining facilities, and printed documents used within the industry. Once the presentation of the training material and demonstration of the application were completed each novice participant was asked to complete a survey to document their preferences of learning methods and advantages and shortcomings of each training method. The expert knowledge level participants were given the demonstration of the prototype application and allowed to experience the training and then asked to complete the survey comparing the prototype application to the training methods they were familiar with that are used at their own facility. Figure 3-13 is a graphical representation of the structure of this phase.

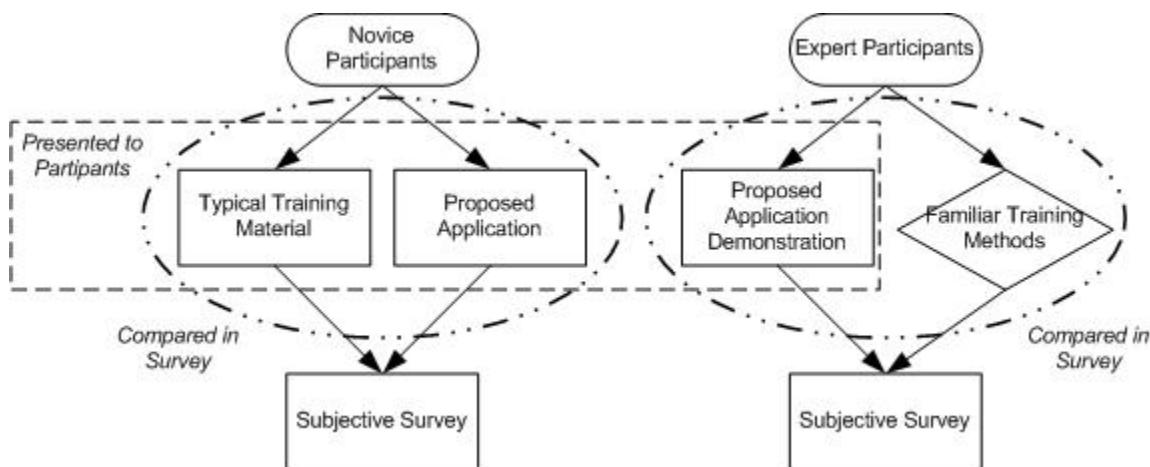


Figure 3-13: Phase 2 – Usefulness Study – study structure

A total of 8 individuals were asked to participate. 2 participants were mining professionals the rest were novice experience level participants.

Some of the common comments documented from the survey as being advantages of using a VR application for safety training were that it allows for the rehearsal of tasks, allows for the experience of consequences without the danger of the real life environment, and offers an interactive training. The shortcomings that were of the most concern were that the VR application requires some computer knowledge and ability to navigate through the environment. This would be difficult for the older generation or individuals who are not computer literate.

5 of the 8 participants agree they would prefer learning from a VR application. The reasons stated were:

- That the VR gives them an interactive experience where they could rehearse processes safely.

- That the users were able to view processes step by step in the instructional-based session and then try them out in the task-based module.
- That the interaction gives them control over their training.

The 3 participants that preferred typical training methods over the proposed VR application cited that the typical training methods allow a personal interaction with an individual of experience who can answer questions and that the typical training methods allow for learning by individuals who do not need to be computer literate or for individuals who learn better in a classroom setting. These participants did agree that there are benefits from using a VR application for training and that it was an effective way to learn for a younger, computer literate, audience.

A full list of questions and comments can be found in Appendix E.

3.6.3. Phase 3 – Performance-based Comparison

This phase of the evaluation will be completed as part of future research as it is beyond the scope of the NIOSH funded research. This phase would involve a developed functional VR application and only be conducted after a navigational control system is found that is easiest for most individuals to use. This study would include an objective comparison of miner performance. Two test groups of novice knowledge level will be needed to complete the performance-based comparison study (Figure 3-14).

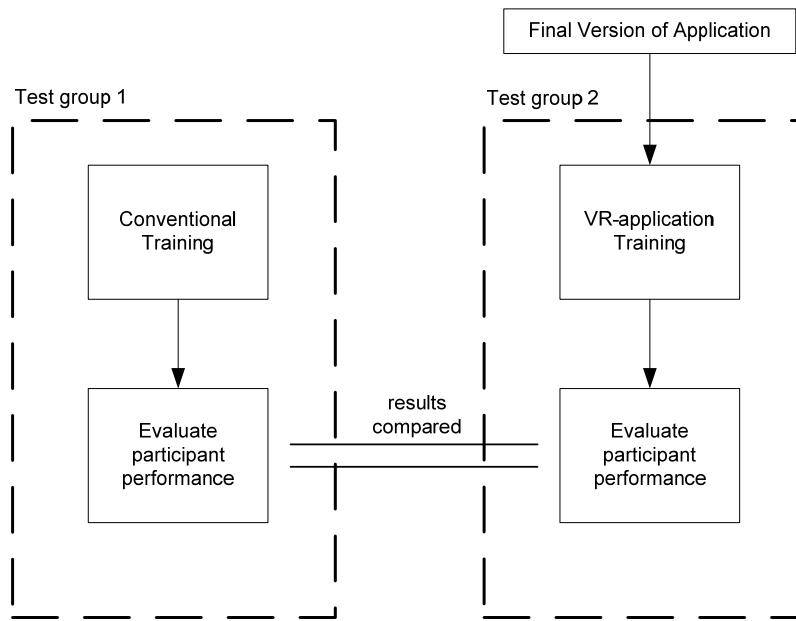


Figure 3-14: Phase 3 - Performance-based Comparison – Study Structure

The first test group would participate in typical training that is customary through the industry. A second test group would participate in the VR application training. Each individual who participated in either test group would then be subject to a performance evaluation. This performance evaluation can be paper-based and conducted on the knowledge the user should have gained through the training or it can be based in the field where the users are given a task to perform and their performance is then evaluated through a structured review process. The results of the performance of the two groups will then be compared and evaluated to see if there is one training method that is more effective than the other group.

To expand this evaluation phase a long term industry evaluation of the training and effectiveness can be conducted by reviewing, at regular intervals, the performance of individuals who participate in different methods of training. Accident rates and skill levels can then be assessed for long-term benefits in training methods.

3.7. Immersive Versus Non-immersive Effectiveness Comparison

After the implementation of the VR application prototype was developed a second research group recreated the application within a 4 screen CAVE environment at Virginia Tech. With an identical VR application running on two separate platforms, a study is being conducted to test the effectiveness of learning and knowledge gain from training in an immersive, CAVE environment, or a non-immersive, personal computer application (Lucas, et.al., 2008b).

There is often perceived benefits of using an immersive environment over that of a non-immersive personal computer because the environment becomes life-size allowing for better perception and further engaging the user, however the size of the CAVE environment and precision set up required rises issues with accessibility to such training applications. If a CAVE environment was used for training the trainee would have to travel to a specific facility. With a personal computer application the trainee can be trained in the local office or in the back of a truck with a laptop. The flexibility of the training environment is greater with a personal computer. The purpose of this study is to try to determine which method is more effective and if the CAVE environment is more effective for learning is it worth the cost of implementation and lack of flexibility. The study uses two groups of novice knowledge level participants who have had no previous experience to conveyor belts or mining. After each participant completes the immersive or non-immersive training module they are given a test the knowledge gain from the two groups are compared. This study is ongoing and will be published with the results of the NIOSH funded research.

3.8. Conclusion and Future Research

The aim of the developed prototype application and subsequent research studies is to examine the potential usefulness and effectiveness of a VR application for safety training for surface conveyors. The goal is to offer safety training professionals a tool that can help them adequately and effectively train an oncoming influx of younger miners that are needed in the industry over the next few years. After completing the subjective studies the results and received data were analyzed. Though there were some usability issues identified through the usability evaluation, the issues with clarity of instructions and clarity of objectives are easily overcome through revisions of explanation. The issues with navigational controls can be overcome with further evaluation studies. Other than the identified usability issues there was initial industry buy-in to the concepts and perceptions of that a VR application offers a useful tool for training younger miners. Within the usefulness study similar perceptions were documented that indicate a potential for a VR safety training application with conveyor belts. Though a true effectiveness cannot be determined until a performance based evaluation as previously described is performed, the responses from the industry and other consulted individuals offer a sense that further development of a personal computer based training application can have a positive effect on training. Industry members feel that allowing new younger miners to participate in computer application training where they can experience the environment, participate in and rehearse work tasks, and experience consequences while being in charge of their training can aid in effectively training this group of miners.

Other future work besides navigation studies and a performance-based evaluation will explore other scenarios in a task-based setting. This can be used to create advanced training sessions involving advanced maintenance issues, other safety issues, and procedures. The same methods and framework used to create the prototype application can be employed for similar sessions.

If a VR safety training application for surface conveyors is successfully implemented into the industry and is proved as a successful method for training young miners similar application can be developed to offer flexible, safe training for other pieces of machinery commonly used within the mining environment.

It is hoped that this research can aid in the safety training of new employees and the continued training of experience employees as required by MSHA. The application is not developed to replace current training methods but fill in the gap of experiential training that currently only exists as on-the-job training which is important for new employees training but also inherently dangerous for someone who is not familiar with all the proper procedures and policies of an actual working environment. To aid in the success of the program much emphasis was put on industry input in the development of the application and industry feedback through the evaluation of the application. If the application fits the industry's training needs it is more likely to be accepted as a valuable piece of their overall training program. It is with the aid of the industry that a program that fits their needs, is easy to use, and is easy to develop and modify can be offered as a potentially valuable tool to improve training and ultimately eliminate injuries and save lives.

3.9. Acknowledgements

This research is being developed with support of a NIOSH Grant # 1 R01 OH008716-01 *Virtual Environment (VE) Applications to Improve Mining Health and Safety Training*. The views expressed in this paper are those of the authors and do not necessarily reflect those of NIOSH.

3.10. Instructional Design of Task-based Module

This section of the chapter was not published under reference Lucas & Thabet, 2008.

Since the task-based module requires user interaction, flowcharts were used in designing the module. These flow charts were set up at different levels of detail. The flowcharts were used to map out the user's interactions with the environment. These flowcharts were design on an overview high level view of the module and then detail was added as each task and sub-task was examined. The actions that the user takes that are incorporated into the flowcharts are mapped based upon the information received during literature review. The processes included are either considered common practice or, in most cases, standard safety requirements (MSHA).

The first flowchart that was created consists of an overview of the entire module (Figure 3-15). This flowchart shows the relationship of each task the user will go through and each sub task that is included within a task. The five tasks that the user goes through are 1.) Identify Hazards and Take Proper Actions to Remove, 2.) Start Belt, 3.) Ensure Belt is Running Properly, 4.) Fix Broken Idler (including locking out and tagging out), and 5.) Start-up Belt. Each task includes sub-tasks which further explain the major steps in completing the task. The sub-tasks of task 1 "Identify Hazards and Take Proper Actions to Remove" do not need to be completed in order, as long as all three hazards are identified and the actions are taken the task is complete. The other tasks require their sub-tasks to be completed in a specific order.

Task-Based Session

OBJECTIVE: Inspect the belt before beginning the shift. The user is to find all hazards, take the steps to start the belt, and ensure it is running properly before completing session.

ENVIRONMENT: The user starts in the environment at the beginning of the shift. The belts are de-energized and there is no one in the work area at the beginning of the shift.

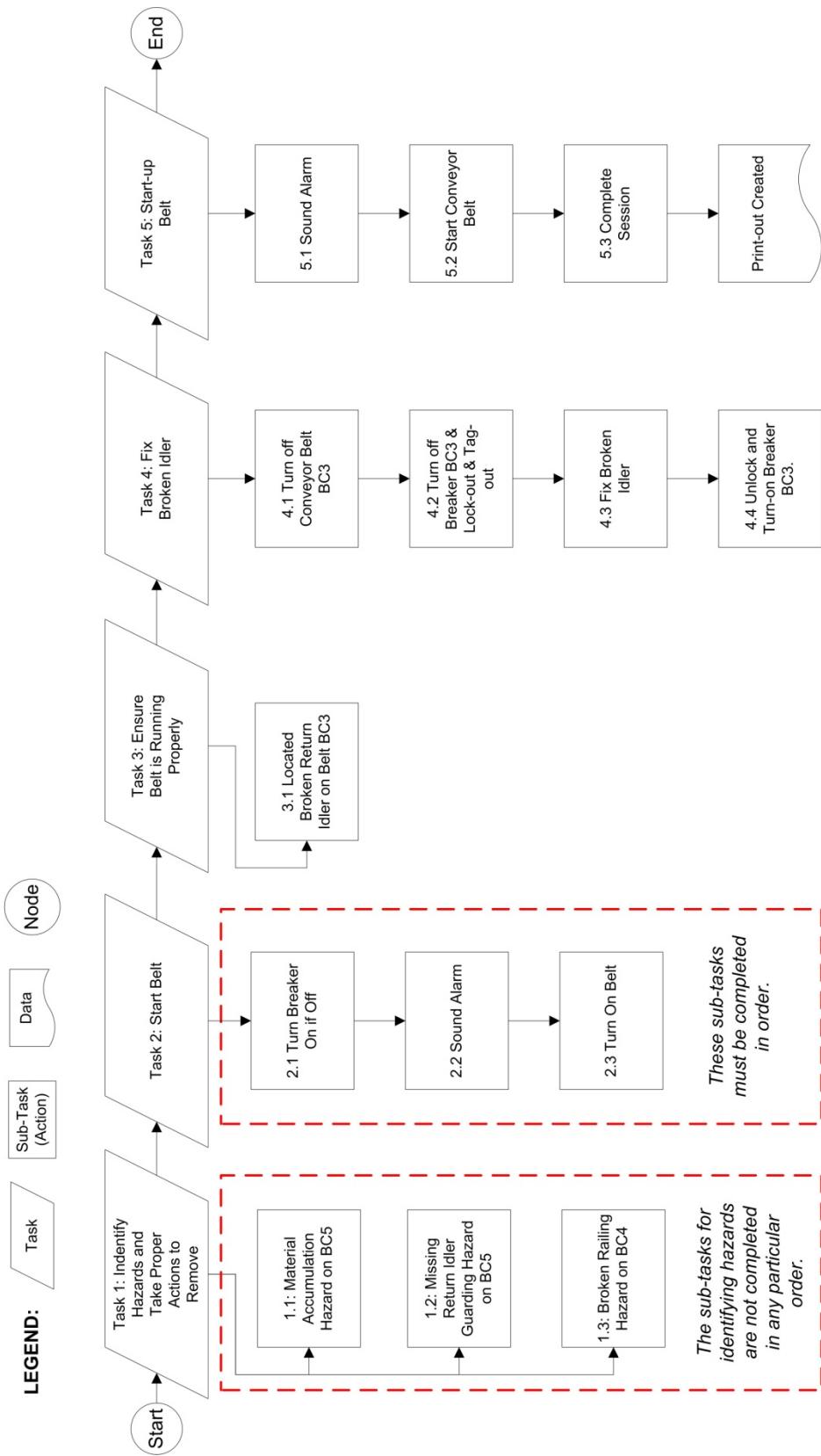


Figure 3-15: Task Overview Flowchart

The sub-tasks for task 1 include 1.1: Material Accumulation Hazard on BC5, 1.2: Missing Return Idler Guarding Hazard on BC5, and 1.3: Broken Railing Hazard on BC4. Each of these sub-tasks is designed with a corresponding flowchart that includes the questions that are asked to the user when the hazard is identified, the possible answers for each question, and the animations or following programmatic functions that occur when each answer is selected.

Figure 3-16 maps out the processes for sub-task 1.1: Material Accumulation Hazard on BC5. It shows that when the user selects the hazard the first question that is asked is 1.1.1. What is wrong with this? Three possible answers are shown to the user. If the user selects A or C, both of which are incorrect answers, the flowchart shows the dialog response that will be given along with an animation that would show the consequences for not taking the proper actions. If the user selects B as the answer, they are given a point for selected the correct answer. After answering question 1.1.1 the user is then presented with question 1.1.2 How would you fix this hazard? Similarly, the user chooses an answer, if A or B are chosen a message appears as to why it is the wrong answer and an animation is shown to the user, if the correct answer (C) is chosen, the user receives the given points and the session continues.

Figure 3-17 shows the flow chart process mapped for sub-task 1.2 and Figure 3-18 shows the flowchart process mapped for sub-task 1.3. These sub-tasks follow a similar method of mapping processes and interactions as sub-task 1.1.

