THE FEASIBILITY OF APPLYING VIRTUAL REALITY SIMULATION TO THE COAL MINING OPERATIONS

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Abstract

In the last two decades, equipment used in the coal mining operations has become much more sophisticated. The way that work is organised and performed in the industry has also changed significantly. Changes in equipment specification or procedures inevitably means that the risk associated with that equipment or procedure also changes.

In an attempt to address this the Joint Coal Board Occupational Health and Safety Trust (JCB) commissioned the University of New South Wales Mining Research Centre and Mine Site Technologies to perform a feasibility study into the development and deployment of Virtual Reality (VR) based training simulators in the New South Wales Coal Industry. The main aims of the study were to identify, the key providers of VR Technology, the VR options available to the JCB and the information that would need to be included in any simulator. It was anticipated that a critical assessment of these components would produce a format for a cost effective, state of the art simulator that could be readily accessed by all mines.

The expectations of the feasibility study were that VR should offer three-dimensional (3D) simulations that are interactive, high-resolution models of real environments based on best practice Safety Management Plans. It was anticipated that the simulations would allow trainees to experience the consequences of poor decision-making and allow them to learn from their mistakes in a safe and forgiving environment. It was envisaged that such simulators would become an addition to the existing training methods used in the industry.

Introduction

This paper discusses the methodology and findings of a feasibility study into the use of VR simulators to train mine personnel. The study was instigated by the JCB as a result of concerns that in recent years, the operation and maintenance of mining equipment had caused injury in the NSW Coal Industry. Two trends may be responsible for these types of accidents. The first is that mining equipment has become more sophisticated and many manufacturers use advanced remote control and computer technology. The second is that the manner in which work is organised and performed in the coal mining industry has changed substantially. Nowadays, the use of contractors and multi-skilling is common. These two trends have altered the level of risk that workers are exposed to due to them performing a greater variety of tasks than before.

The increased complexity in equipment and changes in procedures requires timely and effective training and retraining of personnel to minimise risk.

Nowadays, training in many industries is performed by VR simulation (e.g. aircraft, military, railways). The power of VR simulation is that unfamiliar environments that may present a risk can be accurately modelled and the risks associated with that environment identified. Also, VR simulation can demonstrate the consequences of poor decision making to a user in a safe and forgiving environment.

The JCB quickly realised this potential and embarked on an investigation into the feasibility of applying VR technology to the NSW coal mining industry. This paper discusses the findings of the Feasibility Study.

The concept of applying VR to the NSW coal mining operations

The JCB, UNSW Mining Research Centre and Mine Site Technologies considered the issues of changed risk resulting from complex mining machinery and changed work practices and it was proposed that a solution may lie in the timely and effective training, retraining and continuous improvement of the skills of operators and maintenance personnel through the utilisation of VR technology.

It was proposed that a VR training simulator tailored to the NSW Coal Mining Industry has the capacity to provide the integration of knowledge and skills to achieve safe human responses and enhance existing training methods. Hence the concept of a simulator was developed and this concept gradually crystallised into a requirement for a system that would provide the main elements that describe a model simulator for use in the Coal Mining Industry.

These elements being,

- A Knowledge Management System,
- ‘Best Practice’ Safety Management Plans,
- ‘Best Practice’ Safe Working Procedures,
- A simulator system that would train production and maintenance personnel and assess their competency after training,
- A simulator system that would identify risk takers and facilitate behaviour modification.

Three high-risk items of plant in the form of a Continuous Miner, a Dump Truck and a Roof Bolter were selected for the study. However, it was envisioned that the simulator model would ultimately encompass each piece of mining equipment on site. The pieces of equipment chosen for the study were selected because accidents had occurred in both their operation and maintenance and their use requires the multi-skilling of personnel and the execution of complex tasks.

A plethora of rules and regulations has been established for the operation and maintenance of such mining equipment (Figure 1). However, despite the existence these complex rules and regulations there is a continued occurrence of similar kinds of accidents, as recorded by JCB (1999-2002) statistics, suggesting that there may be deficiencies within these procedures or in their method of delivery.

Alternatively, some other extraneous influences may be present. For example, procedures maybe ineffective due to their not encapsulating learning experiences gained from accidents and incidents that have occurred at other sites in Australia and overseas or, information is available, but not in a form which makes it easy to collate, distribute, use, or understand. It may be also be that the training and the safety procedures are in order, but they are ineffective because of risk-taking.

Clearly, any considered response to improved training via VR simulation should encompass these issues too. That is, a VR simulation should be established that not only replicates the work place environment into which a trainee or team will be placed, but also establish a simulation that presents the trainee or team with a problem based learning exercise where information relating to the task can be accessed from within the simulation and the trainee’s ability to identify and remedy risks be quantified. The simulation should also show graphically the consequences of poor decision-making or risk-taking behaviour to the trainee to enhance the cognitive learning process.

Methodology

It was intended that the development and deployment of training simulators would be delivered through a four stage scoping study. This paper discusses the first two stages of the study. The two stages were run in parallel.

The initial concept of the simulator and the objectives of the first two stages of the study presented a complex task. Areas that required research ranged from safety procedures to technical issues. A project plan was drawn up that addressed the main objectives shown in Table 1. These main objectives were then broken down into simpler sub tasks that in turn were defined by specific goals and challenges. The information collated by each of these sub-tasks was systematically analysed and the results are discussed in the following sections.

