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

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.

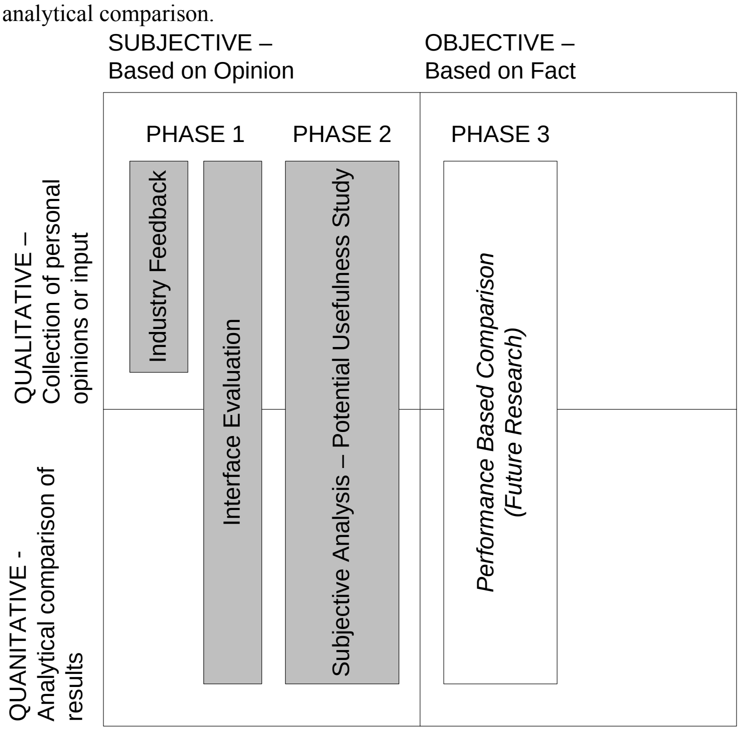

TABLE 1: Evaluation phases

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.

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 2. 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 2: Current industry training programs

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.

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 1, 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 1: 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.

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 (Fig. 2). 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 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.

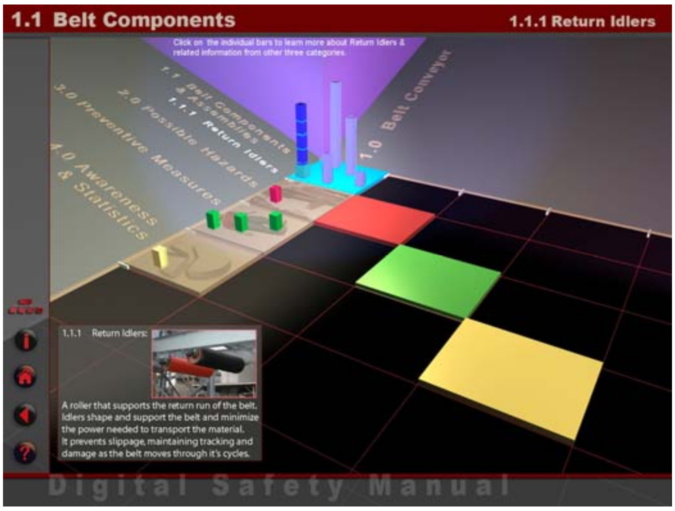

Figure 2: Screenshot from the DSM showing navigation through the 'Belt Conveyor' category

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 (Fig. 3). 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 (Fig. 4). The industry feedback part of the application evaluation (Fig. 4a) 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.

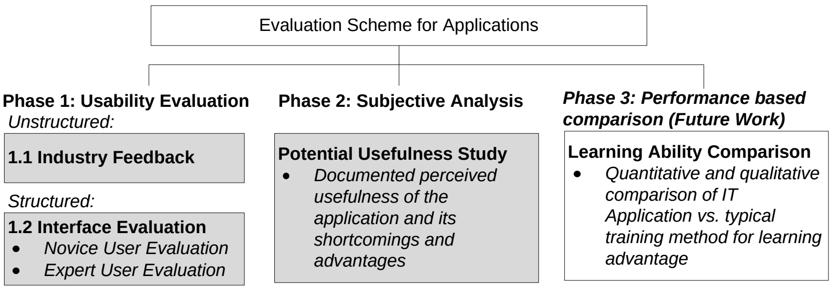

Figure 3: Evaluation Scheme

The revised versions of the two applications were used for the second part of the usability evaluation, the interface evaluations (Fig. 4b). 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.