Task 1: Identify Hazards: Subtask 1.1

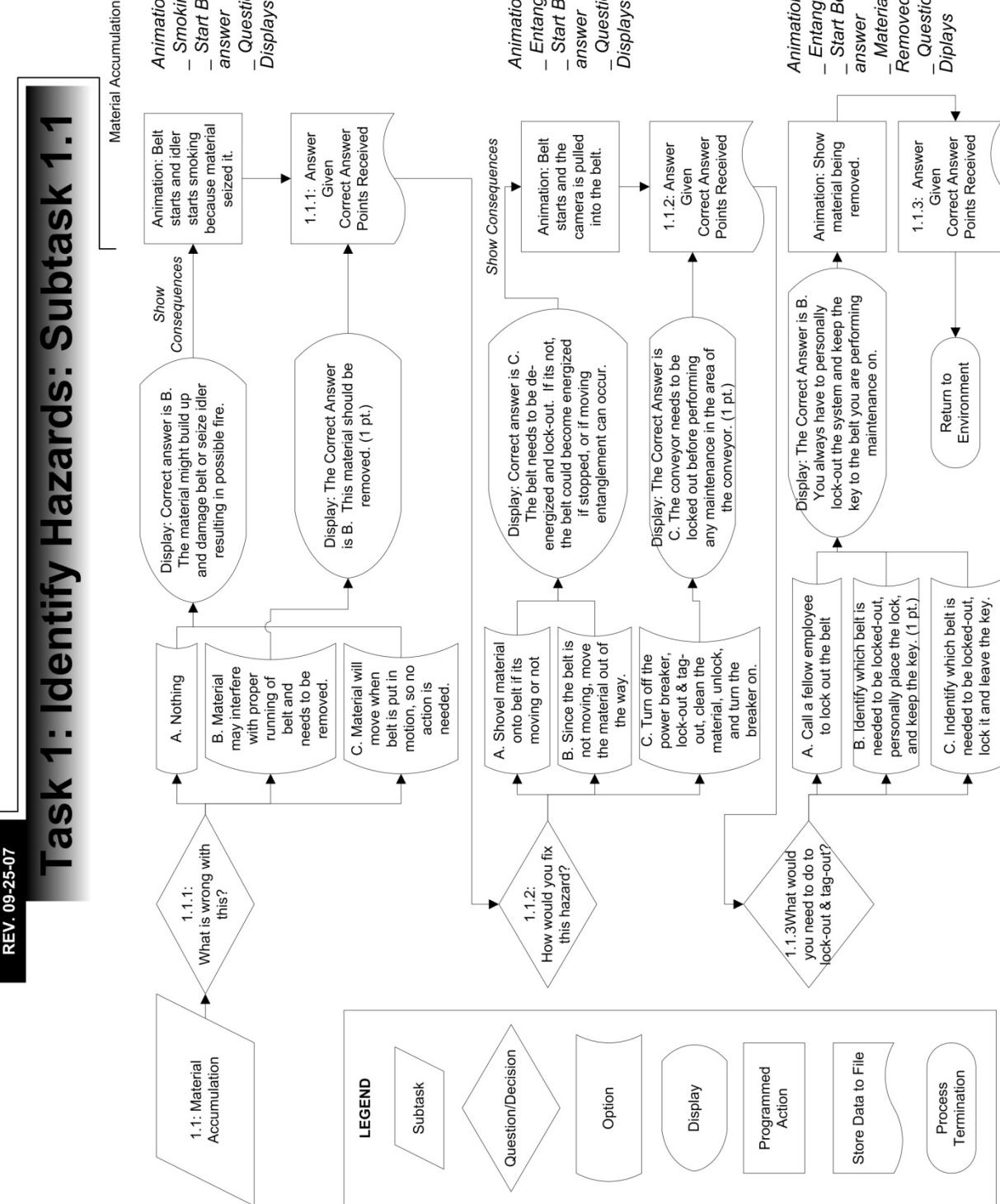


Figure 3-16: Sub-task 1.1 Flowchart

Task 1: Identify Hazards: Subtask 1.2

Missing Idler Guarding

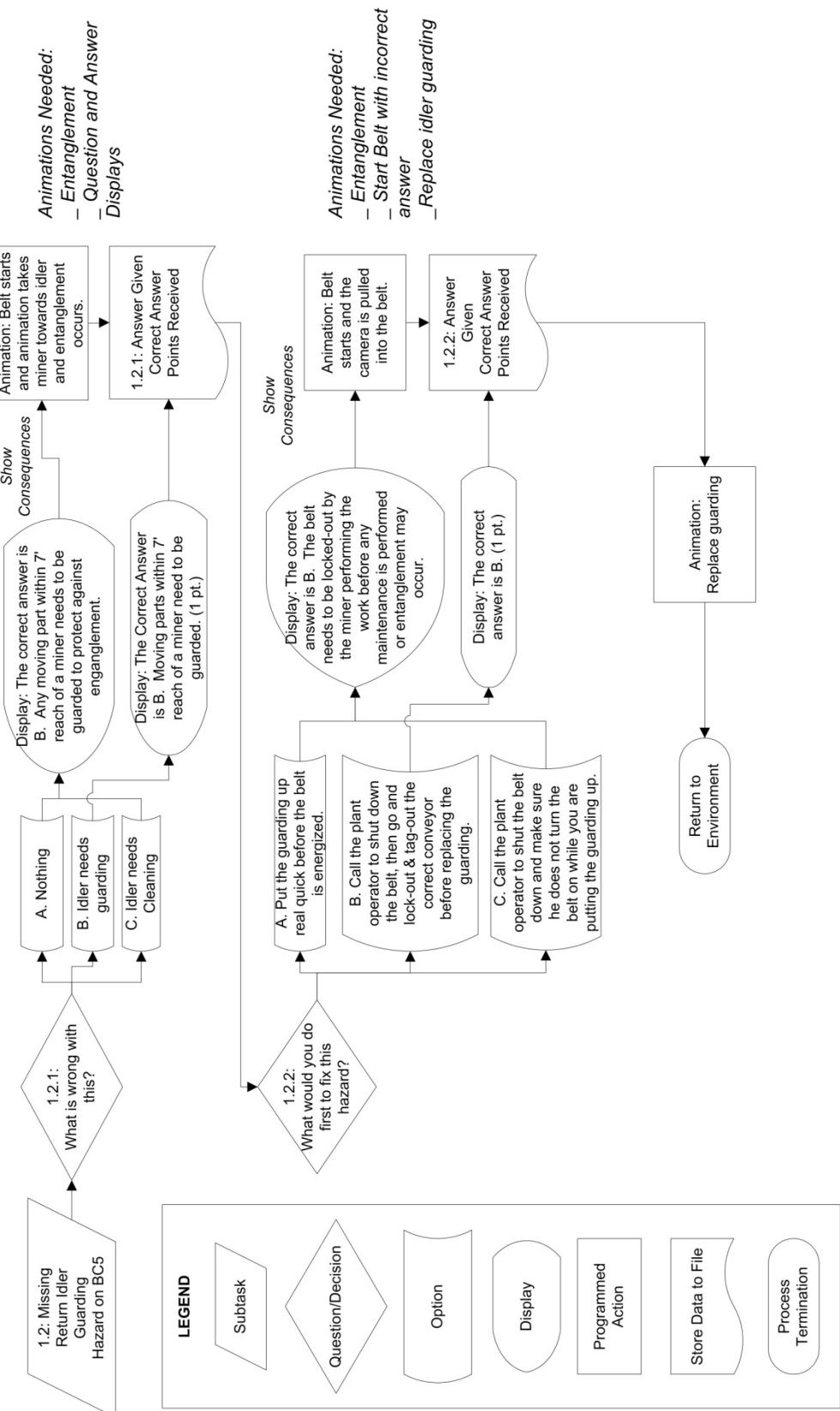


Figure 3-17: Sub-task 1.2 Flowchart

Task 1: Identify Hazards: Sub-task 1.3

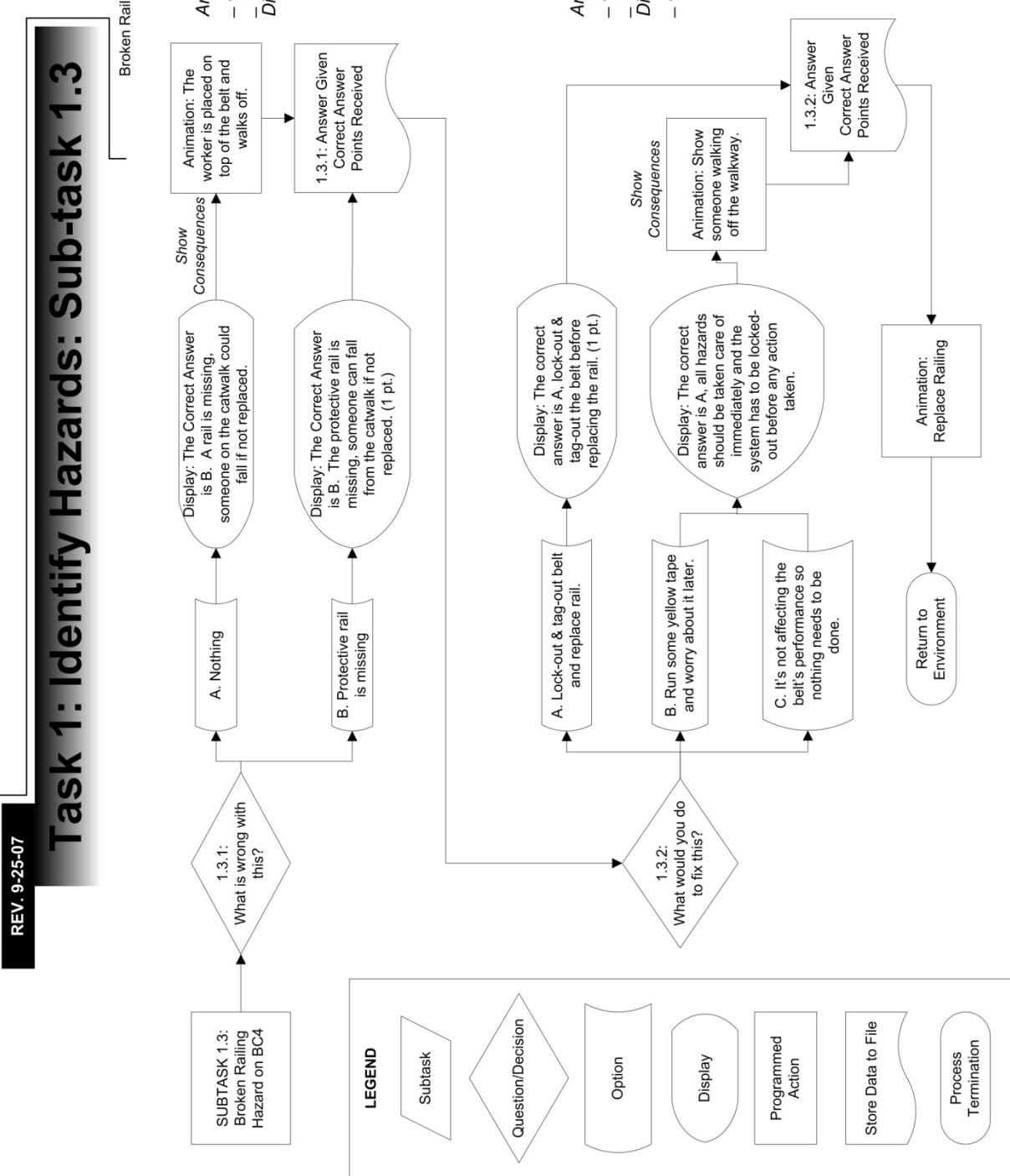


Figure 3-18: Sub-task 1.3 Flowchart

Task 2: Start Belt has three sub-tasks related to it, 2.1 Turn Breaker On if Off, 2.2 Sound Alarm, and 2.3 Turn on Belt. The processes for Task 2 are detailed in the flowchart shown in Figure 3-19. To complete this task the user needs to ensure that the breaker is on. If the breaker is in the off position the user clicks on the breaker and then an animation is needed to change to the lever to the on position. This also changes a system variable to signal the power is on. If the breaker was already on, nothing needs to be done. The next step in completing the process is to sound the alarm in the control room. To do this the user clicks the alarm and then a noise is sounded. Once the alarm is sounded the user is able to turn the belt on. When this is done, the light needs to change colors on the breaker and in the control room as well as the lever being moved to the on position in the control room. An alternate to turning the belts on is to ensure the power is on at the breaker and then calling into the control room to have the belt turned on. Both ways are adequate depending upon how the facility is set up to work. The simulation allows for both methods at various times during the module.

Task 3: Ensure Belt is Running Properly only has one sub-task and that is to locate the broken/smoking idler. This does not require any interaction besides visually locating the problem. Once this is found, the user can proceed to completing Task 4: Fix Broken Idler and Task 5: Start-up Belt. The details for task 4 & 5 are included in the flowchart in Figure 3-20.

In order to fix the broken idler the belt BC3 needs to be turned off. The flowchart shows the different actions that may be taken if the user does not follow the proper procedure. The breaker needs to be turned off before the belt is turned off. When the breaker is clicked to turn off the power, the system checks for the state of the belt to see if it is running or shut off. If the belt is still running an animation of a breaker fire is shown as the potential for the breaker exploding is high if it is shut off when the belt is running. If the belt is turned off nothing happens and the breaker lever is moved to the off position. The user is then required to lock-out and take the key of the breaker. Once this is completed the next proper step is to remove the idler guarding. At this point the system checks for the state of the breaker. If the user should try to remove the idler guarding when the breaker is not in the off position and locked out an animation of entanglement is shown with a description of what happened and the session is restart at the beginning of the process. If the state of the environment is correct, the user is allowed to remove the idler guarding. They can then change the idler and replace the idler guarding. If the idler guarding is not put back in place and the belt is turned on a similar message of possible entanglement is shown. Also when trying to start the belt the system checks to make sure that the lock is removed and the breaker is turned on and the alarm is sound. The flowcharts ensure that the proper procedures are followed as well as allows for programming for any mistakes that are possible within completing the procedure.

Task 2: Start-up Belt

Start-up belt procedures

LEGEND:

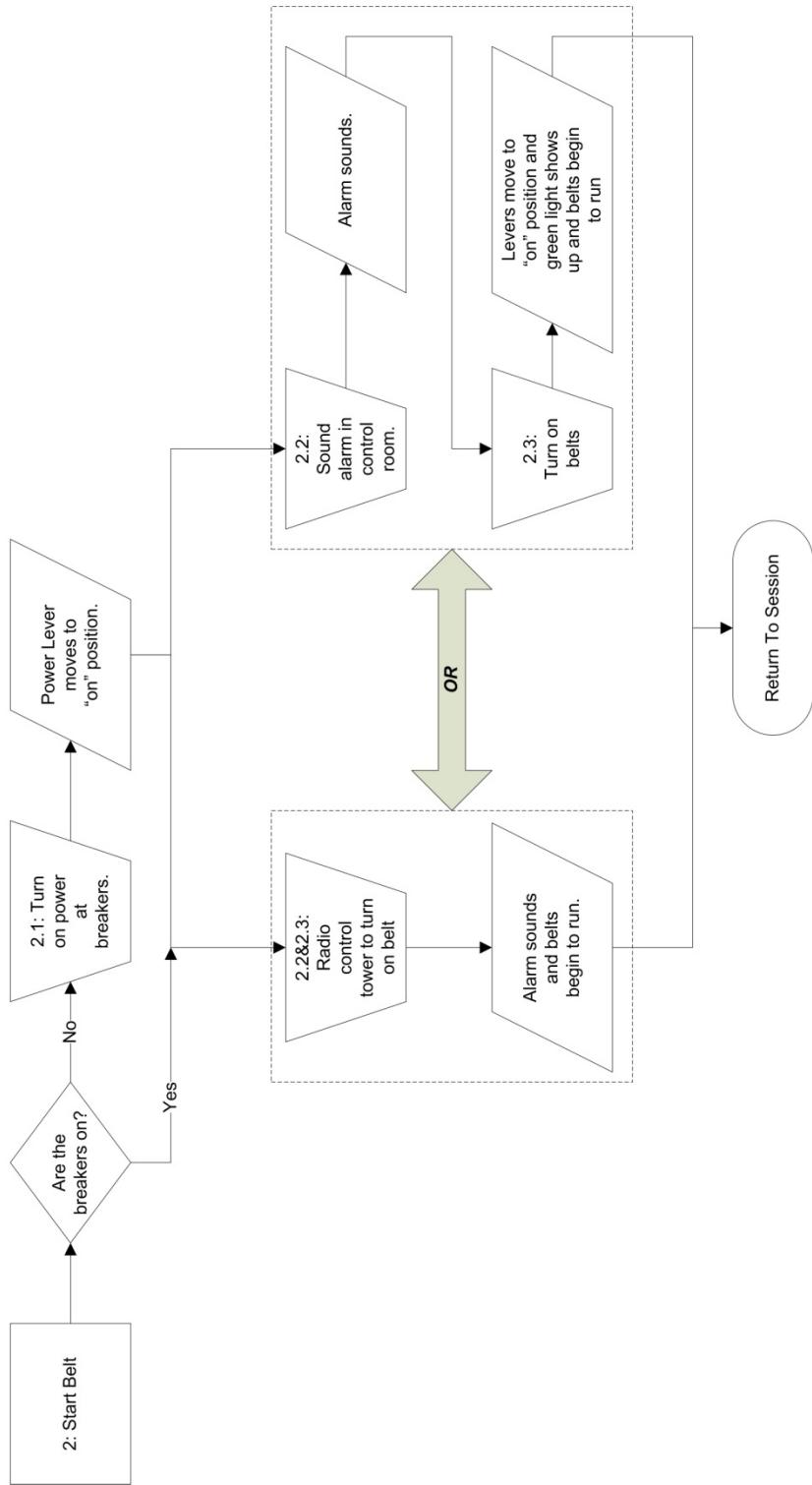
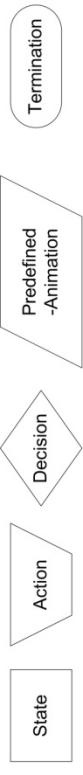


Figure 3-19: Task 2 Flowchart

Task 4 & 5

LEGEND:

Fix Idler and Start-up Belt

 State
 Action
 Decision
 Predefined Animation

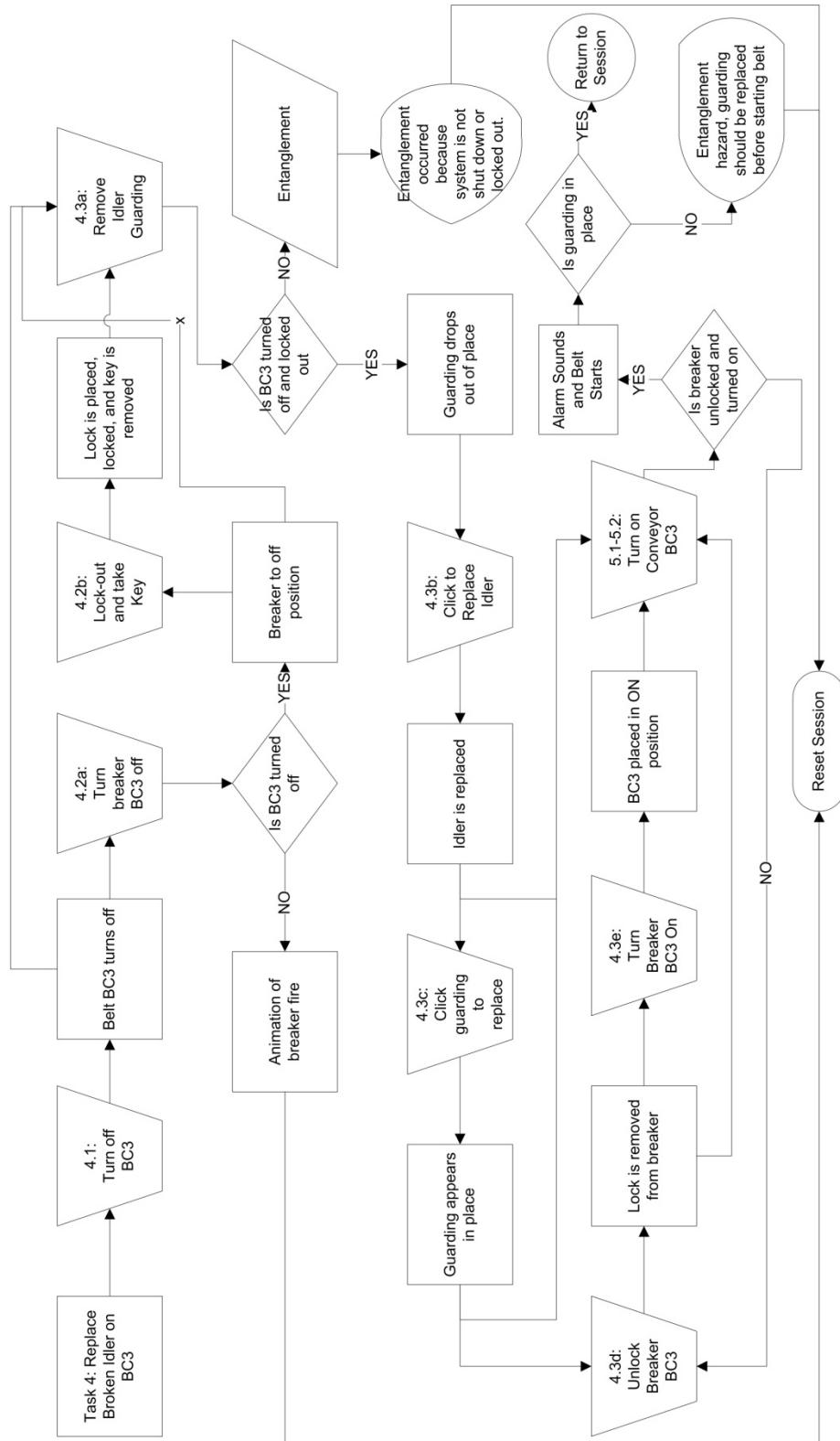
 Node
 Termination


Figure 3-20: Task 4 & 5 Flowchart

4. An Evaluation Scheme for Two Safety Training Applications

“AN EVALUATION SCHEME FOR TWO SAFETY TRAINING APPLICATIONS”

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ABSTRACT: Safety research at Virginia Tech has developed two applications to enhance the mining industry’s training methods. The first application is a virtual reality training application that introduces the information to the user through a 3d model walkthrough of a conveyor belt and then tests, through task-based training, the knowledge the user has gained. The second application, a Digital Safety Manual, is designed to allow users to visualize and manipulate safety information using a non-linear interactive multimedia application.

This paper describes the details of an evaluations scheme to test the usability and effectiveness of the two applications through novice and expert input. This involved a series of site visits to different companies and potential clients to review the information being presented and to get industry feedback. After the system was revised a series of usability studies and evaluations were conducted using novice and expert users to ensure that the applications are user friendly. The feedback and evaluations were then used to revise the applications and ultimately offer a product that would better fit the needs of the industry.

Keywords: training, program, conveyor belt, evaluation, feedback

4.1. Introduction

Working around conveyor belts is inherently dangerous and causes multiple fatalities and a high cost to the industry each year. Lucas et. al. (2007, 2008) studied 534 fatalities between 1995 and 2007 in the United States surface mining industry of which 50 were related to conveyor belts. Each of these fatalities costs the industry \$1.9 million (Goldbeck 2003) (2007 equivalent value as per inflation recorded at U.S. Bureau of Labor Statistics from 1986 study). Current training practices in the industry rely predominantly on a passive approach of using slide-shows and videos in a lecture setting for training, yet the accident rate remains high. With this high annual accident rate there is a need for alternative training methods to complement current practices. New methods are also needed to train large quantities of younger miners as the current workforce is aging and nearing retirement.

The use of visualization tools for improved safety training around conveyor belts is being investigated at Virginia Tech under several research project funded by the National Institute for Occupational Safety and Health (NIOSH) and the Virginia Tech Center for Innovation in Construction Safety and Health (CICSH). Two prototype applications have been developed aid in the training of miners who work around surface conveyor belts. The first is a virtual reality application that was developed to allow the user to walk through a virtual environment of a conveyor belt where information is presented about maintenance issues, safety procedures, and hazard recognition (Lucas et.al. 2007, 2008). The user is then tested on their gain of that knowledge through task-based training (Lucas and Thabet 2007, 2008). The second application is a Digital Safety Manual (DSM); an interactive multimedia application that comprises

various categories of conveyor safety information and allows the user to visualize and manipulate information using a non-linear approach (Worlikar 2008).

Compared to conventional training methods, it is the authors' hypothesis that both applications provide better cognitive learning experiences as they utilize interactive non-linear approaches to training. This allows trainees to better recognize hazards and preventive measures associated with conveyor belts and to better understand the economical impact of accidents on their organizations and the mining industry.

Evaluation is conducted to answer either of the two questions: whether training objectives were achieved i.e. learning issues, and whether accomplishment of those objectives results in enhanced performance on the job i.e. transfer issues (Kraiger 1993). This paper describes an evaluation scheme intended to test the author's hypothesis and verify that the interactive non-linear learning provided by the applications can enhance current industry training methods through learning retention and knowledge transfer on the job site. Other objectives of the evaluation scheme include:

1. Insuring that the information content and training scenarios are comprehensive, realistic, and consistent with industry training standards.
2. Improving the design of the graphical user interface (GUI).
3. Minimize programming and usability problems.

The evaluation scheme was divided into three phases. Phase one involves a usability evaluation that consists of unstructured industry feedback and interface evaluation are both subjective in nature and based on person opinion. The goal of the usability evaluation is to provide feedback in development, supporting an iterative development process (Carroll and Rosson 1985; Gould and Lewis 1985). The usability evaluation phase will allow for verifying the content of the application, get input on the GUI, and fix programming bugs.

The subjective analysis phase involved a subjective analysis to document individuals' opinions on their perceptions of the usefulness of the applications as a training tool. If it is determined that the proposed training application could be beneficial a more developed application is used for the performance based evaluation phase.

The performance based evaluation phase will aim at testing the hypothesis to show a learning improvement gained from the application versus conventional training methods. This will be an objective analytical comparison.

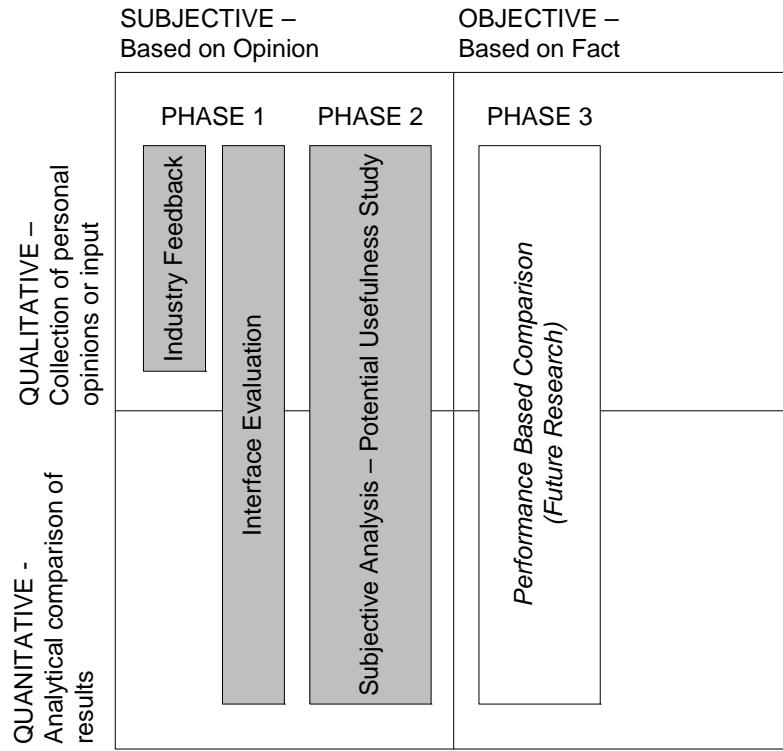


Figure 4-1: Evaluation phases

The process of each phase is discussed in more detail later in this paper with a summary of the quantified results for the usability evaluation and subjective analysis phases.

4.2. Current Industry Training Requirements and Practices

In the United States, the Mine Safety and Health Administration (MSHA) is the governing entity for policies within the mining industry. As part of their Title 30 Code of Federal Regulations (CFR) Part 46, each mining facility is to develop and implement a written training plan that includes programs for new miners, newly hired experienced miners, new tasks, annual refreshers, and site-specific hazard awareness training. Within this plan, new miners are required to complete 24 hours of training, four of which are required before the miner starts any work, the rest within the first sixty days of work. Also within the plan are requirements for new task training and requirements for an 8 hour refresher course.

Besides MSHA's requirements, some literature review and research was performed to determine what to include in a successful training plan. Goldbeck (2003) proposes four training areas for effective training programs which include: (1) general safety practices of using safety equipment, (2) guidance for performing maintenance tasks and inspection hazards, (3) information about conveyor and belt conditions, and (4) procedures for belt training or tracking.

Lastly, interviews were conducted with the industry to see how various companies fulfilled and exceeded MSHA's training requirements, see Table 4-1. Typically, the weekly safety meetings cover any new site specific hazards. The informal safety talks consist of discussing near misses and prevention whenever safety staff thinks it's relevant. The rewards and incentive programs are of both monetary reward and activity rewards and are intended to encourage individuals and teams to continuously practice safety.

| Safety Training Practices | Company 1 | Company 2 | Company 3 |
|---|-----------|-----------|-----------|
| MSHA Required Training (new employee & refresher) | √ | √ | √ |
| Weekly safety meetings | √ | √ | √ |
| Rewards/incentive programs | √ | √ | |
| Informal safety talks | | √ | |

Table 4-1: Current industry training programs

4.3. Training Applications Development

The first step of development for both of the proposed applications was background research that would give a databank of information from which to draw while developing the proposed applications. This information was gathered through literature review, on-site visits, and interviews with industry professionals. Required areas of training were identified and the information was classified into four safety categories: belt conveyors, possible hazards, preventive measures, and awareness & statistics. The two prototype applications were then developed.

4.3.1. Virtual Reality Application Development

The Virtual reality application consists of two modules; an instructional based module (Lucas, et.al. 2007, 2008), is used to train the user. The second module is a task-based module (Lucas and Thabet, 2007) where the user is tested on the knowledge that they were given in the first module. Shown in Figure 4-2, the 3D model of the belt conveyor virtual environment was developed using AutoCAD and 3D StudioMAX (Autodesk, 2008). The model was then imported into the DeepCreator™ (Right Hemisphere, 2008) where animations were added and other information programmed. From the created environment the two modules were then created. LISP programming language was used to create scenarios and track user decisions and scores.



Figure 4-2: Station within instructional-based module – a hot-point is clicked and information in form of animation and text caption is presented

The instructional-based module contains an automated walk-through that takes the user from station to station where they are given a series of hot-points that contain safety information. Lucas, et.al. (2007, 2008) describe the development of the instructional based module in detail. The task-based module is a self guided session where the user is assigned tasks that need to be completed. These include hazard recognition (a broken rail, missing guarding, and material accumulation), proper start-up procedures, and proper lock-out and tag-out procedures before performing maintenance. The user is then scored on the completed tasks and the tally can then be used to track an employee's performance and improvement. Lucas and Thabet (2007) describe the development of the task-based module in detail with sample implementation and coding that was developed in order to track the performance.

4.3.2. Digital Safety Manual (DSM) Development

The framework for the Digital Safety Manual (Worlikar, 2008) is based on a 3D matrix to display the four main categories of information; *Belt Conveyors, Possible Hazards, Preventive Measures, and Awareness & Statistics*. This 3D matrix uses a 4 x 4 grid to store the content related to each of the four categories and provides the users the necessary navigational tools to explore the graphical database. Each square tile in this grid allows access to information and the four diagonal tiles serve as the main navigational nodes to move back and forth in the matrix between the groups of information.

Each of these four navigational nodes brings up a unique combination of information based on the user's selection during the exploration of the DSM. This information is presented as color-coded 3D bars of varying heights where the height symbolizes the amount and type of information that it contains (Figure 4-3). The color-coding is used to provide the visual link between the related information when it appears at different points in time on the surface of the grid. The DSM allows for non-linear interaction and the flexibility of taking unique paths to retrieve safety information. While taking a non-linear approach, the users are also provided with a tool to locate themselves in the hierarchy of the DSM's information organization and to help in understanding relationship between the different categories. The matrix provides a tool to zoom in on one specific piece of information and highlight all the related information from the database at a given point in time irrespective of the categories.

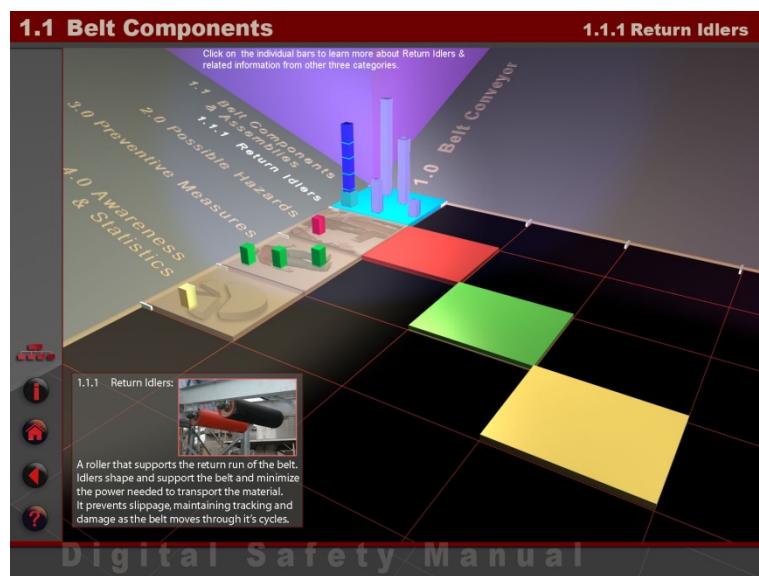


Figure 4-3: Screenshot from the DSM showing navigation through the ‘Belt Conveyor’ category

4.4. Evaluation Scheme

In order to ensure that the two developed applications fit industry needs and to offer an application that is easy to use and understand the following feedback and evaluation scheme was developed (Figure 4-4). The evaluation scheme is divided into three major phases; a usability evaluation phase, a subjective analysis phase, and a performance comparison phase. After each phase the two applications were revised based on the comments received. The first phase focused on the usability evaluation of the two applications and is further sub-divided into two parts, industry feedback (for information review) and interface evaluations (Figure 4-5). The industry feedback part of the application evaluation (Figure 4-5A) was unstructured and was performed by conducting initial on site meetings with various industry professionals to gather their reviews on the completeness and appropriateness of the information that is presented in each of the two applications. During this unstructured industry feedback session, industry professionals were given a demonstration of each application and their comments were recorded and documented to revise the prototype to its next iteration.

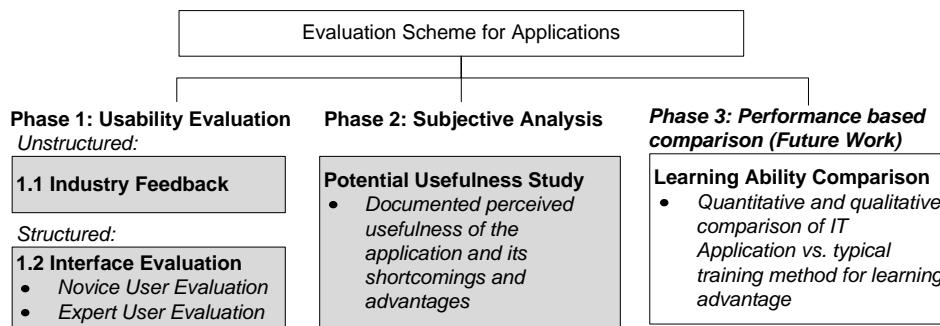


Figure 4-4: Evaluation Scheme

The revised versions of the two applications were used for the second part of the usability evaluation, the interface evaluations (Figure 4-5B). The interface evaluations were conducted using two test groups; novice users, mostly students with various backgrounds and no prior experience with conveyor belts or mining, and industry experts or professionals who have experience with conveyor belts, mining, and are aware of conveyor belt environments. This evaluation aimed at assessing the usability of the GUI of both applications.

