EVALUATING THE INFLUENCE OF VIRTUAL REALITY-BASED TRAINING ON WORKERS' COMPETENCIES IN THE MINING INDUSTRY

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ABSTRACT

The Australian mining industry has achieved remarkable performance and safety results through continuous improvement of its training standards. Interactive virtual reality-based training is the most recent technology used to enhance workers' competencies in a safe and controlled environment that allows for replicable testing of extreme event scenarios. Like any other training method, VR-based training needs to be assessed in order to evaluate the advantages and limitations of this innovative technology, compared with more traditional approaches. Our research aims to design and implement an evaluation framework that can be used to assess VR-based training programs developed, amongst other training methods, by Coal Services Pty Ltd, a pioneering training provider for the coal mining industry in Australia. Our research focuses on specific training programs developed for mining rescue brigades. These teams are made up of highly specialized miner volunteers who are in charge of primary response in case of major incident. The evaluation framework aims at identifying adequacy between competency needs, technological capabilities and the implementation of interactive simulation. Research outcomes are meant to provide evidence-based information on the advantages and limitations of VR-based training for mining rescue brigades. The evaluation framework is flexible enough to be applied to other types of training for the mining industry or even to be adapted for use in other industries.

Keywords: Virtual Reality, Interactive Simulation, Mining Industry, Training, Safety

1. INTRODUCTION

Computer simulation as a learning environment has progressively embraced technological innovations ranging from chart-based interfaces to fully immersive environments (Bell, Taseen et al. 1990, Jou and Wang 2012). Virtual Reality (VR) provides both immersive and interactive features, allowing users to 'feel' that they are actually in the training environment (Raskind, Smedley et al. 2005).

Best practice in the mining industry includes extensive initial and professional training for staff involved in field operations. Simulator-based training is now frequently used to both establish and maintain this training. A VR environment, which is an interactive 3-D representation of the mine, has a high potential to enhance miners' safety through improved techniques for training, retraining and up-skilling. Mine sites are complex underground environments, and a 2-D representation of the environment would not be effective for most training purposes since some relationships might not be present and might be neglected unintentionally (Stothard 2007).

In case of emergency, rescue brigades are the first teams to access a mining incident. Their members are highly skilled volunteers, selected by mine managers at each production pit. Rescue brigades attend frequent training sessions in order to perform effectively in an emergency situation. A VR-based training program for rescue brigades provides a safe environment to perform collective drills for various emergency scenarios. During these sessions, trainees can improve their technical and non- technical skills.

Previous research has showed that flight simulators were very successful at bringing learning and theory into practice in a supervised, safe but highly realistic environment (Deaton, Barba et al. 2005). Despite the rapid development of VR-based training in the mining industry there is no formal evaluation of its impact on miner's skills and competences. Furthermore, due to the specificity of underground mining, it would be dangerously misleading to extrapolate training transfer results from other industries (aeronautics, automotive).

Hence, we describe in this paper an experimental design aiming at evaluating VR-based training programs developed by Coal Services Ltd for underground rescue brigades in Australia. Then, we present preliminary results from this on-going research project.

2. BACKGROUND

Historically, the mining industry is one of the most hazardous industrial sectors. Although the industry has achieved significant success in reducing the number of accidents and limiting their consequences, it remains a risky business.

According to NSW Trade and Investment, the average fatal injury frequency rate (FIFR) decreased by 65% between 2007 and 2012. The overall lost time injury frequency rate (LTIFR) also decreased by 58% over the same period while the serious bodily injury frequency rate (SBIFR) decreased by 56% (NSW Trade and Investment 2013). These records suggest that the Australian mining industry has achieved remarkable performance through continuous improvement of its safety procedures. As working environment-related incidents tend to decrease, the bulk of remaining accidents is due to human errors as showed by Williamson (1990) in Australia and Rushworth and colleagues (1999) in the US. Sources of human errors are diverse and need to be integrated into relevant training programs.

2.1. Human Mistakes and Errors

The ‘human factor analysis and classification system’ (HFACS) is a systematic and evidence-based framework aimed to design, assess and enhance the interaction between individuals, technologies (including equipment) and the organisation (Wiegmann and Shappell 2001). HFACS describes human error at each of four levels of failure: 1) unsafe acts of operators, 2) preconditions for unsafe acts, 3) unsafe supervision, and 4) organizational influences and outside factors (Patterson and Shappell 2010).