Identification of appropriate Knowledge Management Systems

The study found that many mines are not yet embracing the full power of Knowledge Management Systems. Some were using them for the delivery of Safe Working Procedures and Safety Management Plans. However, many more were not and had not identified that personnel required to access safety information are essentially ‘customers’ and their information requirements need to be carefully analysed to ensure effective delivery. The problem can be described in terms of simple supply and demand, dictated by market forces. If the supply of information is not maintained to the standards dictated by the ‘customer’, the ‘customer’ will lose interest, look elsewhere or simply not bother. For mining risk management, this can be disastrous.

Knowledge Management Systems are computer-based software programs intrinsically linked to the Internet that serve as a tool for information manipulation and exchange. Many mine sites have Internet connections and even remote sites can gain access through modern communications networks. Users seek information through a web-browser run on their PC or Workstation, (Figure 2). This information need not necessarily be text based and may be in the form of a Virtual Mine as described by LeBlanc Smith, Caris and Carter (2000).

An example of a Knowledge Management System is the Standards Australia web site (**http://www.standards.com.au**). The site is accessed through subscription and is interrogated through a sequence of steps similar to that of Figure 3. The site is generally very easy to use and understand. The Standards Australia system is logically arranged and while it is interactive in that the user has to put information into the system to obtain an answer to a query, the system only really provides text-based and diagram-based information in the form of documented rules and regulations. That is, the information is presented to the user but is effectively static and not truly interactive. In a mining situation, a simple text based solution may be inefficient. A computer generated graphical representation of a task, procedure or piece of equipment used for education and training may be more suitable and such systems are described by Denby et al (1998) and Squelch (2000). However, McAlpine and Stothard (2003) discuss methods of stimulating the user into interacting with and understanding mining information through the use of online discussions and web based media. The media is provided as video clips of real people discussing real mining problems, supporting documentation, photographs and a series of problem based learning exercises. The above examples suggest that appropriate Knowledge Management System should include information in a form that encourages users to exchange ideas.

Standard Web Browsers now provide this function and allow synchronous and asynchronous information exchange from within immersive VR simulation software and legacy VR training programs. A highly simplified example of this sort of function is shown in Figure 4 where a user logs on to the site and joins the discussion. If the user has a problem a request for information can be sent. Any of the other participants can respond and provide appropriate advice. This collaborative environment has the potential to become a self-perpetuating system of developing 'best practice' safety management. This type of Knowledge Management System is a very powerful medium for knowledge exchange and risk reduction would be possible through collaborative development of safety information between mine sites by learning from other's experiences.

The Internet based system means that mine-sites other than those in New South Wales can potentially access and enhance database included in a Knowledge Management System thus providing an opportunity to broaden the knowledge base. The key is co-operation and collaboration to achieve a dynamic information source that is constantly rejuvenated.

In conclusion, the examples shown above are essentially PC-based Knowledge Management System that can access a central database server. They are very effective in delivering information and with some modification could provide an interactive Knowledge Management System suitable for the training of mine workers through VR simulation in the NSW Coal Mining Industry.

Identification of Safety Management Plans and Safe Work Procedures

The concept of a VR training simulator requires the inclusion of 'best practice' safety information delivered through a Knowledge Management System. An issue raised by this concept is that the formulation of a system of 'best practice' requires a decision on the format and content of any information. It was proposed by the study that this generic system could be based around an approach to safety management already in operation and augmented by examples from elsewhere in the industry.

The study canvassed widely across the industry and drew upon a variety of models and approaches to Safety Management Plans and Safe Working Procedures currently in use. Assistance was sought from eight underground mines, six open-cut mines, and eight equipment suppliers.

A critical assessment of the procedures of the three pieces of mining equipment revealed that the documentation obtained from each source was the result of each site, operator or manufacturer's interpretation of the guidelines into what exactly a Safe Work Method is. This is probably due to the emphasis that the Coal Industry now places on the use of "Risk Assessment" principles in order to ensure that "Duty of Care" obligations are met. This has resulted in many employers developing their own Safe Work Procedures in isolation as one of the measures to control hazards associated with the tasks being undertaken by their employees. It became evident that enough suitable material exists to form the basis of a coherent knowledge database suitable for inclusion in a VR training program. However, it was also noted that most of the information was not in a truly interactive format.

Information obtained by the study was voluminous and is dealt with in detail by Stothard et al (2001) where a method of presentation was developed in the form of a simple matrix as shown in Figure 5. Due to the volume of information, only one matrix is shown in Figure 5. Company names are removed for confidentiality. Figure 5 shows that across the companies that actually provided information the operators of a continuous miner may be exposed to a minimum of nineteen Safe Working Procedures. At mine 'G' the operator may be exposed to seventeen. At mine 'Q' the operators' exposure may be zero.

Figure 5 shows that at present there is disparity between sources with respect to the development of Safe Working Procedures. Clearly, some sites could benefit from collaboration with others with respect to identifying which procedures require development. A shift is needed from isolated development to collaborative development. That is, to develop a system of 'best practice' suitable for inclusion in a VR simulator tailored to the NSW coal mining industry requires collaboration between mine-sites, equipment manufacturers and minerals councils.