PHASE 1: Usability Evaluation

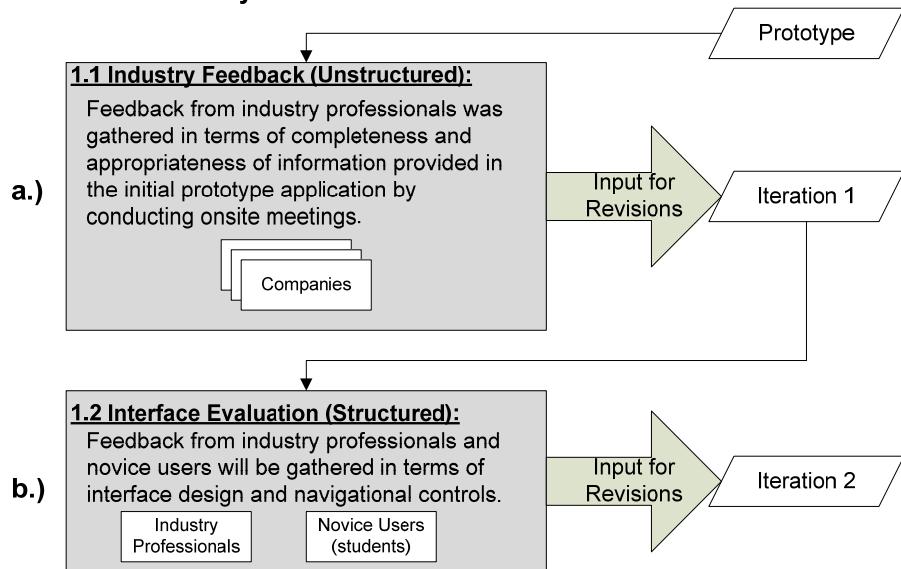


Figure 4-5: Details of Usability Evaluation (Phase 1)

Both groups were asked to complete an evaluation questionnaire where each participant rates their agreement with statements dealing with clarity of instructions, navigation of each application, and presentation of information. Once the findings of the questionnaires were reviewed, revisions to the applications were made and implemented in a new iteration for the subjective analysis phase.

The subjective analysis phase (Figure 4-6) used both novice and experienced subjects to complete a subjective survey designed to identify the advantages and shortcomings of using the proposed training application versus typical training methods. The first group consisting of novice users was given a sample of a typical slide show presentation, videos, and written documents to examine and review. They were then presented a demo of the two applications and then were allowed to test the applications. Upon finishing examination of the typical material and the proposed application the participants filled out a subjective survey to document their perceptions. Experienced mining professionals were asked to complete the same survey based on their experience with training methods used in their facility compared to the proposed applications.

PHASE 2: Subjective Analysis

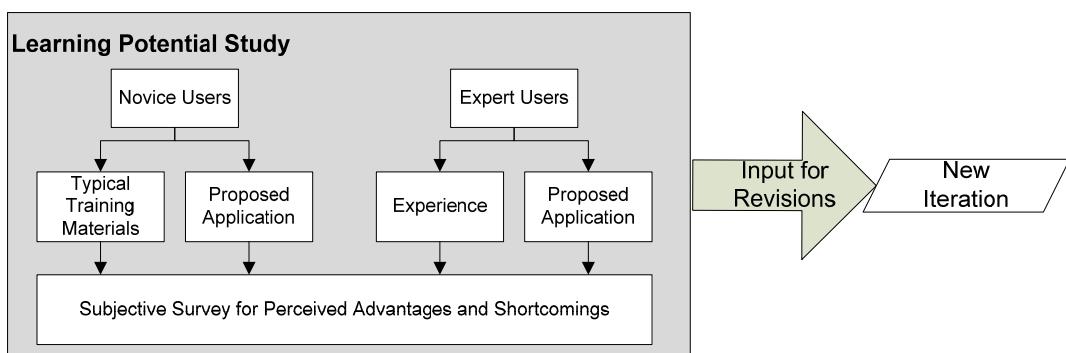


Figure 4-6: Details of Subjective Analysis Phase

Once the data from the subjective analysis phase was collected and reviewed, it was used to develop the new (second) iteration of the applications to be used in the performance based comparison phase of the evaluation (future research). This two-parts assessment phase will validate the effectiveness and efficiency of the training applications. Two groups of users (non-experienced miners) will participate, one in typical training methods of paper manuals, slideshows, and similar media, and the second in using the developed applications (Figure 4-7). Both groups, once they complete their designated training will participate in a general knowledge quiz consisting of questions pertaining to safe working practices within the mining environment. The results will then be compared.

PHASE 3: Performance Based Comparison (Future Work)

Learning Ability Comparison

One group of users will be given paper manual, binders, and photographs and other group will go through this application.

General knowledge test from both the groups will be compared to evaluate the effectiveness of the new application.

Group 1 – traditional training methods

Group 2 – developed IT training application

Quantitative Comparison

Novice users (inexperienced miners) will be used for this phase of the evaluation scheme. This will allow for a pure comparison of results. The same quiz will be given to both groups.

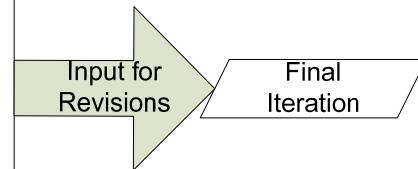


Figure 4-7: Details of Performance Based Comparison Phase

4.5. Virtual Reality Application: Evaluation Results

The virtual reality application followed the scheme laid out above. There were a series of industry meetings in order to check the quality and content of the information being presented followed by interface studies and a learning ability evaluation. Four meetings were held with a total of eleven professionals from the three companies. The attendees were given questions to focus discussion and encouraged to interrupt to make comments. Their comments were documented and compiled and were used in making the revisions of the application. From the meeting, 37 comments were documented for the instructional-based session, twelve of them dealt with existing information and twenty pertained to adding or revising safety information. The task-based session received 33 comments; 13 were revisions and the rest dealt with new information. After each meeting the application was revised to incorporate the new comments received. Once all meetings were complete build 2 of the application was created and used for the next phase of the evaluation scheme.

During the interface evaluation (Phase 1) 13 participants were asked to use the virtual reality application and answer a questionnaire that was broken into four sections: (1) demographics, (2) instructional-based module, (3) task-based module, and (4) general comments. The users were asked to rate their agreement on statements that deal with navigation controls, instructions, information clarity and method of presentation for both of the modules.

The participant's average age was 28, two were experienced miners, and one had previously participated in virtual reality training. For the instructional-based module the users were asked to rate their agreement with questions dealing with instructions, navigational controls, clarity of information presented, and graphics used. The average results for their agreement on a 1-5 scale (5 strongly agree) were as follows: *Instructions* (4.15), *Navigational Controls* (4.46), *Clarity of Information Presented* (4.44), and *Graphics Used* (4.58). For the task-based module the users were asked similar questions dealing with instructions, controls, task instructions, clarity of information presented, and ease of completing tasks. The results were as follows: *Instructions* (3.23), *Controls* (3.42), *Task Instructions* (3.62), *Clarity of Information Presented* (4.03), and *Ease of Completing Tasks* (4.00).

The problems identified within the task-based session were clarity of instructions and navigational controls. Since the task-based session used mouse and keyboard controls, individuals were having difficulties getting accustomed to navigating the environment. If older miners who were not computer literate were required to participate in this training the navigational controls would be a barrier to learning. To prevent these controls from becoming a barrier to individuals who are not computer literate, alternative navigation methods with touch screen, third person navigation, joystick, or game controller controls need to be implemented and explored. A module would also have to be developed to train the trainee on the navigation and test their ability to navigate and complete tasks before testing them on their knowledge to minimize the effect of the navigational controls on the final results of the task-based session.

Eight participants were used in the subjective analysis phase for the virtual reality application. Questions on the subjective analysis survey involved perceived advantages and shortcomings of the proposed application and typical training methods and which was perceived to be a more effective method of learning. 63% of the participants agreed that the proposed application is more effective because of the reasons: (1) the user is learning within an environment that represents real life, (2) that the prototype application provided detail steps for completing processes and then tests the user's ability in completing the processes, and (3) that the prototype application allows for an employee to interact with the environment and view consequences to actions without the result of injury that would occur on the job if the user did not participate in the training. The remaining 37% agreed that the first person interaction within the digital environment is beneficial; however, they thought the personal interaction that exist and allows for a training professional with a wealth of knowledge to answer questions is more effective. They also commented that the miners currently in the industry are more likely to be computer illiterate and that traditional methods of training cover a wider array of training methods that allow for overcoming various learning disabilities of illiteracy and reading comprehension problems.

4.6. DSM Application: Evaluation Results

The DSM prototype follows the evaluation scheme described above in section 4. The concept of the DSM was presented to industry professionals through a series of site visits to the three companies to check its applicability and the accuracy of the information presented. These visits were followed by interface evaluations using novice and experienced subjects and subjective analysis to measure the potential of the DSM concept as a new approach to train workforce in the mining industry.

Industry feedback for information review and interface usability evaluations was conducted simultaneously using the industry experts. There was a range of personnel from different departments

including safety engineers, superintendents, and maintenance personnel among others who were involved in this phase of the information review and interface usability evaluations. In the beginning, demonstrations of the application were given to all the attendees and they were encouraged to ask questions and give feedback concerning information presented during the demonstration. Attendees were then given 20 to 30 minutes to individually explore the DSM. The process was monitored by the research team so that concerns were recorded and resolved, and used in making the revisions of the application. After this exploration of the application by the attendees, all the users completed a questionnaire. This questionnaire was divided into four parts; demographics, navigational issues, design/layout issues, general issues.

During the interface usability evaluations, novice users were provided a brief introduction and a demonstration of the application before they used the application. This process was monitored by the research team to resolve any questions that users were having while navigating through the application. Another questionnaire was completed by each user and all comments and suggestions were noted and included in the next version of the DSM prototype.

The results from the interface usability evaluations helped in determining that instructions for the navigation of the DSM needed to be more clear and accessible throughout the application. The results also indicated that the color-coding used in the current version needed to be more evident throughout the DSM and needed to be included as part of the instructions. The results also helped to determine that some users had problems drawing the link between the categories of information presented on each screen and that it related to the two active categories (column and row) being examined.

The last section of the usability questionnaire asked general questions pertaining to the overall organization of the DSM, the effectiveness of the DSM's organization, and if the DSM exploration is an interesting and engaging experience. General questions pertaining to best features and shortcomings of the DSM, the applicability of the DSM concept in the construction industry, and general comments were also included in the questionnaire. Some of the features of the DSM noted were how it allowed the presentation of information, its use of videos and pictures in a multimedia environment, and its potential as a learning tool. The DSM shortcomings documented included barriers to user friendliness, its lack of tracking system to record user performance, and that it has no defined structure. All these comments were analyzed and used to develop the next iteration of the DSM prototype.

Phase 2 measured the potential of the DSM concept. Novice users examined typical training material and then were presented with the proposed DSM application. Each user completed a questionnaire subjectively comparing the advantages and disadvantages of the typical training methods and the proposed application. Industry experts were also presented with the DSM and were asked to complete the subjective questionnaire comparing the proposed application to training methods used at their facilities.

Feedback received from the subjective analysis was largely positive. Almost 2/3 of the comments received from the participants indicated that the DSM has more advantages over the traditional training method. Comments from the remaining participants had concerns about the incompleteness of the DSM as time of evaluation and that when fully implemented were not sure of its potential.

Overall, 79% of the participants commented that there are more benefits in learning through methods used in the DSM than typical training methods. Few shortcomings were documented by the remaining 21% of

participants. One main concern documented was the years of experience an instructor has is valuable and cannot be replaced by computer-based applications. 69% of the participants said the DSM is an effective way to learn training material if implemented fully whereas 31% said that even though the DSM has many advantages it can be used as a supplementary training aid with the conventional training method typically in use.

When asked about the benefits and the shortcomings of the DSM, comments received from the industry experts were equal. 75% of the comments received indicated that the DSM is an effective and interesting way to learn the training material whereas the remaining 25% of advocated the benefits of the typical training method.

4.7. Discussion

After preliminary research and initial industry discussions, it is believed that these applications would be a valuable addition to augment current training methods. The major concern of the current versions presented is user friendliness and usability, however many comments were received on how this can be improved. The final phase of the evaluation process still needs to be conducted. With the first two phases of the evaluation scheme completed and results analyzed, there seems to be considerable industry interest to further develop the applications and implement them into practice. If this were to happen, extensive further evaluation will have to be performed within the mining industry itself to test effectiveness of the training applications and their usability within the intended user group. Fully functional applications would also have to be integrated into training curricula in select facilities to allow for supervisors to record perceived effectiveness of task performance. Only then can the true effectiveness of the use of these applications be proved.

There is industry interest and belief that these applications, if further developed to fully functional application, would be a valuable addition to the current training methods. This helps support the hypothesis that these applications can be effective in learning and add to the typical training methods currently in use within the industry.

4.8. Acknowledgements

This research is being developed with support of a NIOSH Grant # 1 R01 OH008716-01 Virtual Environment (VE) Applications to Improve Mining Health and Safety Training. The research is also supported by a mini grant from the Virginia Tech Center for Innovation in Construction Safety and Health (CICSH). The views expressed in this paper are those of the authors and do not necessarily reflect those of NIOSH or CICSH.

5. Limitations and Findings

5.1. Limitations of research conducted

The belief before conducting any evaluation based on literature review of past research projects is that the cognitive learning environment created by first person virtual reality interaction offers a more effective method of training as compared to typical training methods that are passive in nature. When a person is able to learn in a cognitive environment they are recalling personal experiences from their memory to solve problems. In order to test this hypothesis an evaluation scheme has been developed, as described in chapter 4, to determine whether a VR based application is more effective.

In proving this hypothesis it has to be noted that there are limitations to this research. The main limitation is that only a prototype has been developed. The prototype was used for the studies conducted to insure accuracy and adequacy of information presented. The prototype would require further development and substantial formal evaluations before industry use. The prototype was also used for the training methods comparison. Because a prototype is used, care is given to make sure that the prototype is an accurate depiction of what a final application can offer. A final application would require further development and testing as described in chapter 6. As reflected in some received comments, navigational controls and the difficulty in their use are a limitation on the success of the studies. Studies for improvement of such controls are considered beyond the scope of the conducted research and technologies used. Suggestions for improving controls are discussed in chapter 6 under future research.

Another limitation to the research is that only individuals who would be considered “younger” miners were used within the discussed studies. The studies did not take a universal design approach by finding the classification of miners who need the most improved training techniques and cater the design of the prototype to that group with the assumption that it would fit the needs of all other classification of miners.

5.2. Evaluation Findings

5.2.1. Phase 1.1 – Industry Feedback

Phase 1.1 consisted of a qualitative subject study that involved collecting the suggestions and comments of industry professionals during a series of meetings. The aim of this phase of the evaluation process was to get preliminary industry buy-in, determine how a VR safety training program could fit the needs of the industry within their current training practices, and determine accuracy and completeness of the presented information.

Four meetings were conducted with three different companies and 11 attendants. The 11 professionals classified their employment position as follows:

Safety Professionals = 3

Safety Education = 3

Engineers = 1

Superintendants/Foreman/Maintenance = 4

The discussion was focused around the following questions for the Instructional Based module:

1. Is the information presented in this session reasonable?
2. Is there any information that can be added?
3. Is anything graphically misrepresented?
4. Was any of the presented information difficult to understand?

5. Would this fit your training needs and how can it be improved to better supplement your training needs?
6. Can you see a program like this being a valuable addition to your current training program?
7. General comments and suggestions.

The discussion was focused around the following questions for the Task-based Session:

1. Is the scenario of the session practical for something an employee might have to perform during training?
2. Are the questions and answers reasonable?
3. If an incorrect answer is given, is the consequence shown adequate? How can it be improved?
4. Is the process for starting a conveyor belt accurate?
5. Are any processes or actions misrepresented?
6. Was any information difficult to understand?
7. Do you have any suggestions of addition task-based sessions?

There were a total of 62 comments received during Phase 1 of the evaluation process. 34 comments were documents for the instruction-based module (Table 5-1). 12 of the 34 comments dealt with editing existing information that was presented, the remaining were suggestions for additions to the application. 28 comments were documented for the task-based module (Table 5-2). 13 of the 28 were concerning revisions and the rest were suggestions for new information including future scenarios.