HFACS has been implemented in various hazardous industries such as civil aviation (Wiegmann and Shappell 2001, Wiegmann, Faaborg et al. 2005, Shappell, Detwiler et al. 2007), air traffic control (Broach and Dollar 2002), logistics (Reinach and Viale 2006, Baysari, McIntosh et al. 2008, Celik and Cebi 2009) and medicine (El Bardissi, Wiegmann et al. 2007).

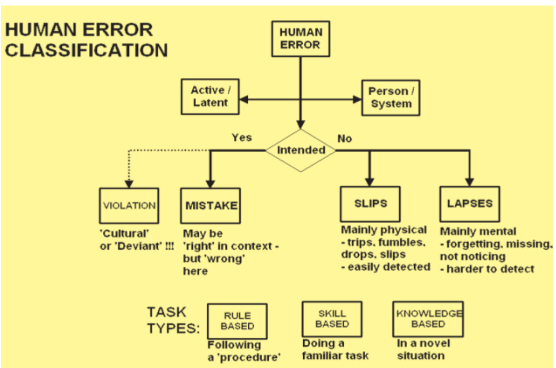

Figure 1: Human Error Classification
(Trade & Investment, 2013)

As will be discussed in our evaluation framework, a list of possible human errors will be compiled from expert’s judgments (mine managers) and compared to the content of VR-based training scenarios for rescue brigades. Their degree of alignment and the success rates at performing requested tasks will inform potential improvements to training programs.

2.2. VR-based Training for Rescue Brigades

Misanchuk (1987) lists the three main factors to evaluate the quality of a training session or program: (1) employee’s ability to accomplish the assigned task, (2) relevance of the training materials to what trainees are expected to do and (3) their motivation to undertake training. Figure 3 shows the framework developed by Coal Services Ltd for rescue brigades. Training requirements and guidelines are based on Australian Coal Mine Health & Safety Acts and regulations.

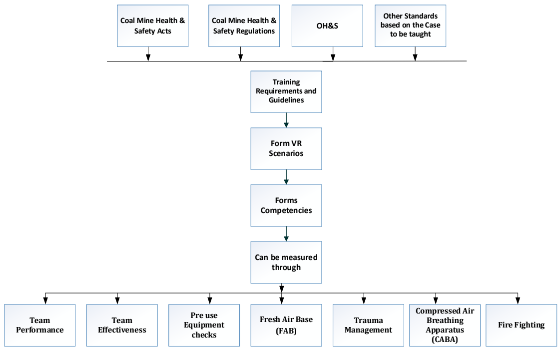

Figure 2: Training Scenario Development and Evaluation (Coal Services Ltd).

Hence, training transfer can be evaluated against: team performance, team effectiveness, pre-use equipment checks, fresh-air base, trauma management, use of the compressed air breathing apparatus and fire-fighting skills.

3. EVALUATION FRAMEWORK

Our evaluation framework (figure 4) includes four nested layers of analysis. Gaps and mismatches at the interface between two layers will help identifying training deficiencies and possible improvements to the current programs set up by Coal Services Ltd.

The outermost layer of the framework corresponds to actual training needs. Interviews with mine managers will constitute the main source of information alongside reviews of the literature produced by the mining industry. The second layer focuses on constraints associated with real-world training (aka traditional training). Coal Services Ltd offers a range of training programs for rescue brigades using various environments: mine sites (real environment), artificial galleries (controlled environment) and 3D simulators (virtual environments). Hence, it will easy to observe responses and performance of rescue brigades across the different training environments. The third layer of focuses on capabilities associated with VR technology. In-depth interviews with VR designers and trainers will help us to better understand potential and actual use of this technology. Finally, the innermost layer corresponds to the learning process experienced by trainees. Over a two-year period, several rescue brigades will be followed through their training programs, focusing on VR-based training sessions and regular safety competitions they have to participate to. Performance during these competitions will be used as a proxy for display of group and individual competences.