In conclusion, Safe Working Procedures and Safety Management Plans exist at most sites however their implementation, content and delivery require considerable modification for inclusion in any interactive knowledge management system or VR simulator. Due to the scale of the task, it may be more appropriate to consider developing some examples of collaborative best practice safety documentation based on less complex machinery first. Proving the concept will assist in achieving the necessary collaboration required for more complex procedures.

Technology options

The study performed a review of readily available VR technologies and found that VR simulators are effective training tools that allow trainees to make decisions and provide them with the opportunity to see the consequences of their decisions. A review of VR as an industrial training and marketing tool is presented by Squelch (2000) and the conclusions drawn are that VR has the potential to provide relevant and improved training a conclusion that concurs with the finding of Stothard et al (2001). That is, an interactive technology that has the capacity to greatly improve safety through improved training of operators in a safe environment. The study found that VR-based training is an affordable technology and the $3000 VR simulations that Denby et al (1998) describe and that run on personal computers are powerful enough to manage complex VR. Their performance is continually increasing. Williams et al (1998) describe a low cost truck simulator suitable for hazard spotting. Also, the market for VR software is increasing and the price of the development is decreasing. This is a key factor when attempting to make VR simulation technology available at all mines.

The study reviewed VR systems in detail and considered the design and application of a number of simulators and technologies. The conclusions drawn were that the technology and framework for a simulator that could be tailored to the NSW coal industry certainly exists. However, they are fragmented and there is no one combination of technologies that currently satisfies the requirements of a JCB simulator. Simulators have generally been purpose designed for operator training on one specific piece of equipment. The true potential of VR simulators with respect to mine safety and risk management is yet to be realised by mine-sites. Four leading technologies have emerged. They are,

a) The University of Nottingham AIMS Research Unit. They offer Safe-VR, a program that is, interactive, modular in construction, graphically programmed through drag and drop modelling software, and provides hazard spotting, links to video clips, links to a web based database and proven cost effective simulation.
b) Continuum Resources VR offers, platform independent architecture for the Knowledge Management System, interactive VR, immersive environment, modular construction, graphical programming, high quality computer based images.
c) Fifth Dimension Technologies offer, existing continuous miner simulation, interactive VR, immersive VR, real machine controls interfaced to the simulation.

d) Immersive Technologies offer, a dump truck simulator, interactive VR, immersive VR, real machine controls.

These four providers offer high quality simulators. However, Figure 6 shows that none of the four systems satisfy all of the requirements of a simulator suitable for the NSW coal mining industry as described under the concept of the integration of knowledge and skills to achieve safe human responses. A simulator that addresses the main points of the concept of a VR simulator for the NSW coal mining industry needs to incorporate a combination of the positive attributes of the four main technology options in one simulator.

After considering the options available, the conclusion that can be drawn is that the preferred solution is a modular based system that provides the framework for safety and training simulation. The design should be of open architecture using flexible software to allow for site specific and machine specific changes. The software must allow for splicing and pasting of video images and video footage so that the simulator is context sensitive and realistic. The simulations must be represented by textures inputted from digital and/or CAD images of the mining machines and surroundings that the trainee will experience in reality.

Virtual reality training must also be interactive and not just an animation of the task. Unlike in many other training forums, people cannot switch off when being trained on an interactive simulator. The training must be a real life experience for the trainee and the trainee must receive immediate feedback on the consequences of poor decision-making and skill levels.

The system layout that will achieve the desired qualities of a simulator tailored to the NSW coal industry is shown in Figure 7 where the concept of a site based; immersive, interactive simulator with real machine controls that accesses a central database of safety information is demonstrated.

Therefore, the recommended technology for the NSW coal mining operations is a hybrid simulator that includes all the positive attributes of existing technologies. The reasons for selecting the layout of Figure 7 as the most appropriate layout are that it is site based making it easily accessible to trainees. It also propagates site ‘ownership’ and is easier to maintain and keep up to date than a mobile version.

In conclusion, VR simulator technologies are widespread and applied to many situations. The building blocks for a VR simulator that can interact with a knowledge management system appropriate to the NSW mining industry is readily available. It is feasible to apply appropriate VR technology to risk management in the NSW coal industry.

Identifying risk taking behaviour in VR simulations

The concept of the simulator suitable for the NSW coal mining industry requires that the simulator have the ability to determine if an individual is a risk-taker before he/she operates, maintains or supervises the operation or maintenance of mining equipment. This is an important factor in risk reduction and it would be of great benefit to identify trainees prone to risk taking prior to exposure to real mining situations.

In an attempt to address risk-taking behaviour, the study identified a computer-based technology known as the Driver and Operator Assessment Battery (DOAB) that appears to be a system suitable for this task. The DOAB is a computer-based system designed to assess the human factors associated with driving and operating machinery. The system measures those characteristics of human behaviour that place people at greater risk of having an accident and can be used in the selection process or in targeted training such as after an accident. The study believes this system may be applicable to determine if an individual is a risk-taker, before that person operates, maintains or supervises the operation, or maintenance of, mining equipment and may be adaptable for use in a simulator. Stothard et al (2001) consider the DOAB in some detail. It should be noted, however, that the company that strongly promoted the product in 2000, is no longer in existence. This casts some doubt on the product however, the DOAB Battery had enough merit to warrant consideration and a discussion of those merits is as follows.