Table 5-1: Findings of Phase 1.1 – Industry Feedback Sessions for Instructional-based Module

Text in italics represents comments for future research that were not built into the prototype application used for the following phases of the evaluation process.

| Station | New or Existing | Comment | Meeting |
|---------|-----------------|--|---------|
| 1 | | Miner – Safety Information (Safety) | |
| | E | jewelry, rings to be added as part of miner work attire (Law in Virginia) | L1 |
| | N | Respiratory protection is sometimes desirable though not required by MSAH | L1 |
| 1 | | Entanglement (Hazard) | |
| | E | Animation of miner avatar becoming entangled within the environment | B1 |
| 1 | | Pinch Point (Hazard) | |
| | E | Move arrow to a lower height of an idler that would be an issue | L1 |
| 1 | | Recognizing Belt Damage (Safety) | |
| | E | Mention causes of belt damages in the text. | L1 |
| | E | Use picture of belt splicing and damages instead of sketch/diagram | L1 |
| 1 | | Inspect Handrails (Safety) | |
| | E | Max. Railing ht 42" & middle rail ht 21" from walking surface & vertical rail 8'-12' apart. | L1 |
| | E | Detailed pre-shift inspection- of Handrail, walkways, guarding, etc. does not happen. Only obvious issues are typically noticed. | L1 |
| | E | Failed weld joints is a major problem | L1 |

| | | | |
|---|---|---|----|
| 1 | | Falling Material (Hazard) | |
| | E | A miner should have constant awareness of the possibility of material falling from a conveyor belt. | B2 |
| 2 | | Falling From Heights (Safety) | |
| | N | Add scenario for fall protection in relation to using safety harness. | L1 |
| 2 | | Drive Motor (Component) | |
| | E | Drive motor guarding very important. Guards need to be bolted in place. | L1 |
| 2 | N | Harness needed to perform work (Safety) | |
| | N | Catwalk can only access one side of the conveyor belt. A harness is needed when working on any part of the conveyor not immediately accessible from the catwalk. | L1 |
| 3 | | Tail Pulley (Component) | |
| | E | Need guards above gravity take up at walkway level | L1 |
| 3 | | Missing Guarding (Safety) | |
| | N | Individual components needs to be guarded Guards need to be 4"-6" above ground to hose out the spillages underneath. | L1 |
| | E | Tail pulley guards with full grates a few inches from the bottom of the belt are not practical (use site pictures to update it) | L1 |
| 3 | | Impact Idler (Component) | |
| | N | Need to show guarding around the impact idler. | L1 |
| 4 | N | Cross-over (Component) | B1 |
| | N | -Need guarding at any exposed moving parts near the crossover catwalk | L1 |
| 4 | | Bend Pulley (Component) | |
| | N | Need guarding near catwalk & crossover | B2 |
| 4 | | Take-up Pulley (Component) | |
| | N | Need guards above gravity take up at walkway level | L1 |
| | N | Grease lines should run from the take-up pulley and bend pulley to a location on the catwalk or on the ground | B2 |
| 5 | | Lock-out & Tag-out (Safety) | |
| | N | In animations add names on the locks or tags to the locks.(tag out procedure) | L1 |
| | N | More than one lock can be placed on a breaker if more than one person is working on that piece of equipment. | L1 |
| | N | Only the person who placed the lock should remove the lock. Only the foreman (or project manager depending on plan) can remove someone's lock after contacting the person, or after thorough inspection to make sure that work is complete and that person is not within the area of the conveyor belt. | L1 |
| | N | Each worker is responsible for their locks; they need to be tagged or labeled with who is responsible for the lock. | L1 |
| 6 | N | Control Tower Alarm (Safety) | B1 |
| 6 | N | Start-up Procedures (Safety) | B1 |
| | | General comments and additions needed | |
| G | N | Grease lines can be used for lubricating bearings | B1 |
| G | N | Start-up Procedures – the breaker being turned on does not turn on the belt. | B1 |
| G | N | Explain what the alarm is used for | B1 |
| G | N | The belt needs to be stopped before the breaker is turned off, otherwise it might explode or start a fire. | B1 |
| G | N | Consider having material spilled on catwalk and how to deal with it. | B2 |

Table 5-2: Findings of Phase 1.1 – Industry Feedback Sessions for Task-based Module

Text in italics represents comments for future research that were not built into the prototype application used for the following phases of the evaluation process.

| Station | New or Existing | Comment | Meeting |
|---------|-----------------|---|---------|
| 1 | | Material Accumulation Hazard | |
| 1 | | What is wrong with this? | |
| 1 | | How would you fix this hazard? | |
| E | | Mention root cause for the hazards in the right answer | L1 |
| E | | Change position of material accumulation to tail pulley | L1 |
| N | | You can hose out the accumulation while the belt is running. With guarding you can shovel out the material without locking and tagging out while it is running. | L1 |
| N | | Find out what is causing the accumulation and fix that problem | L1 |
| 1 | | What would you need to do to lock-out & tag-out? | |
| 1 | | Missing Return Idler Guarding Hazard | |
| E | | Put a person or Indicate ht (dimension line) where return idler is unguarded | L1 |
| E | | Mention 7' or reachable in Return idler text. | L1 |
| N | | Possible question – “Should this be guarded” | L1 |
| N | | <i>Possibly make the guarding loose so they would be more tempted to just push it up or tighten it</i> | L1 |
| N | | Place guarding on the ground | L1 |
| 1 | | What is wrong with this? | |
| 1 | | What would you do to fix this hazard? | |
| 1 | | Broken Railing Hazard | |
| E | | Fix it now in addition to just recognizing the hazard. Barricading access to that area | L1 |
| E | | Use of temporary cables and yellow tapes (include as part of answers) | L1 |
| N | | Most important to deny access the hazardous area unless if wearing a harness and tied off | L1 |
| N | | Rail can be fixed while the belt is running | L1 |
| N | | <i>Show the yellow tape when answering the question, tape needs to be placed at both ends to prevent access to the area</i> | L1 |
| N | | It is not a good idea to leave the yellow tape too long, there should be plans to fix it | L1 |
| 1 | | What is wrong with this? | |
| 1 | | What would you do to fix this? | |
| 2 | | Start the belt | |
| 2 | | Turn on power at breakers | |
| 2 | | Sound alarm in tower | |
| E | | Needs to wait after alarm sounds to give people time to move out of way, no more than 30 seconds as required by MSHA | L1 |
| N | | Operator needs to observe visually if anyone is there around the belt before starting the belt. Maybe add a person in the scenario to help make the point of clearing the area. Make person visible from the tower. | L1 |
| N | | Make sure the area is clear before starting the belt or sounding the alarm | L1 |
| N | | <i>Show counter to make sure the belt is started within 30 seconds</i> | L1 |

| | | | |
|---|---|---|----|
| 2 | | Start belts | |
| 3 | | Ensure belt is working properly | |
| 3 | | Locate the broken idler | |
| | N | <i>Extinguish fire first so belt doesn't start on fire and then turn off the belt. Smell the fire add as a point in text. If only smelling friction of hot rubber, then shut down the belt and fix the idler.</i> | L1 |
| 4 | | Replace broken idler | |
| | N | Need guards on the return idlers near cat walk at 12' ht. (or raise catwalk) | L1 |
| 4 | | Turn off BC3 | |
| 4 | | Turn breaker BC3 off | |
| 4 | | Lock-out and take key | |
| | N | Make User remove key | B1 |
| | E | tag is missing on the lock | L1 |
| 4 | | Fix broken idler | |
| 4 | | Click to remove guarding | |
| 4 | | Click to replace idler | |
| 4 | | Click to replace guarding | |
| 4 | | Unlock breaker BC3 | |
| 4 | | Turn on breaker BC3 | |
| 4 | | Turn on conveyor BC3 | |
| G | N | Ask questions to user | B1 |
| G | N | Need to show more breakers – one for each piece of equipment | B1 |
| G | N | Need to label belts and breakers | B1 |
| G | N | Need control tower/room | B1 |
| G | N | Instruction – Reminders of what task is being completed | B1 |

During the industry feedback meetings a general sense of preliminary industry buy-in to using a desktop virtual reality system was received. Some reasons that training professionals provided were:

- That it gives a sense of interaction especially to the younger generation used to working with the computer.
- It offers an interaction and practicing of procedures in a close to life environment.
- Different people learn different ways and this would offer a better method of teaching to some who do not do so well with other methods of training.

5.2.2. Phase 1.2 – Interface Evaluation

Phase 1.2 is a subjective qualitative and quantitative study conducted to find programming bugs and usability issues. The study involved both novice education level users (mostly graduate students) and industry professionals as participants. A survey was completed by each participant where they rated their agreement to each statement on a scale from 1 to 5, 1 being strongly disagree and 5 being strongly agree. Other questions were also included in the survey to allow participants to write comments about their perceptions of the program.

12 subjects participated in Phase 2 – Interface Evaluation. The demographics are listed in Table 5-3.

| | |
|---|--|
| Gender of participant | Male = 10 Female = 2 |
| Age range | 20 to 40 |
| Average Age | 28 |
| Occupation | 10 Student 2 Mining professionals |
| Experience of mining professionals | 5-10 years |
| Experience with conveyor belt training | 3 Total 1 student, 2 mining professionals |
| Responsible for safety training program | 2 (both mining professionals) |

Table 5-3: Demographics of Interface Evaluation Participants

All 12 subjects were asked of their experience with video games and navigational controls. The results to those questions listed in Table 5-4.

| | |
|--|--|
| Experience playing first person computer games | 11 (9 students and 2 mining professionals) |
| Experience with mouse and keyboard controls | 9 out of 11 who have played first person games |
| Rate of play | Not often – 5 hours a week |
| Experience with virtual reality training | 1 |

Table 5-4: Previous experience with computer controls and VR training by participants

The survey had three sections where the participants ranked their agreement with the listed statements: (1) instructional-based module, (2) task-based module, and (3) general statements dealing with the relation of information disseminated within the instruction-based module to its use in the task-based module. Each statement was ranked on a scale of one through five representing strongly disagree, disagree, neutral, agree, and strongly agree respectively. The closer the average for each section is to five the greater agreement with the statement. All statements are positive in nature. A full listing of statements is found in Appendix F.

The questions for the instructional-based module are broken into four categories dealing with: (1) instructions, clarity of instructions and their ability to convey the purpose of the application, (2)

navigation, ease of navigation controls, (3) information understandability, and (4) graphics, which deal with the ability of the graphics (animations, etc.) to convey what the captions state.

The results for the instructional-based module section of the interface evaluation survey are listed in Figure 5-1. Figure 5-2 represents a breakdown of responses for questions dealing with instructions, Figure 5-3 represents a breakdown of responses for questions dealing with navigation, Figure 5-4 represents a breakdown of responses for questions dealing with information understandability, and Figure 5-5 represents a breakdown of responses for questions dealing with graphics.

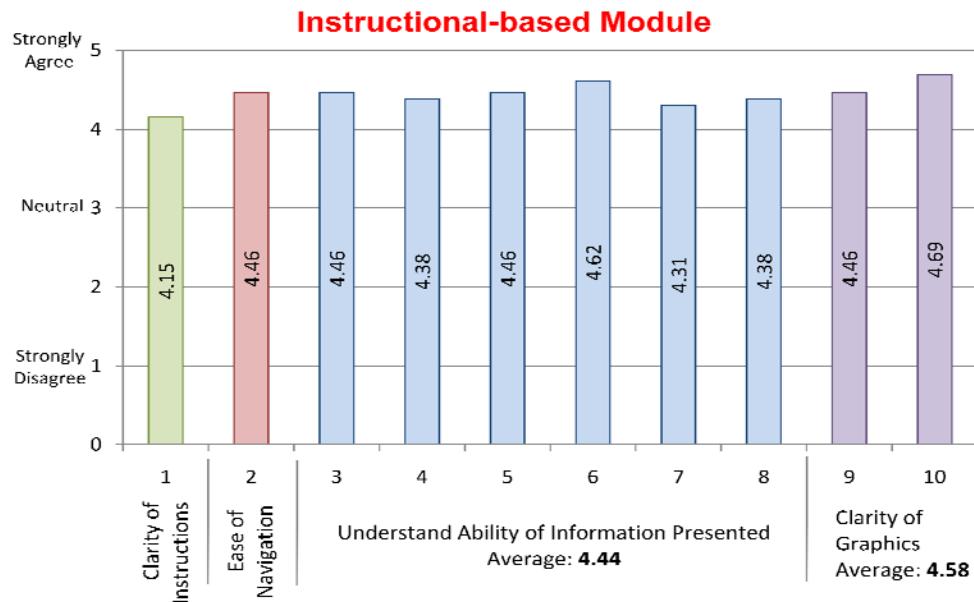
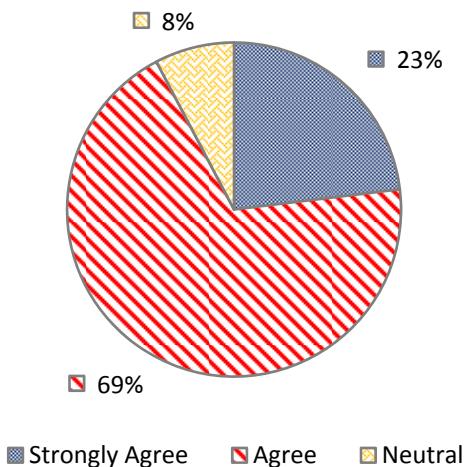


Figure 5-1: Average results for Instructional-based module section of interface evaluation

For the Instructional-based module there was agreement that the instructions were clear, navigation was easy, information was understandable, and the graphics were easily understood as to what they were depicting.

Rate of Agreement for Instructions



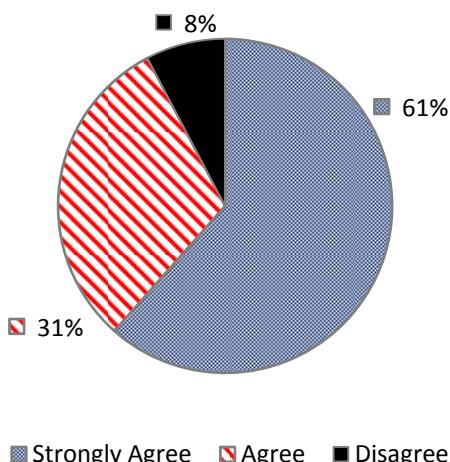
| Question | Average | Low | High |
|----------|---------|-----|------|
| 1 | 4.15 | 3 | 5 |
| Total | 4.15 | | |

The rate of agreement represents the distribution of levels of agreement for statements dealing with Instructions of the Instruction-based Module.

Breakdown of responses for each statement dealing with Instructions of the Instructional-based Module

Figure 5-2: Response breakdown for Instructions of Instructional-based Module

Rate of Agreement for Navigation



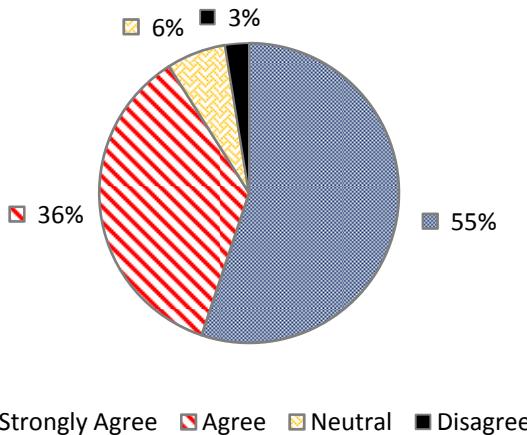
| Question | Average | Low | High |
|----------|---------|-----|------|
| 2 | 4.46 | 2 | 5 |
| Total | 4.46 | | |

The rate of agreement represents the distribution of levels of agreement for statements dealing with Navigation of the Instruction-based Module.

Breakdown of responses for each statement dealing with Navigation of the Instructional-based Module

Figure 5-3: Response breakdown for Navigation of Instruction-based Module

Rate of Agreement for Information Understandability



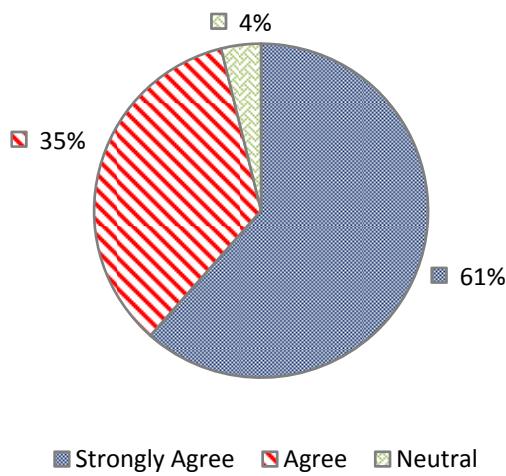
| Question | Average | Low | High |
|----------|---------|-----|------|
| 3 | 4.46 | 4 | 5 |
| 4 | 4.38 | 3 | 5 |
| 5 | 4.46 | 3 | 5 |
| 6 | 4.62 | 3 | 5 |
| 7 | 4.31 | 2 | 5 |
| 8 | 4.38 | 2 | 5 |
| Total | 4.44 | | |

The rate of agreement represents the distribution of levels of agreement for statements dealing with Information Understandability of the Instruction-based Module.

Breakdown of responses for each statement dealing with Information Understandability of the Instructional-based Module

Figure 5-4: Response breakdown for Information Understandability of Instruction-based Module

Rate of Agreement for Graphics



| Question | Average | Low | High |
|----------|---------|-----|------|
| 9 | 4.46 | 3 | 5 |
| 10 | 4.69 | 4 | 5 |
| Total | 4.58 | | |

The rate of agreement represents the distribution of levels of agreement for statements dealing with Graphics of the Instruction-based Module.

Breakdown of responses for each statement dealing with Graphics of the Instructional-based Module

Figure 5-5: Response breakdown for Graphics of Instruction-based Module

The questions for the task-based module are broken into five categories dealing with: (1) instructions, clarity of instructions and their ability to convey the purpose of the application, (2) navigation, ease of use

of the keyboard and mouse navigation control, (3) clarity of objectives, (4) information clarity, and (4) completion of tasks, which deals functionality of objects within the environment needed to complete tasks (i.e. breaker lever to lock-out, alarm for start-up, etc.).

The results for task-based module section of the interface evaluation survey are listed in Figure 5-6.

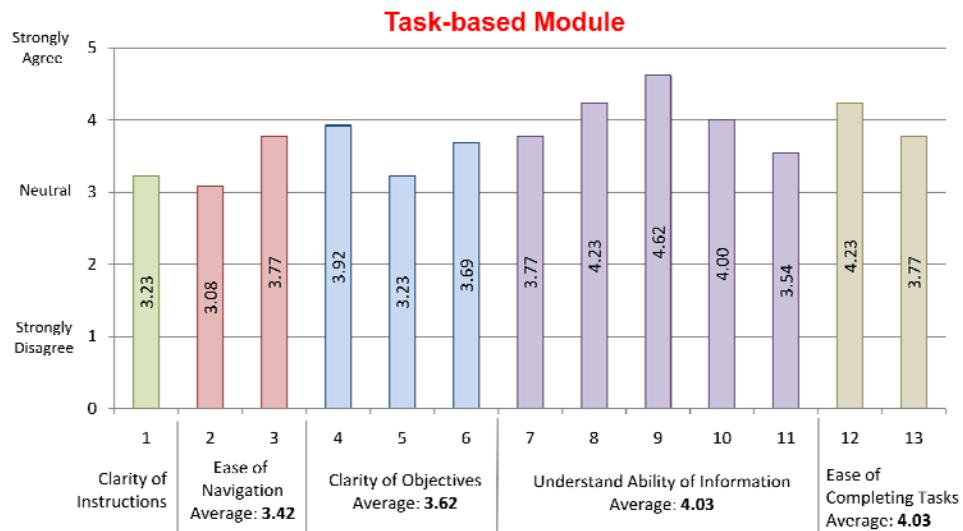
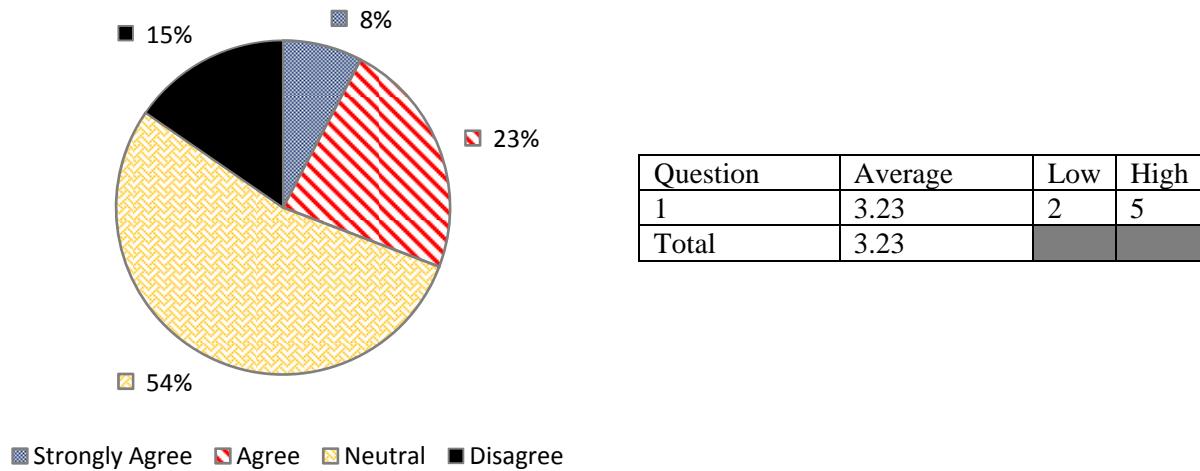


Figure 5-6: Average results for Task-based module section of interface evaluation

The average agreement for statements dealing with the clarity of instruction, ease of navigation, and clarity of objectives was neutral. The instructions were revised based on received comments about what was unclear. The navigation proved difficult to become accustom to for some study participants. This leads to ideas of future research listed in the following chapter about additional implementations and studies that can lead to a better solution. Some participants did not think navigation was a barrier, the goal would be to find a navigation control system that would be easy to adapt to and usable by the largest population. The clarity of objectives was revised within the application based on comments about what caused the initial confusion. The agreement for information understandability and completion of tasks was strong. This helped determine that the questions asked were clearly stated with clearly stated answer and that the functionality of the environment for completing the tasks was manageable by most of the study participants.