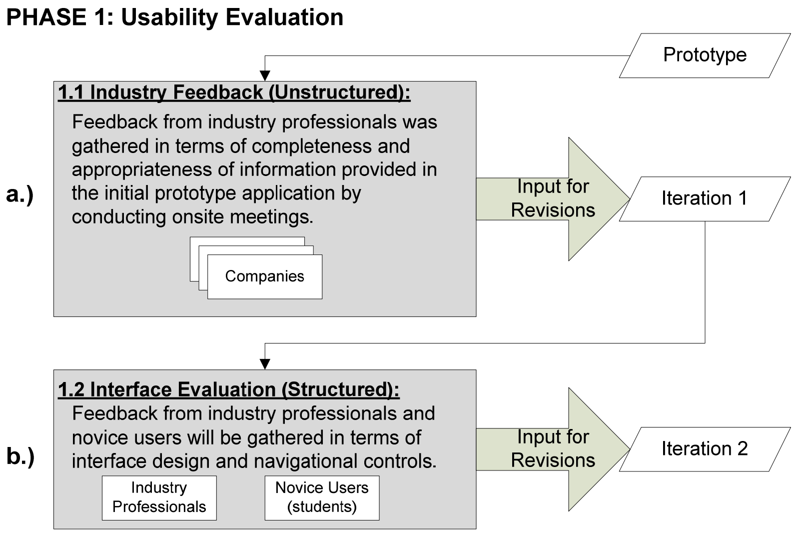

Figure 4: Details of Usability Evaluation (Phase 1)

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 (Fig. 5) 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.

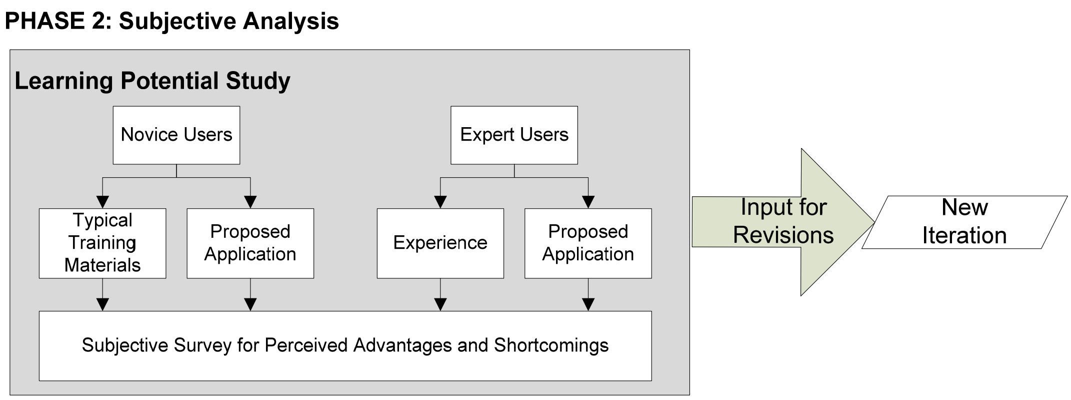

Figure. 5: Details of Subjective Analysis Phase

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 (Fig. 6). 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.

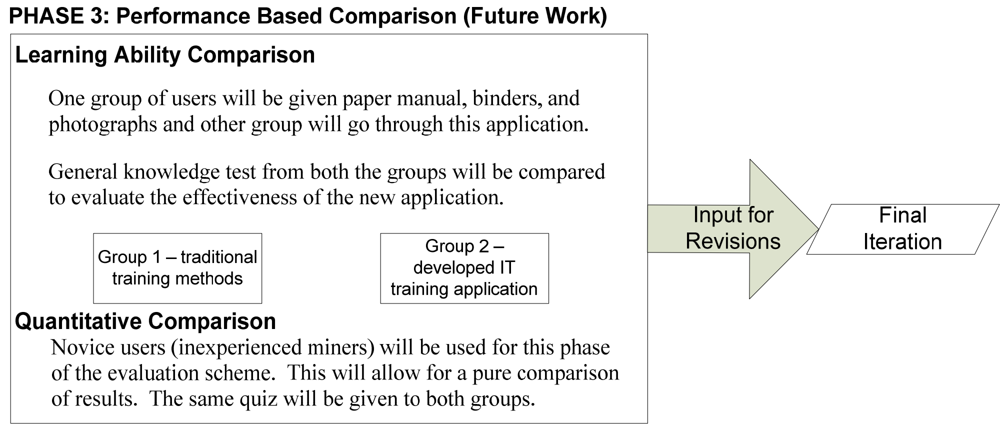

Figure 6: Details of Performance Based Comparison Phase

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.

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.

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 cad add to the typical training methods currently in use within the industry.

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