Generally speaking, computer-based technologies such as DOAB have the potential to overcome the significant drawbacks of conventional testing, including paper and pencil tests with their necessity for literacy skills and the fact that they are static and skills-based. However, before this system is acquired for any simulator, it is recommended that further investigations be carried out in the form of a field trial at a mine site to assess the performance in a real-life mining situation. The DOAB was developed to overcome some of the drawbacks of the numerous conventional, static "paper and pencil" aptitude tests.

Driving and operating is an "over learnt" skill and it is the wrong use of these skills, that can cause accidents. The DOAB system consists of a five interactive computerised battery sub-tests which measure, in an operating environment, those human factors thought to contribute to increased accident risks. These factors include:

- Reaction time problems (too fast or too slow),
- Impulsiveness,
- Appropriateness of risk-taking.

- Tracking or fine motor skills deficiencies.
- Tracking measures directional control; and,
- Division of attention.

The promoted benefits of DOAB over a paper-and-pencil aptitude test include,

- Its interactive nature allows DOAB to be individually structured;
- Tests required to be performed are similar to normal operating tasks;
- Factors like impulsivity and optimal reaction time are virtually impossible to accurately assess in written form;
- Measurements are made in units such as milliseconds and millimetres;
- It is virtually impossible to artificially create a good impression; and,
- All assessment and scoring is done by the computer and is thus objective and accurate.

The trainee is assessed in a one-on-one situation in a non-threatening environment. The promoters suggest it should be used in conjunction with skills and knowledge testing and operator record evaluation to increase its effectiveness. There is little available information of actual field investigations on the use of the DOAB or any other similar, computerised battery testing system. The results of a test in Newcastle using DOAB and a full driving simulator were subjected for analysis and it was found that four factors were significant. These were risky behaviour, goal attainment, efficient perception and fast driving. Driver simulation offers considerable advantages in the form of control by the experimenter over the experimental variables and ability to accurately measure physical aspects such as pedal and steering wheel use. This could clearly be modified to a mining scenario.

The DOAB aims to assess individuals before they do generic training to find out what their learning capacities are and if they have weaknesses or problems. The DOAB can be applied in the recruitment and selection phase but also at other times such as moving to new rosters. Another use is in post-accident investigations. As far as fitness-for-duty is concerned, an individual's response to different substances is revealed by different criteria. For example, if the trainee has taken alcohol or marijuana, the tracking skills are affected.

Computer-based assessments of human behavioural traits such as those offered by DOAB should be tested by a survey of operators in the coal mining industry to see if they perceive the value of such an assessment. The cost of the assessment must be reasonable in comparison with the alternatives, or an outcome may be the bypassing of the assessment to go straight to the real life operating system. Table 2 is an assessment of the applicability of the DOAB to the operation of three high-risk systems used in mining. The relevance of each component to each system has been graded from very high, high, medium, and low. Because it was originally designed to assess driving factors, the assessment is probably most suited in its current form to operating trucks. It can be seen that reaction times, tracking skills and division of attention are extremely important factors in mining and as far as continuous miner operations are concerned, it is essential that operators, supervisors and maintenance personnel are not risk takers – the punishment in real-life can be severe. Operators, supervisors and maintenance personnel need to have a very strong ability to be aware of their environment and be able to carry out the tasks while being subjected to significant (and non-significant) stimuli. Therefore the DOAB on this component is also very high. In roof bolting, it is essential that risks are not taken – a good operator has to err on the side of caution rather than being reckless. Like the operation of a continuous miner, the roof bolter operator must be aware of events happening in the area that may be of critical significance and thus division of attention must receive a very high grading. Clearly, the table indicates that the DOAB has some relevance to all three systems. This alone is probably sufficient justification to proceed to actual trials of operators, maintenance personnel and supervisors in a real-life mining context with a view to including DOAB in a VR simulator**.**

Conclusions

Changing work conditions and machinery specifications have altered the risk associated with the operation and maintenance of mining machinery. To address this change, the JCB commissioned a scoping study into the feasibility of using of VR technology to train mine workers in the NSW Coal Mining Industry.

A concept of a simulator suitable for the NSW coal mining industry was developed and a series of prerequisite elements for simulator training were established. These were, a knowledge management system, ‘best practice’ safety documentation, a simulator that would train maintenance and production personnel and assess competency and can identify and modify risk-taking behaviour.

An example of a Knowledge Management System and the components that ensure true interaction with the Knowledge Management System are identified. The level of interaction for deep learning of tasks has also been highlighted. Levels of interaction range from video clips to information exchange through online discussion and problem based learning.

The safety documentation and procedures for three high-risk items of machinery was acquired from a number of sources. This documentation was found to be variable and demonstrate that to develop a system of ‘best practice’ safety documentation requires collaboration between mine-sites, manufacturers and minerals councils. Developing safety documentation in isolation does not incorporate the experience gained by others and may provide an opportunity for repeated incidents. Developing a system of ‘best practice’ for all three pieces of equipment is a large task. It may require the collaborative development of ‘best practice’ Safety Management Plans on a smaller scale to prove the concept and refine the method. Proving the concept on a smaller scale may assist in identifying the level of collaboration between companies needed to produce ‘best practice’ Safety management Plans for larger pieces of equipment. Collaboration of this type may assist in developing the Safe Working Procedures at sites where the Safe Working Procedures are less developed.