Figure 5-7 represents a breakdown of responses for questions dealing with instructions, Figure 5-8 represents a breakdown of responses for questions dealing with navigation, Figure 5-9 represents a breakdown of responses for clarity of objectives, Figure 5-10 represents a breakdown of responses for questions dealing with information understandably, and Figure 5-11 represents a breakdown of responses for questions dealing with completion of tasks.

Rate of Agreement for Instructions

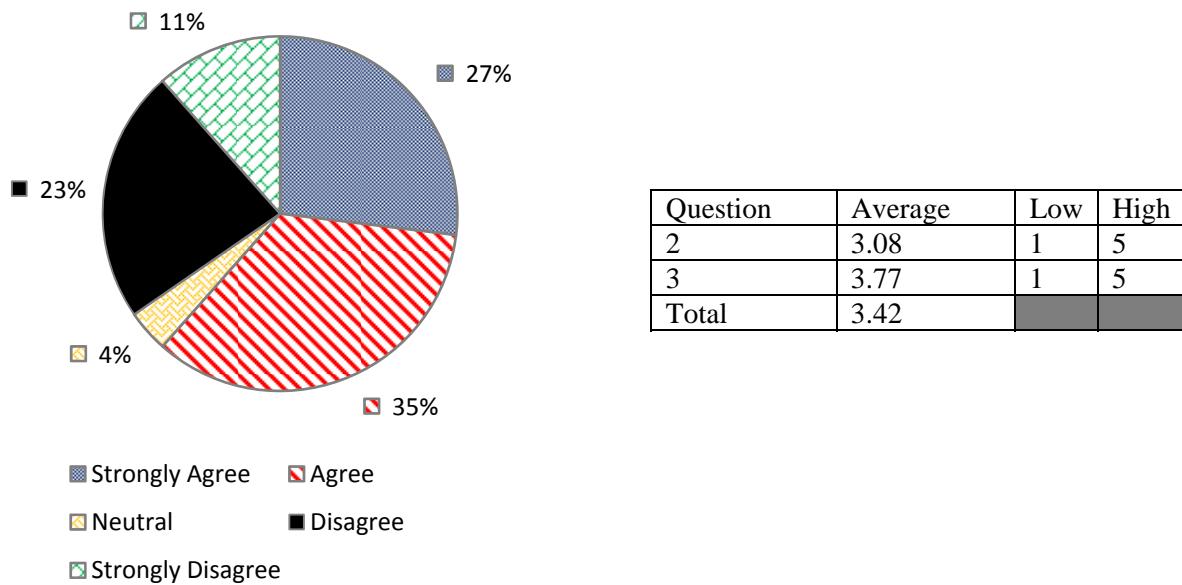


The rate of agreement represents the distribution of levels of agreement for statements dealing with Instructions for the Task-based Module.

Breakdown of responses for each statement dealing with Instructions for the Task-based Module

Figure 5-7: Response breakdown for Instructions for Task-based Module

Rate of Agreement for Navigation

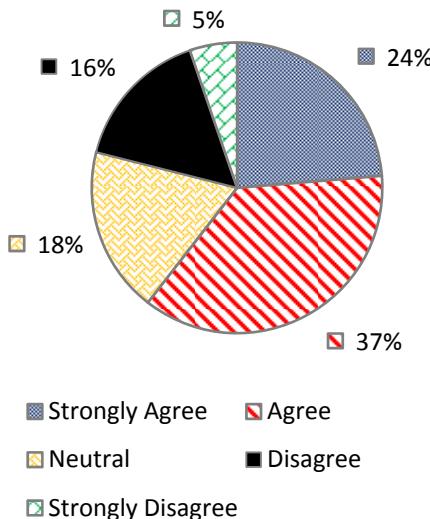


The rate of agreement represents the distribution of levels of agreement for statements dealing with Navigation for the Task-based Module.

Breakdown of responses for each statement dealing with Navigation for the Task-based Module

Figure 5-8: Response breakdown for Navigation for Task-based Module

Rate of Agreement for Clarity of Objectives



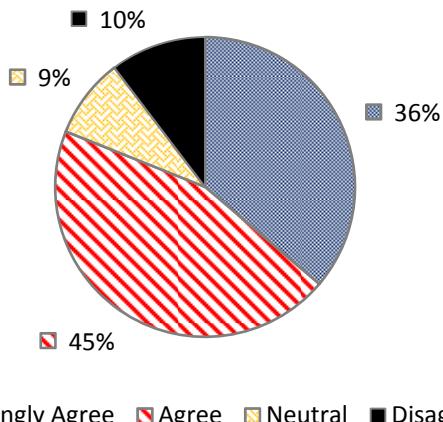
The rate of agreement represents the distribution of levels of agreement for statements dealing with Clarity of Objectives for the Task-based Module.

| Question | Average | Low | High |
|----------|---------|-----|------|
| 4 | 3.92 | 2 | 5 |
| 5 | 3.23 | 1 | 5 |
| 6 | 3.69 | 2 | 5 |
| Total | 3.62 | | |

Breakdown of responses for each statement dealing with Clarity of Objectives for the Task-based Module

Figure 5-9: Response breakdown for Clarity of Objectives for Task-based Module

Rate of Agreement for Information Understandability



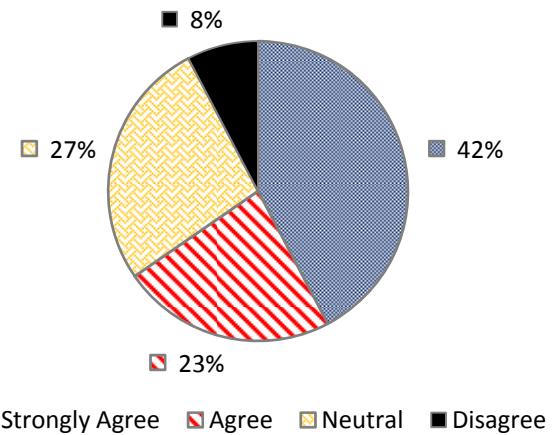
The rate of agreement represents the distribution of levels of agreement for statements dealing with Information Understandability for the Task-based Module.

| Question | Average | Low | High |
|----------|---------|-----|------|
| 7 | 3.77 | 2 | 5 |
| 8 | 4.23 | 3 | 5 |
| 9 | 4.62 | 4 | 5 |
| 10 | 4.00 | 2 | 5 |
| 11 | 3.54 | 2 | 5 |
| Total | 4.03 | | |

Breakdown of responses for each statement dealing with Information Understandability for the Task-based Module

Figure 5-10: Response breakdown for Information Understandability for Task-based Module

Rate of Agreement for Completion of Tasks



| Question | Average | Low | High |
|----------|---------|-----|------|
| 12 | 4.23 | 3 | 5 |
| 13 | 3.77 | 2 | 5 |
| Total | 4.00 | | |

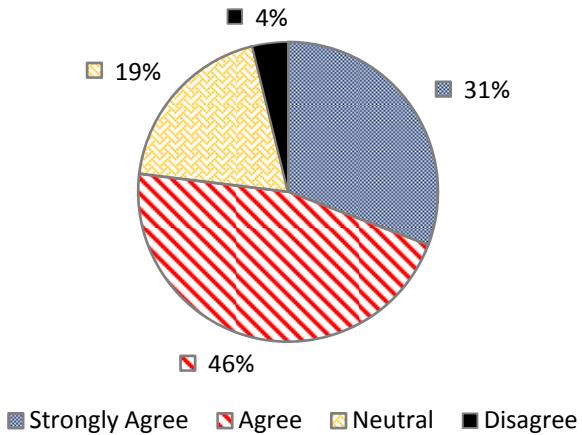
The rate of agreement represents the distribution of levels of agreement for statements dealing with Completion of Tasks for the Task-based Module.

Breakdown of responses for each statement dealing with Completion of Tasks for the Task-based Module

Figure 5-11: Response breakdown for Completion of Tasks for Task-based Module

For the General Questions portion of the interface evaluation survey the participants were asked two questions on the coordination between the two modules of the prototype application. The average rate of agreement was 4.04 or slightly above strong. The distribution of agreement is documented in Figure 5-12.

Rate of Agreement for Coordination of Modules



| Question | Average | Low | High |
|----------|---------|-----|------|
| 1 | 4.15 | 3 | 5 |
| 2 | 3.92 | 2 | 5 |
| Total | 4.04 | | |

The rate of agreement represents the distribution of levels of agreement for statements dealing with the Coordination of Modules.

Breakdown of responses for each statement dealing with the Coordination of Modules

Figure 5-12: Response breakdown for general statements of Coordination of Modules

5.2.3. Phase 2 - Subjective Analysis

The subjective analysis that was completed consists of a series of questions to aid in comparing typical training methods to the developed prototype. Industry professionals were given a demonstration of the VR application and allowed to navigate through it and then asked to fill out the survey comparing the VR application to the training methods they are accustomed to within the industry. Novice level participants were given a demonstration of videos, slide-shows, and other handouts that are used as training material within the industry as well as a demonstration of the VR application. After reviewing all training material and both methods of training the novice users were asked to complete the survey based on what was reviewed.

Eight individuals participated in the subjective analysis phase. Two of the eight were industry professionals with the remaining being novices with backgrounds in construction (4), engineering (1), and early childhood education (1). Each participant was presented the methods of training and asked to complete a survey designed to capture perception of advantages and shortcoming of the proposed application and typical training methods and which method was perceived to be a more effective method of learning. The questions and corresponding comments are documented in Table 5-5.

Table 5-5: Subjective Analysis – Survey Answers

| Question | Comment Received | # agree |
|--|---|---------|
| 1. What are some advantages of a typical training method you are familiar with over the reviewed application? | Typical methods are more common so most people are familiar with that method of learning and it does not have a user interface. (does not require computer knowledge) | 3 |
| | There is an instructor who is telling you exactly what you need to know and who can answer questions. It's very structured with person to person interaction. | 3 |
| | Typical method often give handouts, etc. that can be referred to later. | 1 |
| | Typical training accommodates more learning styles and easier to cover learning disabilities. | 1 |
| 2. What are some of the advantages of the reviewed prototype application over the typical training methods? | Allows personal involvement, interaction, with training in a (close to) real world environment with consequences. | 6 |
| | Allows for a wide range of informational material. | 1 |
| | You can rehearse tasks and not just have someone tell you about it. | 2 |
| 3. What features of the reviewed application do you see as the most beneficial for learning the training material? | You are actually performing an action rather than just looking, listening, or reading about it | 3 |
| | You are immersed in the environment to perform your job. | 1 |
| | The hand-on nature can test how the trainee will perform in real life. | 3 |
| | It is very interactive and engaging. | 1 |
| | You are learning the steps to take in a sequence and then have to complete the same processes. | 1 |
| | Freedom to self train. | 1 |
| | Cause/effect situations are demonstrated, what would really happen in real life is shown. | 1 |
| 4. What challenges/shortcomings do you see in | Usability for older generation or individuals who are not familiar with computers/video games. | 3 |

| | | |
|--|--|---|
| learning the training material using the reviewed application? | Applying the material for all education and computer skill levels so that the entire industry population can use it. | 2 |
| | Without audio if someone is illiterate or has reading comprehension issues they might not learn as much from the application. Other languages might be preferable for the text. | 1 |
| | Navigation problems. | 6 |
| 5. Do you think the proposed training application is an effective way to learn the material? Why or why not? | Yes – with improvements to navigational controls it presents a realistic learning environment with consequences. | 3 |
| | Yes – for the younger generation who is familiar with video games and can relate to virtual reality easier than older generations. It offers them an interactive and visual way of learning. | 2 |
| | Yes – because it can easily test and train people “hands on” in a safe environment. | 1 |
| | Yes – it gives the user the chance to make the mistake without the real life consequence thus helping to insure that the job will be done safely and correctly in real life | 3 |
| | Yes – it keeps the user engaged and tracks every step of the process ensuring it is done correctly | 2 |
| 6. Which method of training do you perceive as a more effective way of learning? Why? | Proposed – it allows for visible examples of and situations for works to experience. | 2 |
| | Proposed – provides detailed steps for completing processes and then the rehearsal of those processes | 2 |
| | Traditional – in a person to person situation where the individual can ask questions they have a better chance of learning the material | 2 |
| | Proposed – it has a higher level of engagement by the user | 2 |
| | Traditional – covers more learning styles and accounts for more learning disabilities. The proposed would be better for visual learners. | 1 |

All eight participants commented that the proposed method of training was perceived as effective way to learn. Some gave stipulations that it would be more effective for individuals who are computer literate and the younger generation, though they all foresee benefits of using it as a training tool in the future. Overall 5 of the 8 preferred the proposed application over traditional methods. The 3 who preferred typical training methods mentioned its ability to cover more learning styles and learning disabilities and the interaction with a trainer who can answer questions as the main reasons for preferring those methods.

6. Future Work and Conclusion

6.1. Future Work

Since only a prototype has been developed there are several areas of future research that need examination.

Future Work 1: Navigational Controls

From the interface usability studies it is clear that the navigational controls are a barrier and need to be studied in depth for the best solution. Navigation is a key issue for the success of any technology and multimedia based application. Finding the best solution could involve navigational studies between various types of controls. Some suggestions that came from the studies conducted are the use of touch screens, joysticks, game controls, or mouse and keyboard with the addition of cues and aids in navigation. No matter which method of controls proves to be most beneficial, aids can be introduced to help with user orientation with the environment. This would mean when a user enters a room where they had to perform a task the application would orientate the camera towards the work surface, helping with loss of orientation and easier completion of tasks. Also dealing with navigation would be the introduction of a navigational control tutorial. Such a tutorial would minimize navigation controls as a barrier by ensuring that the user can complete the tasks they were given and were able to navigate through the environment.

Future Work 2: Performance Based Evaluation

Once usability issues are overcome there would need to be evaluation for effectiveness within the industry by training professionals and extensive roll-out and studies to make sure that individuals being trained are being trained sufficiently. This would involve the use of a performance based comparison. This comparison can be completed in a few ways. One proposed method would be to have a group of total novice miners, meaning no previous training within the mining industry, participate in the VR training application (both modules). Another test group of the same population and demographics would complete traditional training. Once both groups have completed the training they would participate in a performance evaluation (Figure 6-1). This would involve a test of their knowledge in the field and their ability to complete tasks, explain tasks, or answer questions on certain situations and scenarios. The results of their performance would then be compared to determine which method of training is more effective. Their performance can also be observed long term to determine any benefits of training methods, track accident rates, etc.

Another method to complete the performance based application would be to have one test group of novice miners complete the instructional-based module of the application and another test group complete typical training method. The task-based module can then be used as the test for both groups. The downfall with this structure would be that the task-based module of the application is being tested but is the test. This method would be valuable to test retention of knowledge from the instructional training methods.

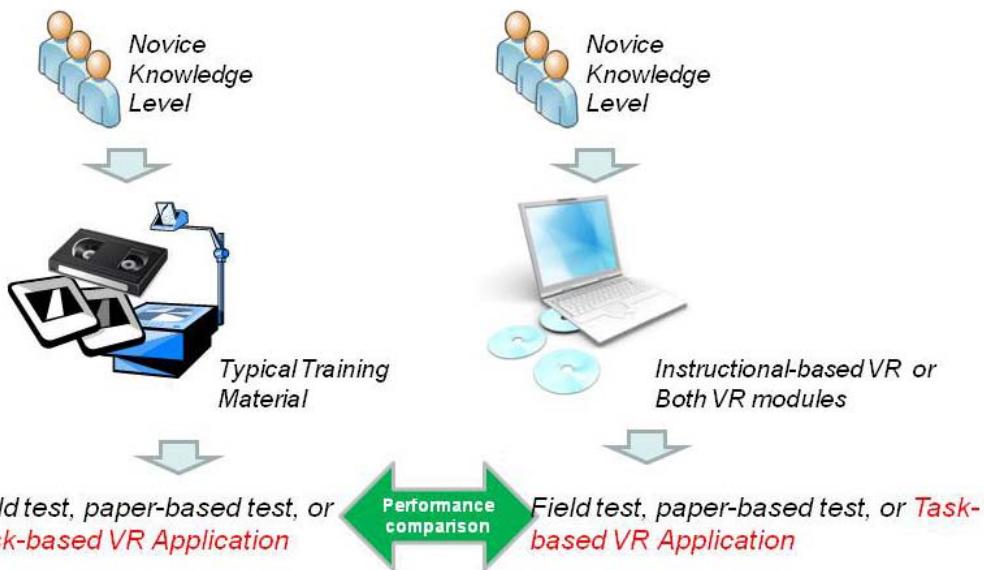


Figure 6-1: Performance Based Evaluation

Future Work 3: More Development and Customization Features

Further implementation would be needed in forms of advanced task training and testing and additional features to the program. This will give training professionals tools for training employees on advanced procedures and tasks in a controlled environment where user performance can be tracked. The framework used in developing the prototype modules can be used in the development of advanced training sessions.