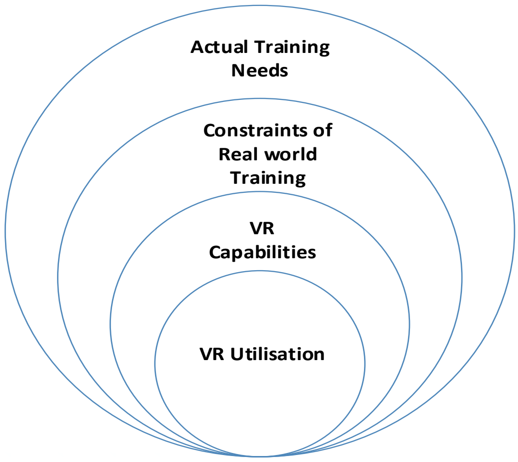

Figure 3: Evaluation Framework

3.1. Actual Training Needs

Subject matter experts (SMEs), such as team supervisors and mine managers, will be interviewed to identify potential training needs. Then, based on their responses, a Likert-scale type questionnaire will be developed. The questionnaire will be distributed to trainees in order to determine: (i) current competency level of trainees in an identified area, (ii) the most relevant training areas to trainee's actual role and (iii) trainee's level of motivation and desire to attend the VR training session. Those training areas which score below 3 for competency and above 3 for relevance will be identified as training needs (McKillip 1987).

3.2. Real-World's Constraints

Focus groups, made up of subject matter experts (SMEs) will be tasked with identifying (i) types of usual human mistakes in mining environments, (ii) constraints associated with real-world training and (iii) potential for VR-based training to overcome these limitations.

3.3. VR-based Training Capabilities

Based on the above, an initial set of desirable VR-based training features will be identified. Interviews with VR designers and trainers will identify: (i) the current capabilities of VRs, (ii) the limitations of VR and potential for upgrade, and (iii) the relevance of VR technology features for training purposes. Another questionnaire will also be developed to identify: (1) the role of simulation features and resources in overcoming the identified training challenges, and (2) the challenges of using each simulation feature. The VR-based training environment used by coal Services Ltd corresponds to a state-of-the-art 360^{o} interactive theatre with 3-D immersive visualization.

3.4. VR-based Training Utilisation

Over a two-year period, several rescue brigades will be followed through their training programs across four training facilities (Woonona, Mangerton, Singleton and Lithgow in NSW). Each trainee will have to fill a short questionnaire before and after a training session in order to record previous experiences, expectations, responses to VR environments and self-assessment of individual performance. Equivalent questionnaires will be provided to trainers as well. Finally, all aspects elicited in each analytical layer will be fed into a competency model (figure 4).

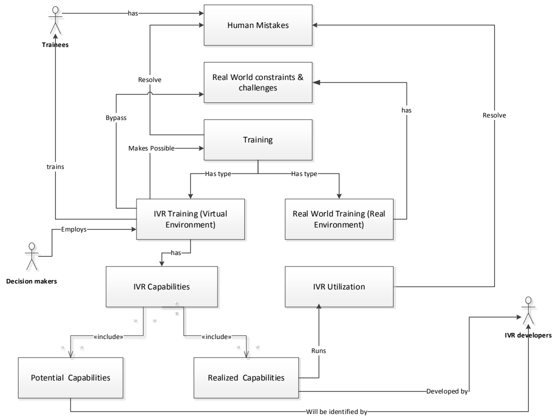

Figure 4: Entity Diagram between different factors affecting competency

Self-assessed performance during training will be first compared with evaluation from trainers. Then, these results will be compared with actual demonstrations of competence during rescue competition. As many rescue brigades will have been through different training sequences (real-world, controlled and virtual environments) and display contrasted individual characteristics (mining experience, team bonding experience, motion sickness…), the quality of training transfer will be assessed using a Hidden Markov Model (HMM).

4. PRELIMINARY RESULTS

This is an on-going research project and results provided below correspond to a preliminary analysis of 25 VR-based training sessions only (93 trainees and 25 trainers in total). Interviews with SMEs and VR technology designers have not been completed yet. Likewise, results from rescue competitions will be collected in coming months.