The technology options available to the JCB for VR simulation are well developed. Four interactive VR systems are presented and they range from desktop applications to larger complex vehicle simulations. Their power is that they are interactive and allow the user to learn through performing a task. However, none has all the attributes required to satisfy the prerequisite elements identified by the concept of a VR simulator for the NSW coal mining industry. What is required is a hybrid simulator composed of the positive attributes of existing simulators that are combined with an interactive Knowledge Management System.

The identification of risk takers is an area that requires work. DOAB is a software system that claims to be able to identify risk-taking traits thus allow behaviour modification. This system could potentially be an addition to the simulator and run during simulator training. However, field trials in a mining environment are required prior to its application. The developers of the system are no longer in business and the study identified the systems merits however, there has been little take up of the system. Again, a hybrid system based around DOAB may be more appropriate for a simulator suitable for the NSW coal mining industry.

Overall, the development and application of VR simulation to the coal mining industry is feasible. VR technology is established and proven in mining through truck simulations and continuous miner simulations however, to apply the simulations to the NSW coal mining industry requires the development of a hybrid simulator that encompasses experience and safety documentation from many sources thus enabling best practice to be established.

Further work

The JCB are continuing with the development of VR simulators and expect to have three functional simulations that build on the experience gained from the feasibility study. The simulations will be available by late 2004.

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List of Figure Captions

Tables

Stage 1
• Identify suitable or easily adaptable Knowledge Management Systems
• Identify optimum ‘best practice’ Safety Management Plans for three major items of equipment
• Establish the feasibility of identifying and acquiring optimum Safe Working Procedures for equipment for input into any simulation model.
• Evaluate the feasibility of an industry wide Knowledge Management System.
• Assess how to develop an on-line community of trainees and trainers.
• Assess how to keep the system up to date.
Stage 2
• Identify the function of the simulator.
• Identify the technical specifications of the simulator.
• Identify simulation components

Table 1. Main objectives of the scoping study.

DOAB Component	Reaction time	Impulsiveness	Risk-taking	Tracking	Attention
Operating system					
Cont’ miner operation	medium	medium	very high	high	very high
Cont’ miner maintenance	medium	medium	very high	low	very high
Cont’ miner supervision	high	high	very high	low	very high
Roof bolter	high	high	very high	medium	very high
Haul truck	very high	high	high	very high	very high

Table 2. Applicability of DOAB to mining operating systems.