Other areas of development to include would be first person experiences of those who were injured or those who witnessed an accident. These first person accounts can offer a powerful example to the new employees of the reality of working within a dangerous environment.

It was revealed through literature review and industry meetings that different companies have different methods of performing some procedures. As is, the prototype is set up as a knowledge based prototype which consists of general concepts of things that need to be done with examples of how to complete these processes. The developed prototype does not necessarily address all the possible options. A user customizable library can be part of further development to turn the prototype into a skill based application. This library would allow for configuring the conveyor belts in a way that is used at a certain facility. The library would also allow for different options to complete processes. For instance the process of turning on or off the belt, or locking and tagging out have certain ideology behind them but can be completed in a number of ways depending upon how a certain facility operates.

Future Work 4: Detailed Demographics Study and Validation Study

The studies that were conducted within the research used a user group to verify the concepts and identify issues. Before a performance based evaluation can be properly conducted the prototypes need to be updated and tested with various demographic groups. These groups would include the prominent age with the highest needs of users. This will also validate if the proposed application would only be useful for the younger generation, as is part of the hypothesis and driver for using younger miners, or if it has potential to be used for all miners. The demographics study would include surveys of individual miners

to identify age, education level, level of computer literacy, preferences to learning, challenges, and various needs. This type of study will aid in proving or disproving the second hypothesis that the younger miners are more computer literate and have more experience with technology. Another round of interface and feasibility studies would also be conducted with various groups of miners of different demographics to validate the ideas and issues brought forth within this research.

Future Work 5: Other Applications to Construction

This type of concept can be applied to other areas of construction that require regulated processes. Some examples of these would include electrical work, especially with high power lines, that pose the risk of electrocution. Other examples would be heavy equipment operation, such as crane operation when used for steel erection, as well as completing other work tasks. The type of application developed with this research offers potential for improving training for processes that pose high risk of injury when not followed properly.

6.2. Conclusion

The research conducted developed a databank of information to include within a training application for conveyor belts. Upon review of the information collected, the main training areas were defined to include overview of belt conveyors, possible hazards, general safety practices, and trainee assessment methods with scenarios for training. This information was then used in the development of a two module application to disseminate information to the user and then test the user on their ability to complete tasks based on that information. The system allows for the showing of consequences to actions and tracking user performance. Lastly, an evaluation scheme was developed to determine issues with usability, programming bugs, and effectiveness of the application.

In summary, the evaluation processes revealed areas of benefits and shortcomings for the use of VR as a training application. Usability is a major issue and the success of a program depends on the ability of the users to easily navigate to retrieve the necessary information without getting frustrated or distracted from the main purpose of the training which is to learn the material. Benefits were largely focused on the application ability to allow for user interaction with their training, the rehearsal of tasks and procedures in a safe environment, and the ability to test the users on their ability to complete processes. Some of the main shortcomings determined were that typical training methods allow for a person to person interaction with a training professional who can answer questions, that usability would be an issue for the older generation of miners, and that typical training methods have the ability to cover a wider variety of learning styles.

It is not argued that VR is the most beneficial and effective method of learning material however it is effective and feasible. Other possible training methods would be full scale mock-up for training. This option tends to be costly and due to the sheer size of the equipment used would require a large space for training.

Other options for training would include augmented reality, however with the same concern for size of the actual equipment this may be difficult and costly to implement.

Lastly, on-the-job training is currently used and the use of VR should not replace this training but enhance it. On-the-job training does not give the benefit for safely rehearsing activities and demonstrating the consequences for mistakes while VR does.

Assuming that navigational issues are resolvable, the hypothesis of VR being an effective method of learning material can be proved based upon the opinions of study participants. This is especially true for training younger miners who are more likely to be computer literate and familiar with game controls. The application, if fully developed, can be part of the solution of effectively training a large number of younger miners. VR is supported by the industry as a valuable tool that has the potential to be very useful for the training of new young miners in an interactive, safe environment.

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8. Appendix

Appendix A: Summary Review of Belt Related Fatal Accidents between 1995-2007

| Accident Category | MSHA Case References | Maintenance Task Performed | Belt Assembly contributing to accident | Accident Scenario |
|-------------------|----------------------|--|--|--|
| 1.0 Entanglement | M-1996-21 | Cleaning - spilled and built-up material | Head pulley | The miner climbed onto the conveyor to shovel off material. The conveyor started, and the miner was transported approximately 150' where he was caught in an 8" gap between the head pulley cross member and the pulley. |
| | C-1996-7 | Installation/repair | Power rollers | During the repairing of conveyor belt, the miner was pushing on the belt with his hands to maintain tension between the belt and power rollers to help feed the belt thru the tandem drive rollers on the belt drive. He became entangled between the two power rollers of a belt conveyor drive. |
| | C-1997-27 | Installation/repair | Drive motor | The miner was standing on the belt conveyor structure beside the drive roller sprocket, while performing repair work on broken chain between the drive motor and drive roller. The drive motor unexpectedly became energized and the miner became entangled in the drive unit. The electrical power to the drive had not been locked out and tagged, and the drive unit had not been blocked against motion. |
| | M-1996-16 | Installation/repair | Crusher | While helping in setting up two portable crushers, the miner got crushed between two crushing units. |
| | M-1997-7 | Cleaning - spilled and built-up material | Tail pulley | The actual reason for the accident is not known as there are no eyewitnesses but it is believed that the miner was working around energized conveyor belt. The victim became entangled in an unguarded tail pulley and died. |
| | M-1997-29 | Loading of pit material in the feed hopper | Return idler | A truck with load of pit material was loading material in the feed hopper. While raising the truck bed truck driver noticed the screen feed conveyor surging. After getting down from the truck he saw the victim's right arm had become entangled between unguarded return idler and conveyor belt. How accident happened is not clear, as there was no eyewitness. |
| | M-1997-18 | Belt alignment | Tail pulley | The miner went underneath the unguarded portion of the belt to the adjustment bolt on the East side of the tail pulley as the belt was starting to untrack because of built up material in the wings of the pulley. The victim became entangled in an unguarded |

| | | | |
|-----------|--|------------------------------|---|
| | | | tail pulley while conveyor was in motion and died. |
| M-1997-2 | Cleaning - spilled and built-up material | Tail pulley | The victim was caught in an unguarded tail pulley of the crusher belt and died. There are no eyewitnesses to the accident but it appears that the miner was attempting to remove frozen material from the moving belt while belt was in motion. |
| M-1998-17 | Cleaning – spilled and built up material | Drive pulley and bend pulley | Accident occurred due to failure to de-energize the conveyor before cleaning. The victim's arm got pulled into pinch points between unguarded drive pulley & the bend pulley. |
| M-1998-20 | Cleaning – belt assembly | Return idler | While cleaning return idler, the victim was caught and drawn into pinch point between unguarded return idler and moving belt. |
| M-1998-14 | Cleaning – spilled and built up material | Tail pulley | The victim was cleaning material from around an unguarded conveyor belt tail pulley under the crusher. The self-cleaning tail pulley caught his clothing, drawing him onto the conveyor and he was wedged between the conveyor and a tension (snubber) pulley. |
| M-1999-12 | Belt alignment | Return Idler | The victim's arms got caught and drawn between the unguarded return idler and the belt resulting into the death of the victim. Accident occurred due to failure to provide crossover to safely access both sides of conveyor. |
| M-1999-31 | Cleaning – belt assembly | Return idler | The victim was caught & drawn into the pinch point at an unguarded return roller while conveyor was in motion. |
| M-1999-52 | Installation/repair | Self-cleaning pulley | The accident occurred due to entanglement of victim's clothes in an unguarded self-cleaning pulley. The victim had entered into a confined space area containing an unguarded self-cleaning pulley that was in operation to shovel the spilled material from along side of the conveyor belt. |
| M-2000-13 | Maintenance of service equipment | Tail pulley | While working on the maintenance of a front end loader (used for cleaning and clearing material around the belt), Accident occurred due to entanglement in an unguarded tail pulley while conveyor was in motion. |
| M-2000-12 | Belt alignment | Bend pulley | The victim and a co-worker were making adjustments to a new conveyor installation. The victim was aligning the extended grease lines for the bend pulley from inside the conveyor frame. The victim became entangled in the unguarded bend pulley and died. |
| M-2001-2 | Cleaning – spilled and built up material | belt | Accident was caused by the failure to de-energize the power to the conveyor. The victim became entangled in a conveyor belt |

| | | | |
|-----------|--|----------------------|--|
| | | | and died. |
| M-2001-26 | Cleaning – spilled and built up material | Take-up pulley | Accident occurred because maintenance was being performed while conveyor components were in motion. The victim became entangled in the discharge belt take up pulley and died. |
| C-2001-7 | Inspection | Take-up pulley | Accident occurred during an examination of a 54" belt conveyor drive take-up unit while the belt conveyor was still in motion. The rotating rollers of the belt conveyor take-up unit detached the victim's left arm. |
| M-2002-16 | | Conveyor snub pulley | While monitoring the stockpiling of crushed ore over feeders, the victim was fatally injured at an open pit copper operation. His shovel became entangled in an unguarded conveyor snub pulley. |
| M-2002-29 | Cleaning – spilled and built up material | Tail pulley | Accident occurred while the victim was removing fines that had packed around a winged type tail pulley of a belt. As the spillage was removed, the bound conveyor belt moved backward a short distance and caught the victim's arm between the belt and the tail pulley. |
| M-2005-1 | Cleaning – spilled and built up material | Return idler | Worker was cleaning spilled material underneath the conveyor belt. Accident occurred because a guard had not been installed on the return idler. The miner was cleaning spilled material underneath the moving belt and became entangled in an unguarded return idler. |
| M-2005-20 | Cleaning – spilled and built up material | Return idler | Accident occurred when miner was cleaning up the built-up material on a return idler. His shovel got caught between moving belt and return idler. |
| M-2005-18 | Belt alignment | Tail pulley | Worker was making adjustments to the belt. Accident occurred due to performing repair work around an unguarded tail pulley. The victim's arm became entangled in the moving belt and tail pulley. |
| M-2006-5 | Cleaning – spilled and built up material | Tail pulley | Accident occurred when the victim entered the area under the crusher and travelled near the backside of the discharge conveyor tail pulley to clean the spillage beneath the crusher discharge from the sides of the conveyor tail pulley and his clothing became entangled in the rotating tail pulley. |
| M-2006-9 | Installation/repair | Return idler | Worker was adjusting the return idlers while the belt was in motion. He became entangled between the belt and the return idler. |

| | | | | |
|--|-----------|---------------------------------|-----------------------|---|
| | C-2004-19 | Installation/repair | Tail pulley | Accident occurred while the miner was trying to install belt scraper at a tailpiece while the belt was in motion. A chain attached to the scraper was caught by the belt, dragging it and the victim into the tail pulley. |
| | M-25-2007 | Cleaning | Take-up Pulley | Accident occurred while the victim was trying to shovel spilled material behind an unguarded take-up pulley. His shovel got entangled in between an unguarded take-up pulley and moving belt. |
| 2.0 Collapse of structure, belt components or falling material | M-1997-20 | Sampling | conveyor belt | A worker was sampling material coming off the bin feeder. The discharge conveyor belt under the storage bin was running and caused the material within the bin to slide and engulf the miner. The victim died from suffocation. |
| | M-1997-15 | Installation/repair | | A large portion of roof and rib (22 feet long x 42 inches wide x 26 inches thick), fell onto the miner resulting in fatal injury. |
| | M-1997-13 | Installation/repair | Drive unit | While installing belt conveyor drive unit the chain on the lever hoist holding the boom suddenly broke and the boom section swung toward the drive unit crushing the miner against the drive roller. |
| | M-2000-3 | Cleaning – belt assembly | Shaft kiln draw floor | Accident occurred while cleaning of the shaft kiln draw floor. Accident was caused by the failure to lock out the tripper conveyor and block the counterweight against motion before cleaning the guarded framework. The victim was crushed between a descending counterweight and counterweight's guard. |
| | M-2001-29 | Cleaning – | Feed hopper | The victim was pounding on the sides of the hopper with a bar and hammer and working from the elevated bucket of the front end loader attempting to free the flow of materials inside the primary feed hopper. The victim entered the feed hopper to dislodge a hang up, when he was engulfed by material and suffocated. |
| | M-2002-19 | Installation/repair | belt | Victim was repairing portable conveyor system. Accident occurred due to removing of a support structure on a portable conveyor. The conveyor was positioned on a hydraulic jack supported by two wooden blocks when it shifted and fell crushing the victim. |
| | M-2002-40 | Installation/repair | Belt walkway | Victim was engaged in the removal of lower sections of walkway near tail pulley for replacement. Accident occurred when the walkway section collapsed killing the worker. |
| | M-2004-11 | Cleaning – spilled and built up | Hopper | While clearing the blockage of material at discharge chute accident occurred when the |

| | | | |
|-----------|--|----------------|---|
| | material | | victim entered the hopper from the top without wearing a secured safety harness and lanyard when the material suddenly gave way and engulfed him. |
| M-2004-19 | Cleaning – spilled and built up material | belt | The victim was using a water hose to clean spillage under a conveyor. A large rock fell from a conveyor located overhead and struck him, resulting in fatal injuries. |
| M-2004-9 | Installation/repair | Crusher/belt | The victim was dismantling a crusher. Accident occurred when the victim was attempting to remove the pin from a support arm, was struck by a portion of the conveyor resulting in fatal injury. |
| M-2006-24 | Installation/repair | Head pulley | Worker was standing underneath the head pulley section of a conveyor preparing to attach a chain that was to be used to move the conveyor. The accident occurred when the bolts connecting the conveyor truss sections in the conveyor's frame failed, causing the head pulley section to fall and strike the victim. |
| M-2001-12 | Installation/repair | | The victim was fatally injured while helping to assemble the plant. Accident occurred due to failure to provide suitable rigging equipment and to properly attach it to the load being hoisted. Need more explanation to show falling parts. |
| M-1995-36 | Installation/repair | Take-up pulley | A cement take-up pulley weight for a conveyer was being lifted into position by a crane. The miner was riding on the 3,000-pound weight as it was being lifted. One of the pins pulled out of the weight causing the miner to lose his balance and fall 35 feet to the ground. |
| C-1995-41 | Cleaning - spilled and built-up material | belt | The belt structure was being used to route and sort coal at the discharge locations where the different grades of coal are discharged and stored on the ground. Six miners were shovelling the coal spillage when the belt structure shifted, broke free, and fell. One miner fell with the collapsed structure and died. |
| C-1995-21 | | belt | A roof-bolting machine operator was attempting to cross a moving conveyor belt. The miner lost his balance and fell onto the belt, which carried him over a head roller, resulting in fatal injuries. |
| M-1996-20 | Installation/repair | | The miner was working on an elevated crusher installing bolts in the I-beam supports for the crusher hopper. He slipped off the crusher and fell 15 feet to the ground resulting in fatal injury. |
| M-2004-16 | Installation/repair | belt | During the installation of conveyor belt, the victim was standing on the steel support structure for the conveyor and fell 12 feet |

3.0 Falling from height

| | | | | |
|--------------------------|-----------|--|------|---|
| | | | | when the rope he was pulling unexpectedly came loose from the end of the belt. |
| 4.0 Miscellaneous | M-2002-12 | Cleaning – spilled and built up material | belt | Worker was clearing a blockage inside a cement clinker drag conveyor located in a tunnel. The victim got fatally burned due to outburst of the steam. |
| | M-2006-11 | Installation/repair | | Victim was working from the bucket of a front-end loader to install a roller on a conveyor belt 15 feet above ground. Accident occurred when the loader moved forward crushing the victim against the conveyor framework. |
| | M-2005-31 | | | The victim was moving a radial stacking conveyor to a new location. He was fatally injured when the wheels of the conveyor got stuck and rolled over him. |
| | C-2005-6 | Cleaning – other | | Worker was removing a piece of canvas that was wrapped around the section feeder rotary pick breaker. Accident occurred when the rotary breaker started pulling the victim under the picker. |
| | C-2004-8 | Cleaning – belt assembly | | Accident occurred due to performing belt-cleaning task on the moving conveyor belt. This is not clear. We need more explanation |