4.1. Trainee's Perception

Our preliminary analysis concentrates on three subjective evaluation criteria: (i) perceived success, (ii) perceived usefulness and (iii) perceived realism. The first one aims at eliciting trainee's perception of his performance during the VR-based training session. The second one aims at evaluating how much trainees learnt during the session. Finally, the third one focuses on eliciting trainee's opinion on the degree of 'realism' of the VR-based training session.

Nearly 87% of the trainees felt that they had been 'relatively successful' to 'very successful' at completing requested tasks during the training session. Likewise, 90% of the trainees thought that the VR-based training session had been 'useful' or 'very useful' for the development of their skills. Only 22% of trainees thought that the VR environment was 'realistic' or 'very realistic' while 34% felt that it was 'unrealistic' or 'very unrealistic' (44% of trainees neither agreed nor disagreed). Reasons provided to justify the lack of realism ranged from the inability to 'walk' through the scenario (trainees stand in the middle of the theatre and the virtual environment revolves around them) to specific (and unrealistic) details that spoilt the experience.

A cross-tabulation between perceived 'usefulness' and 'realism' criteria shows that 32% of the trainees who found the training session 'useful' or 'very useful' considered the VR environment as 'unrealistic' or 'very unrealistic' while another 45% had a neutral perception of its degree of realism (figure 5). Although these are only preliminary results drawn from a relatively small sample, the apparent dichotomy between both criteria is worth investigating further when more data will be available.

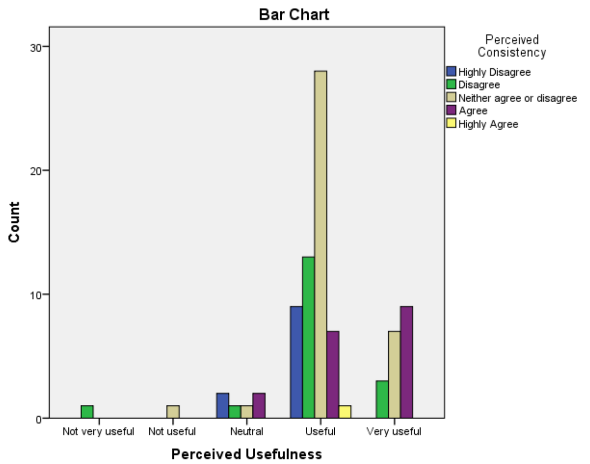

Figure 5: relationship between perceived usefulness and consistency (realism) of the VR-based training session (85 valid trainee's responses).

4.2. Trainer's perception

Although our small sample (25 trainers) does not allow us to draw any statistically significant conclusion, figures show that trainers are slightly more positive about the usefulness of training sessions and performance of rescue brigades during training. 36% of trainers (9 cases) consider that their session was 'very useful' and 'highly successful' while 52% of trainers (13 cases) considered that their session was 'useful' and 'successful'.

A cross-examination of responses from trainees and trainers was conducted using a Mann Whitney U test as most variables don't display Normal distributions. Comparison between perceived usefulness from trainee's and trainer's viewpoints show that there isn't any significant difference between both groups ($Z=-1.563$; $p=.118>.05$). Likewise, comparison between perceived success from trainee's and trainer's viewpoints show that there isn't any significant difference between both groups ($Z= -0.967$; $p=.333>.05$).

These preliminary results start to inform the innermost part of our evaluation framework. Competition outcomes will allow us to evaluate the quality of training transfer according to various training sequences over a two-year period. Later on, interviews with SMEs and VR designers will allow us to inform outer layers of our evaluation framework.

5. CONCLUSION

This research aims to evaluate the effects of VR-based training on the competency of rescue brigades in the mining industry. Hence, a research framework has been proposed to qualitatively evaluate and assess the role of VR-based training in achieving these competencies. The proposed framework can be used as a guide to evaluating the adequacy of implementing interactive simulation in order to improve competency and prevent or deal successfully with accidents in different industries.

This framework aims to collect a broad range of data to help with a qualitative analysis of the impact of mining simulators on improving workforce competency and safety. The evaluation framework is flexible enough to be applied not only to other types of training for the mining industry but also to be adapted to other industries. Our evaluation framework will be applied to four VR-based training facilities operated by Coal Services Ltd in NSW, Australia.

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