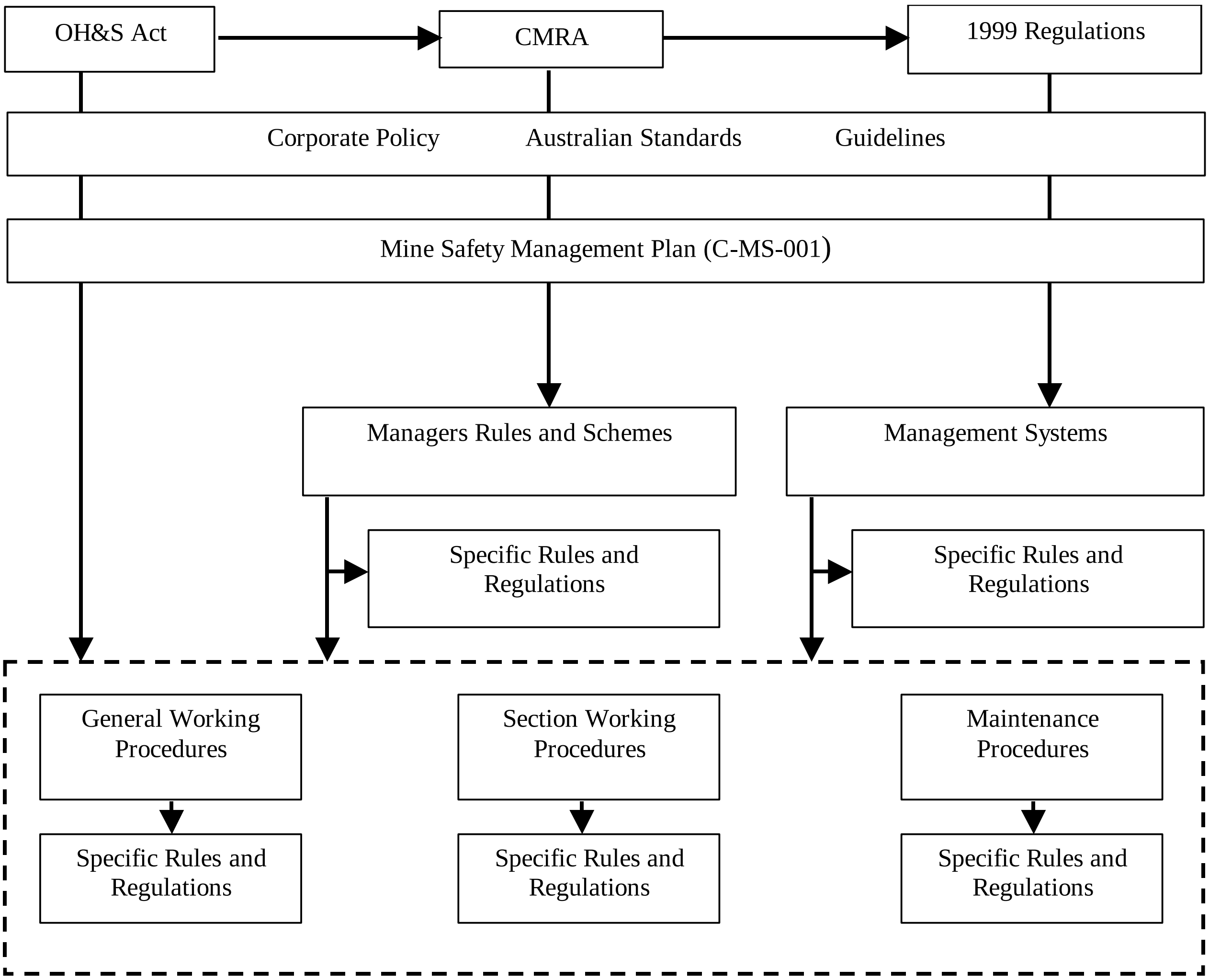

Figure 1. Example of the complexity of the rules, regulations and procedures in the NSW coal industry.

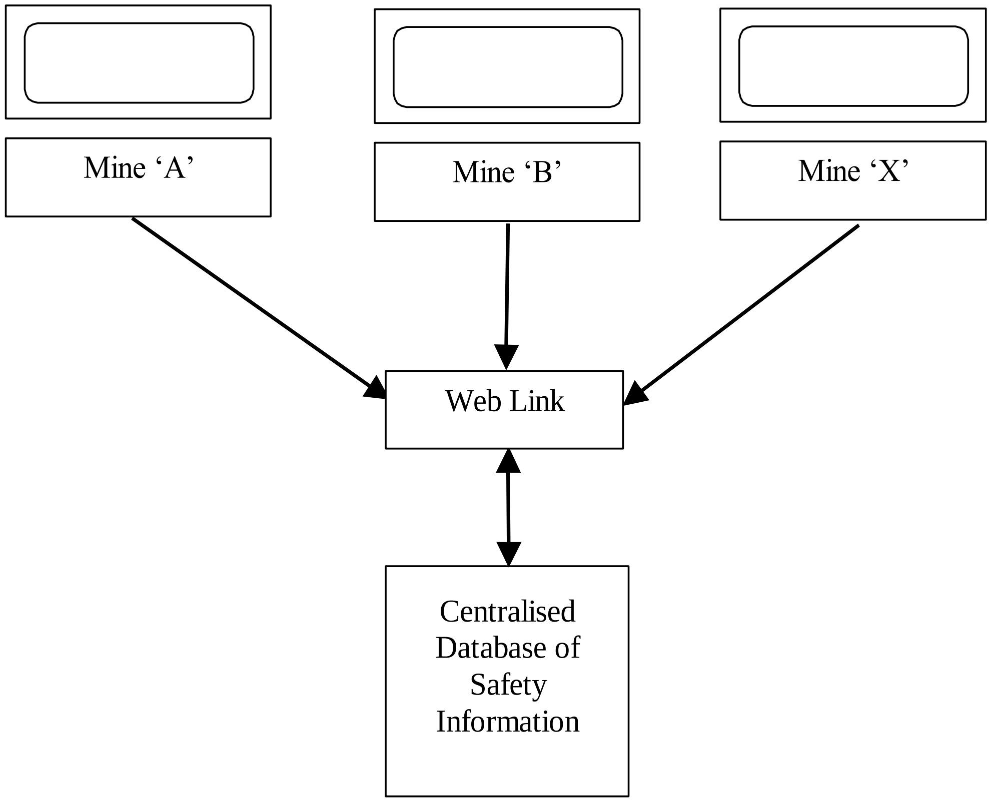

Figure 2. Centralised Knowledge Management System.

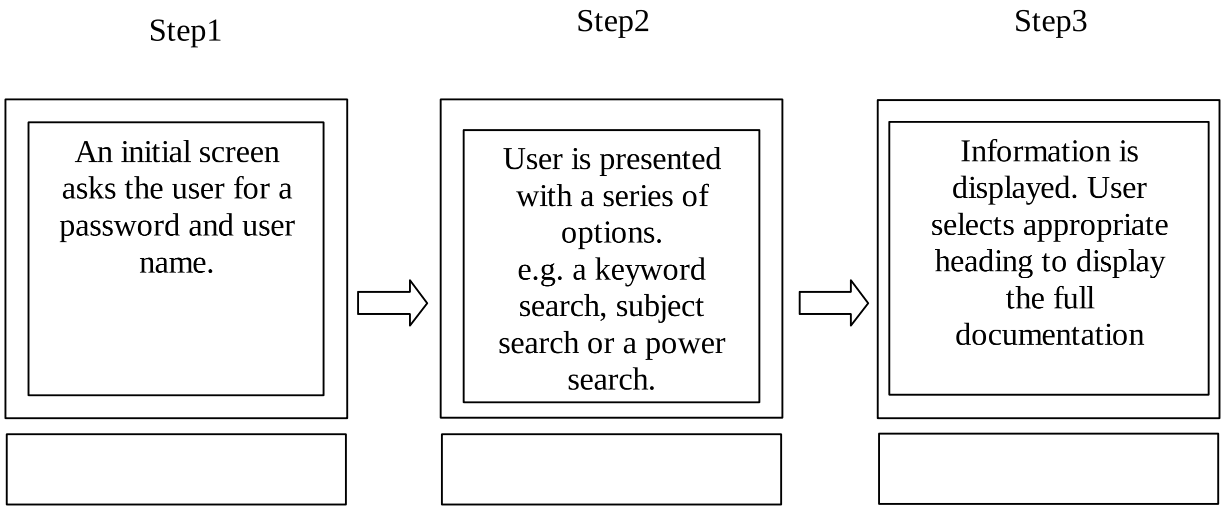

Figure 3. Interrogation of a Knowledge Management System.