Appendix B: Reviewers' Comment Summary

| Station | New or Existing | Comment | Meeting |
|---------|-----------------|--|---------|
| 1 | | Miner – Safety Information (Safety) | |
| | E | Jewelry, rings to be added as part of miner work attire (Law in Virginia) | 3 |
| | N | Might want to mention the need for respiratory protection, MSHA does not require it, but it is a common practice | 3 |
| 1 | | Entanglement (Hazard) | |
| | E | Miner becomes entangled in environment | 2 |
| 1 | | Pinch Point (Hazard) | |
| | E | Move arrow to a lower height of an idler that would be an issue | 3 |
| 1 | | Recognizing Belt Damage (Safety) | |
| | E | Mention causes of belt damages in the text. | 3 |
| | E | Use picture of belt splicing and damages instead of sketch/diagram | 3 |
| 1 | | Inspect Handrails (Safety) | |
| | E | Max. Railing ht 42" & middle rail ht 21" from walking surface | 3 |
| | E | Detailed pre-shift inspection- of Handrail, walkways, guarding, etc. does not happen. Only obvious issues are typically noticed. | 3 |
| | E | Failed weld joints is a major problem | 3 |
| 1 | | Falling Material (Hazard) | |
| | E | A miner should have constant awareness of the possibility of material falling from a | 4 |

| | | | |
|---|---|---|-----|
| | | conveyor belt. | |
| 2 | | Falling From Heights (Safety) | |
| | N | Add scenario for fall protection in relation to using safety harness. | 3 |
| 2 | | Drive Motor (Component) | |
| | E | Drive motor guarding very important. Guards need to be bolted | 3 |
| 2 | N | Harness needed to perform work (Safety) | |
| | N | Catwalk can only access one side of the conveyor belt. A harness is needed when working on any part of the conveyor not immediately accessible from the catwalk. | 3 |
| 3 | | Tail Pulley (Component) | |
| | E | Need guards above gravity take up at walkway level | 3 |
| 3 | | Missing Guarding (Safety) | |
| | N | Individual components needs to be guarded Guards need to be 4"-6" above ground to hose out the spillages underneath. | 3 |
| | E | Tail pulley guards are good looking in the animations but not practical- use site pictures to update it. | 3 |
| 3 | | Impact Idler (Component) | |
| | N | Need to show guarding around the impact idler. | 3,4 |
| 4 | N | Cross-over (Component) | 2 |
| | N | Need guarding at any exposed moving parts near the crossover catwalk | 3 |
| 4 | | Bend Pulley (Component) | |
| | N | Need guarding near catwalk & crossover | 4 |
| 4 | | Take-up Pulley (Component) | |
| | N | Need guards above gravity take up at walkway level | 3,4 |
| | N | Grease lines should run from the take-up pulley and bend pulley to a location on the catwalk or on the ground | 4 |
| 5 | | Lock-out & Tag-out (Safety) | |
| | N | In animations add names on the locks or tags to the locks.(tag out procedure) | 3 |
| | N | More than one lock can be placed on a breaker if more than one person is working on that piece of equipment. | 3 |
| | N | Only the person who placed the lock should remove the lock. Only the foreman (or project manager depending on plan) can remove someone's lock after contacting the person, or after thorough inspection to make sure that work is complete and that person is not within the area of the conveyor belt. | 3 |
| | N | Each worker is responsible for their locks; they need to be tagged or labeled with who is responsible for the lock. Some locks are kept on the person; others are kept in a cabinet near the breakers, depending on the operation. | 3 |
| 6 | N | Control Tower Alarm (Safety) | 2 |
| 6 | N | Start-up Procedures (Safety) | 2 |
| G | N | Missing emergency shut-off on inclined belt | 2 |
| G | N | Go-back buttons | 2 |
| G | N | Grease lines can be used for lubricating bearings | 2 |
| G | N | Start-up Procedures | 2 |
| G | N | Explain what the alarm is used for | 2 |
| G | N | The belt needs to be stopped before the breaker is turned off, otherwise it might explode or start a fire. | 2 |
| G | N | Consider having material spilled on catwalk and how to deal with it. | 4 |

Appendix C: Industry Feedback Questions and Comments

During each review session the meeting attendees were presented with the following questions to stimulate discussion about the information presented within the prototype during the review sessions:

1. Is the scenario of the session accurate for something an employee might have to do?
2. Do the questions asked have the proper answers?
3. Are the scenarios for possible solutions to hazards reasonable?
4. Are the processes depicted accurate?
5. Are any of the processes or actions misrepresented?
6. Was any of the information presented difficult to understand?

Some general questions were also asked about the concept and framework of the prototype application:

1. Would this fit your training needs and how can it be improved to better fit your training needs?
2. Can an application like this be a valuable addition to your current training material?

This table includes the full list of comments that the research team received from the industry feedback sessions. Comments in *italics* were suggestions for future scenarios.

| Station | New or Existing | Comment | Meeting |
|---------|-----------------|---|---------|
| 1 | | Material Accumulation Hazard | |
| 1 | | What is wrong with this? | |
| 1 | | How would you fix this hazard? | |
| | E | Mention root cause for the hazards in the right answer | L1 |
| | E | Change position of material accumulation to tail pulley | L1 |
| | N | You can hose out the accumulation while the belt is running. With guarding you can shovel out the material without locking and tagging out while it is running. | L1 |
| | N | Find out what is causing the accumulation and fix that problem | L1 |
| 1 | | What would you need to do to lock-out & tag-out? | |
| 1 | | Missing Return Idler Guarding Hazard | |
| | E | Put a person or Indicate ht (dimension line) where return idler is unguarded | L1 |
| | E | Mention 7' or reachable in Return idler text. | L1 |
| | N | Possible question – “Should this be guarded” | L1 |
| | N | Possibly make the guarding loose so they would be more tempted to just push it up or tighten it | L1 |
| | N | Place guarding on the ground | L1 |
| 1 | | What is wrong with this? | |
| 1 | | What would you do to fix this hazard? | |
| 1 | | Broken Railing Hazard | |
| | E | Fix it now in addition to just recognizing the hazard. Barricading access to that area | L1 |
| | E | Use of temporary cables and yellow tapes (include as part of answers) | L1 |
| | N | Most important to deny access the hazardous area unless if wearing a harness and tied off | L1 |

| | | | |
|---|---|---|----|
| | N | Rail can be fixed while the belt is running | L1 |
| | N | Show the yellow tape when answering the question, tape needs to be placed at both ends to prevent access to the area | L1 |
| | N | It is not a good idea to leave the yellow tape too long, there should be plans to fix it | L1 |
| 1 | | What is wrong with this? | |
| 1 | | What would you do to fix this? | |
| 2 | | Start the belt | |
| 2 | | Turn on power at breakers | |
| 2 | | Sound alarm in tower | |
| | E | Needs to wait after alarm sounds to give people time to move out of way, no more than 30 seconds as required by MSHA | L1 |
| | N | Operator needs to observe visually if anyone is there around the belt before starting the belt. Maybe add a person in the scenario to help make the point of clearing the area. Make person visible from the tower. | L1 |
| | N | Make sure the area is clear before starting the belt or sounding the alarm | L1 |
| | N | Show counter to make sure the belt is started within 30 seconds | L1 |
| 2 | | Start belts | |
| 3 | | Ensure belt is working properly | |
| 3 | | Locate the broken idler | |
| | N | Extinguish fire first so belt doesn't start on fire and then turn off the belt. Smell the fire add as a point in text. If only smelling friction of hot rubber, then shut down the belt and fix the idler. | L1 |
| 4 | | Replace broken idler | |
| | N | Need guards on the return idlers near cat walk at 12' ht. (or raise catwalk) | L1 |
| 4 | | Turn off BC3 | |
| 4 | | Turn breaker BC3 off | |
| 4 | | Lock-out and take key | |
| | N | Make User remove key | B1 |
| | E | tag is missing on the lock | L1 |
| 4 | | Fix broken idler | |
| 4 | | Click to remove guarding | |
| 4 | | Click to replace idler | |
| 4 | | Click to replace guarding | |
| 4 | | Unlock breaker BC3 | |
| 4 | | Turn on breaker BC3 | |
| 4 | | Turn on conveyor BC3 | |
| G | N | Ask questions to user | B1 |
| G | N | Need to show more breakers – one for each piece of equipment | B1 |
| G | N | Need to label belts and breakers | B1 |
| G | N | Need control tower/room | B1 |
| G | N | Instruction – Reminders of what task is being completed | B1 |

Appendix D: Usability Survey Statements and Results

Clarity of Instructions – Statements 1 – Average 3.23

| Clarity of Instructions – Rates of Agreement for Statements 1 | | | | |
|---|----------|---------|-------|----------------|
| Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| 0% | 15% | 8% | 23% | 8% |

1. The instructions were clear on what to do. (*Average Response 3.23*)

Please rate the instructions dealing with how to complete the tasks and identify hazards.

Ease of Navigation – Statements 2-3 – Average 3.42

| Ease of Navigation – Rates of Agreement for Statements 2 - 3 | | | | |
|--|----------|---------|-------|----------------|
| Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| 11% | 23% | 4% | 35% | 27% |

2. The mouse controls were easy to get used to. (*Average Response 3.08*)

3. The keyboard controls were easy to get used to. (*Average Response 3.77*)

Clarity of Objectives – Statements 4-6 – Average 3.62

| Clarity of Objectives – Rates of Agreement for Statements 4 – 6 | | | | |
|---|----------|---------|-------|----------------|
| Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| 5% | 16% | 18% | 37% | 24% |

4. The objective was easy to understand. (*Average Response 3.92*)

Objective: the scenario that was created “Pre-shift inspection...”

5. It was easy to navigate through the session in order to complete the desired tasks. (*Average Response 3.23*)

6. The tasks I had to complete were clearly understood. (*Average Response 3.69*)

Tasks in this session included identifying hazards, starting the belt, and replacing broken component.

Understand Ability of Information – Statements 7-11 – Average 4.03

| Understand Ability of Information – Rates of Agreement for Statements 7 – 11 | | | | |
|--|----------|---------|-------|----------------|
| Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| 0% | 10% | 9% | 45% | 36% |

7. The hazards are easily recognizable. (*Average Response 3.77*)

Hazards in this session included the spilled material, missing idler guard, and broken rail.

8. The questions that are asked with each hazard were clear. (*Average Response 4.23*)

9. The possible answers were clearly written and easy to understand. (*Average Response 4.62*)

10. It was clear what the animations for selecting a wrong answer were trying to show. (*Average Response 4.00*)

11. The lock-out, tag-out process was easy to complete. (*Average Response 3.54*)

The lock-out, tag-out process deals with the entire process of turning off the breaker, picking up the lock, placing the lock, taking the key, and placing the tag.

Ease of Completing Tasks – Statements 12-13 – Average 4.00

| Ease of Completing Tasks – Rates of Agreement for Statements 12 – 13 | | | | |
|--|----------|---------|-------|----------------|
| Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| 0% | 8% | 27% | 23% | 42% |

12. It was easy to turn on the belt (sound the alarm and turn the lever). (*Average Response 4.23*)

13. It was easy to find and replace the broken component on the belt. (*Average Response 3.77*)

Appendix E: Usefulness Study Survey Questions and Responses

1. What are some advantages of a typical training method you are familiar with over the reviewed application?

- Typical methods are more common so most people are familiar with those methods of learning and it does not require interaction with a computer.
- There is an instructor who is telling you exactly what you need to know, who you can interact with, and who can answer questions.
- Typical training accommodates more learning styles and allows for covering learning disabilities.

2. What are some of the advantages of the reviewed prototype application over the typical training methods?

- That the VR application allows personal involvement, interaction with the training in a (close to) real world environment with consequences and feedback to actions.
- The VR allows for a wide range of information material.
- The VR allows the user to rehearse tasks and not just have someone tell you about it.

3. What features of the reviewed application do you see as the most beneficial for learning the training material?

- The user is performing the task in the required sequence rather than just looking, listening, or reading about it.
- It allows for the trainee to interact with the environment to perform a job hands on. Testing the trainee of their ability to perform the task in real life.
- It allows for the demonstration of cause/effect situations and shows what would likely happen in real life if the required process was not followed

4. What challenges/ shortcomings do you see in learning the training material using the reviewed application?

- Usability for the older generations or individuals who are not familiar with computer/video games and their navigation.
- Applying the material for all education and computer skill levels so that the entire industry population can use it.

5. *Do you think the proposed training application is an effective way to learn the material? Why or why not?*

- That the VR gives them an interactive experience where they could rehearse processes safely.
- That the users were able to view processes step by step in the instructional-based session and then try them out in the task-based module.
- That the interaction gives them control over their training.

6. *Which method of training do you perceive as a more effective way of learning? Why?*

5 yes

- It allows for an interactive, self controlled training
- The user can view the process and rehearses process and not just read about it. They can experience the consequences without the danger of a real life environment

3 no

- Allows a personal interaction with an individual of experience who can answer questions
- The typical training methods allow for learning by individuals who do not need to be computer literate or learn better in a classroom setting.

Appendix F: Usability Study Survey

VIRTUAL REALITY USABILITY EVALUATION

This usability evaluation is being used to test the usability of a virtual reality application that has been developed to be used as a safety training program for conveyor belts. Your agreement with the statements that are asked will help with determining what information needs to be explained more clearly, what needs to be modeled easier, and if the instructions for completing the session are clear.

The evaluation process will be as follows:

- Complete the “DEMOGRAPHICS” portion of the questionnaire.
- Complete the first module of the program.
- Complete the “MODULE 1” portion of the evaluation.
- Complete the second module of the program.
- Complete the “MODULE 2” portion of the evaluation.
- Complete the “GENERAL QUESTIONS” portion of the evaluation.

Module 1 is an instructional-based module that will take you along an automated path. Here you will be taken to 6 different stations with various hot-points. Read the instructions and click on BEGIN SESSION to start. Please take note of information being presented, the method of presentation, and the way in which you interact with the environment.

Module 2 is a task-based module that will test the skills of the user. You need to navigate yourself around the environment and complete the instructed tasks. For the purposes of this evaluation, it is more important for you to focus on your interactions with the environment than on the final score and session outcome that is recorded.

Thank you for your participation in this evaluation process.

VIRTUAL REALITY APPLICATION

USABILITY QUESTIONNAIRE

Date: _____

DEMOGRAPHICS

Demographics are only going to be used to track trends; no personal information will be released.

1. What is your gender? (circle one) male female

2. What is your age? _____

3. What is your occupation? (please indicate which best describes you)

| | | |
|------------------|-----------------|-------|
| Student | Mining | Other |
| BC | 0-5 Years | _____ |
| Mining | 5-10 Years | — |
| Mining w/ intern | < 10 Years | — |
| Safety Center | Position: _____ | |
| Other _____ | | |

4. Have you had experience with training on conveyor belts before? Yes No

5. Have you been in charge of safety or a safety training program before? Yes No

6. Have you played first person (shooter type) games on the computer before? Yes No

If yes, was it a keyboard and mouse navigation control game? Yes No

If yes, how often do you play these types of games?

- not very often
- less than 5 hours a week
- between 5 & 10 hours a week
- more than 10 hours a week

7. Have you taken any type of virtual reality training on a personal computer before? Yes No

STOP HERE! Do not continue to the next session until you have completed Module 1 of the virtual reality application. At that time complete the “Module 1” session of the application.

MODULE 1 (Instructional-based Module)

After completing the Module 1 of the application please answer the questions related to that section and stop before answering the questions for Module 2 (the task-based module).

To the best of your ability rate your level of agreement with the following questions:

1. The instructions were clear and easy to understand.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

2. The **navigation** of the instructional-based session is simple to use and easy to get used to.

Navigation: the user's ability to move through the environment.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

3. The safety related information presented is understandable.

Safety related information: guarding requirements, proper clothing apparel, lock-out &tag-out

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

4. The information about the components is understandable.

Components are the pieces of the belt. i.e. Return Idler, Head Pulley, etc.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

5. It was easy to tell what piece of the conveyor the captions are referring to.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

6. The information about the hazard issues is understandable.

Hazard issues: missing railings, missing guarding, pinch-points

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

7. The information that was a menu structure was easy to understand and well organized.

Menu structure: the information presented outside of the virtual environment. i.e. safety attire, conveyor maintenance, and conveyor damage.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

8. The method of presentation of the information is easily understood.

Method of presentation: the text, animation, menus, etc. are easy to understand.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

9. The animations to explain processes (lock-out & tag-out, start-up) were easy to understand.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

10. Animations were helpful in order to understand what the textual information was talking about.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

General Comments for Instructional-Based Session:

STOP HERE! Do not continue until you have completed Module 2 (the task-based section) of the virtual reality application.

MODULE 2 (Task-based module)

After completing Module 2 (the task-based section) of the application please answer the questions related to that section.

To the best of your ability rate your level of agreement with the following statements:

1. The instructions were clear on what to do.

Please rate the instructions dealing with how to complete the tasks and identify hazards.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

2. The mouse controls were easy to get used to.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

3. The keyboard controls were easy to get used to.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

4. The objective was easy to understand.

Objective: the scenario that was created “Pre-shift inspection...”

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

5. It was easy to navigate through the session in order to complete the desired tasks.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

6. The tasks I had to complete were clearly understood.

Tasks in this session included identifying hazards, starting the belt, and replacing broken component.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

7. The hazards are easily recognizable.

Hazards in this session included the spilled material, missing idler guard, and broken rail.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

8. The questions that are asked with each hazard were clear.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

Questions that were not clear please comment on here:

9. The possible answers were clearly written and easy to understand.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

Answers that were not clear please comment on here:

10. It was clear what the animations for selecting a wrong answer were trying to show.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

Answers that were not clear please comment on here:

11. The lock-out, tag-out process was easy to complete.

The lock-out, tag-out process deals with the entire process of turning off the breaker, picking up the lock, placing the lock, taking the key, and placing the tag.

| | | | | | |
|---------------|---|--------------|---|---------------------|---------------|
| 1 Strongly | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------|---|--------------|---|---------------------|---------------|

disagree

12. It was easy to turn on the belt (sound the alarm and turn the lever).

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

13. It was easy to find and replace the broken component on the belt.

| | | | | | |
|---------------------------|---|--------------|---|---------------------|---------------|
| 1 Strongly disagree | 2 | 3 Neutral | 4 | 5 Strongly agree | I do not know |
|---------------------------|---|--------------|---|---------------------|---------------|

General Comments for Task-based session:

Please continue to the final section.

General Questions:

1. The sessions were coordinated well to help with the understanding of the environment.

| | | | | |
|-------------------|---|---------|---|----------------|
| 1 | 2 | 3 | 4 | 5 |
| Strongly disagree | | Neutral | | Strongly agree |

2. The information presented in the instructional-based session helped to complete the tasks in the task-based session.

| | | | | |
|-------------------|---|---------|---|----------------|
| 1 | 2 | 3 | 4 | 5 |
| Strongly disagree | | Neutral | | Strongly agree |

General Comments:

Thanks for your participation!