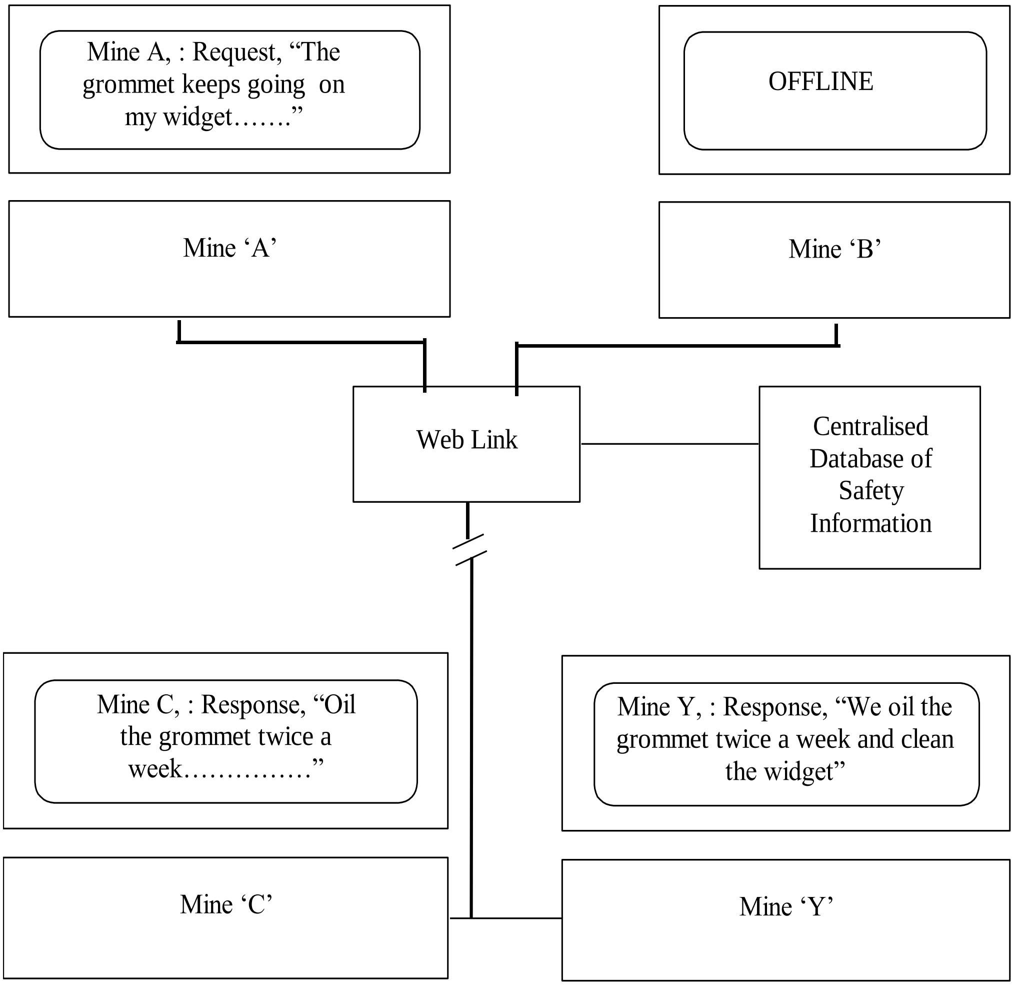

Figure 4. Example of an online discussion.

Contributor

Operator Tasks SWP	A	B	C	D	E	F	G	H	P	Q
Pre Start	V	x	x		x		x	v	x	
Start Up	x	x	x		x		x	x	x	
Flit Miner	v	v	x		x		x	x		
No stand zone (a)	v	v	x	v	x		o	x		
Cut coal		v	x	v	x		x	x		
No stand zone (b)	v	v	x	v			x	x		
Straight ahead cut	v	v	x	v			x	v		
Break right	v	v	x		x		o			
Break left	v	v	x		x		o			
Pillar lift		v	x							
Electrical isolation	v	v	v		x		v		x	
Change picks	v	v	x				v		x	
Fill miner oil	v	v	x				v			
Shut down		v	x				v		x	
Recovery of miner	v						v			
Replace water sprays	v		x				v			
Change cable							v		x	
Lube miner			v				v		x	
Frictional ign. mitigation		v								

v = Written as SWP
x = Training and assessment
o = Part of larger SWP

Note:
Contributor F material was not considered to be readily used as work procedure.
Contributor Q was a supplier who had some suitable material for maintenance but not for operators.

Figure 5. Matrix showing variation in availability of Safe Work Procedures (SWP) relating to continuous miner operator tasks.

Feature	Nottingham VR	5DT	Continuum	Immersive	*NSW VR Simulator*
VR Software	✓	✓	✓	✓	✓
Modular	✓	x	✓	x	✓
Open Architecture	✓	x	✓	x	✓
SWP Platform	x	x	x	x	✓
Machine Interface	x	✓	x	✓	✓
Immersive Environment	semi	✓	✓	✓	✓
Hazard Spotting	✓	x	x	x	✓
Interactive	✓	✓	✓	✓	✓
Applications • Safety	✓	x	x	x	✓
• Training	✓	✓	✓	✓	✓
• Visualisation	✓	x	✓	✓	✓
• Risk Taking	x	x	x	x	✓
• Accident Investigation	✓	x	x	x	✓

Figure 6. Comparison of attributes of VR simulators.

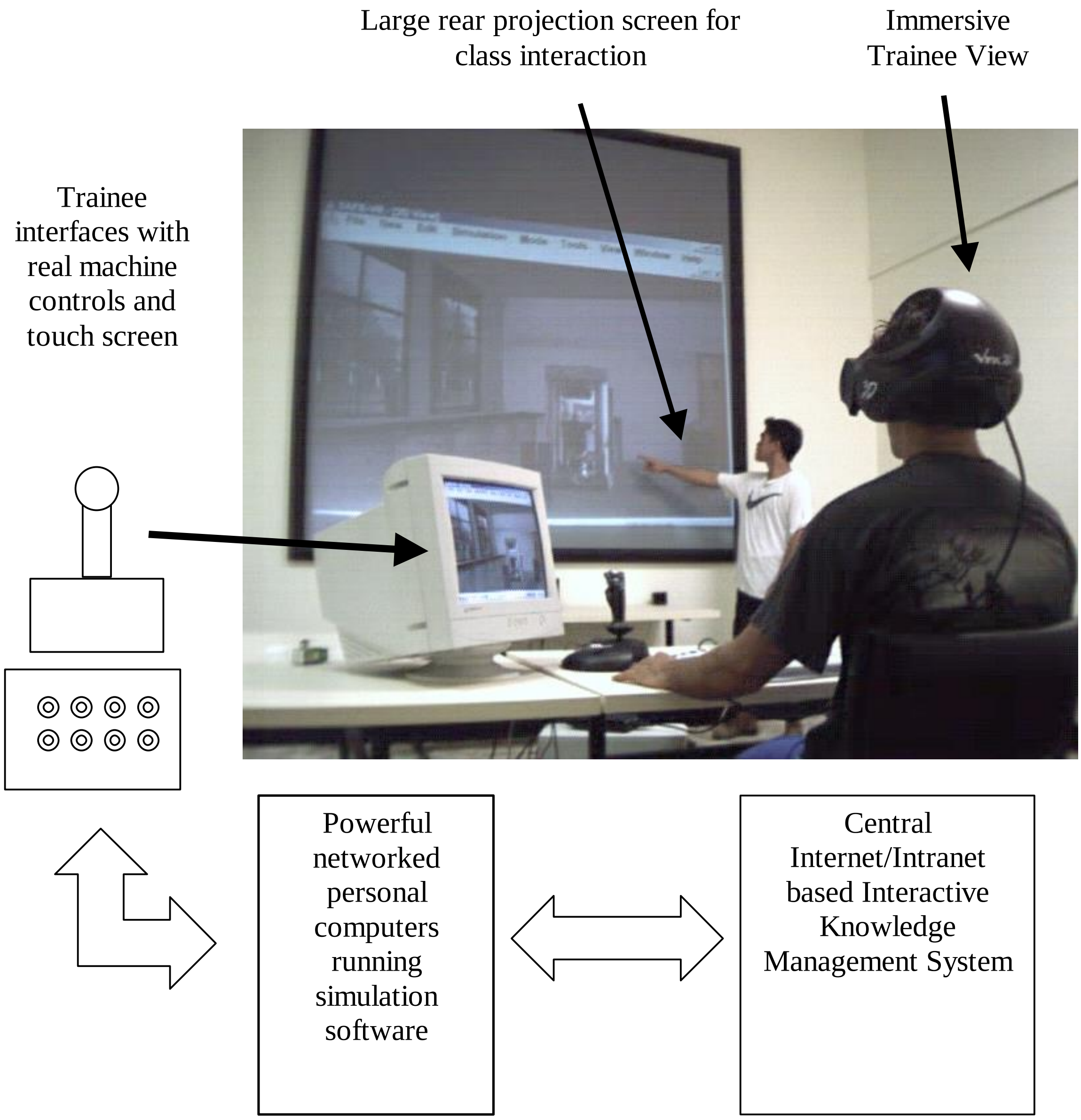

Figure 7. Site based, immersive, interactive simulator with real machine controls.

Heading Levels

Level 1 headings

THE FEASIBILITY OF APPLYING VIRTUAL REALITY SIMULATION TO THE COAL MINING OPERATIONS

Level 2 headings

Abstract

Introduction

The concept of applying VR to the NSW coal mining operations

Methodology

Identification of appropriate Knowledge Management Systems

Identification of Safety Management Plans and Safe Work Procedures

Technology options

Identifying risk taking behaviour in VR simulations

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References