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MINE SITE TECHNOLOGIES

e-minesafe SAFETY AND TRAINING SIMULATOR
The Integration of Knowledge and Skills to Achieve Safe Human Responses

Joint Coal Board
Health and Safety Trust

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Executive Summary

BACKGROUND

The Joint Coal Board (JCB) is concerned about the number of accidents and fatalities associated with the operation and maintenance of equipment in the New South Wales coal industry. In the last decade, equipment has become more sophisticated and the manner in which work is organised and performed in the industry has changed significantly. Therefore, through its Health and Safety Trust, the JCB commissioned a consortium comprising Mine Site Technologies and the School of Mining Engineering at the University of New South Wales to research the introduction of equipment training simulators into the industry. The research is planned to be undertaken in four stages.

This report presents the outcomes of the first two stages. It recommends the development and testing of an interactive, immersive, virtual reality prototype simulator providing true to life imagery. The simulator will be modular in design such that various items of equipment can be plugged in as required. It is proposed that the evaluation of the prototype simulator be based on a continuous miner and a roof bolter, with the option to add a dump truck. This is because a high accident rate is associated with these items of equipment. Most of the research undertaken on the project to date has focused on these machines.

The research has confirmed that JCB Simulators have a huge potential to improve:

- Mine Safety
- Productivity
- Business Performance

RESEARCH APPROACH

A need was identified at the start of the project to:

- Encapsulate knowledge from multiple mine sites by using information age technology to capture and learn from experiences of others, and to
- Provide timely and effective training, re-training and up-skilling in order to keep competencies relevant and current.

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Numerous procedures apply to the operation and maintenance of sophisticated equipment. A simulator offers the potential to not only train and assess the competency of mine personnel in these procedures but also to evaluate the effectiveness of the procedures themselves. In order to do this effectively, the simulator must be designed around the procedures and be simple and inexpensive to update as procedures are modified and added.

Therefore, the research is being staged in the following manner:

Stage 1. A Scoping Study concerned with:

- Identifying suitable or easily adaptable Knowledge Management Systems (KMS)
- Identifying optimum Best Practice Safety Management Plans (SMP) for each of the three items of equipment
- Establishing the feasibility of identifying and acquiring optimum Safe Working Procedures (SWP) for each piece of equipment for input into simulation model
- Evaluating the feasibility of an industry wide KMS.
- Assessing how to maintaining e-minesafe up-to-date
- Investigating how to develop an on-line community of trainees and trainers.

Stage 2. A Scoping Study concerned with determining the:

- Function
- Technical specifications, and
- Cost of a prototype JCB Simulator

Stage 3. Prototype manufacture and fields trials

Stage 4. Full product commercialisation

BENEFITS OFFERED BY VIRTUAL REALITY SIMULATION

The research has established that virtual reality simulation offers benefits relating to:

- Flexibility in time, place, rate and privacy of learning
- Developing understanding and retention of learning
- Staff induction
- Customised ‘on the job’ training in a safe environment
- Refresher training

- Fault-finding
- Equipment assembly and maintenance training
- Visualisation of the hidden
- Visualisation of the future
- The literacy level of the trainee
- Evaluation of consequences of an action
- Communicating complex data
- Identification of risk takers
- Tracking of learning progression and understanding
- Competency assessment
- Consistency of training and assessment
- Accident investigation and reconstruction

REALISING THE BENEFITS OF VR SIMULATION

For simulators to be effective, their development must be based on a 'training needs analysis' rather than just on the blind or spot application of technology. The research has established that in order to achieve the potential benefits of VR simulation for operator and maintenance training in the coal industry, the simulator needs to have the following characteristics:

- Interactive
- Immersive
- Realistic to actual environment, not just stick creatures
- Built on best practice SMP and SWP.
- Allow trainees to make decisions and to experience the consequences of these decisions
- Embedded hazard spotting
- Identification of attitudes and reactions to risk taking
- Simply and quick to keep up-to-date
- Affordability relative to the small size of the market

Nevertheless, it must be appreciated that the difference between a person knowing how a task should be done versus how they actually undertake the task will remain. The attitudes and aptitudes of a person will still determine how they apply the knowledge and skill imparted by simulated training. The IMPS will still apply:

IMPetuous – act without thinking of consequences

IMPatience – knows better but cannot wait

IMPunity – cannot happen to me

IMProvise – contravene SWP

The research has identified that there is potential for VR simulators to assist in identifying persons prone to these IMPS.

TECHNOLOGY OPTIONS

The research has considered the design and application of a number of simulators and technologies. The technology and framework for a JCB Simulator certainly exists. However, it is fragmented and there is no one combination of technologies in the market place that satisfies the requirements of a JCB Simulator. Simulators have generally been purpose designed for operator training on one specific piece of equipment. The developers of the technology have not realised the true potential of VR simulators with respect to mine safety.

Four leading technologies have emerged and been researched in detailed. They are

1. The AIMS Safe-VR, University of Nottingham. This offers the following features:
    - Interactive
    - Modular construction
    - Graphical programming
    - Hazard spotting embedded in the software
    - Environment can be textured to a degree
    - Links to video clips

- AIMS is experienced and has a track record for producing VR simulations
- Can be effectively linked to a web based database
- Cost effective

2. Continuum Resources offering:
    - Platform independent architecture for the Knowledge Management System.
    - Interactive
    - Immersive
    - Modular construction
    - Graphical programming
    - High quality computer based images

3. Fifth Dimension Technologies offering:
    - Continuous miner operator simulation
    - Interactive
    - Immersive
    - Real machine controls
    - Field experience - already trained 400 miners in operations in South Africa

4. Immersive Technologies offering:
    - Dump truck simulator
    - Interactive
    - Immersive
    - Real machine controls
    - Field experience – already trained drivers in operations

These four main players offer high quality simulators. However, the accompanying table shows none of the four systems satisfy all of the requirements of the JCB Health and Safety Trust with respect to the integration of knowledge and skills to achieve safe human responses. The JCB *e-minesafe* Simulator needs to incorporate a combination of the positive attributes of the four main technology options.

Feature	Nottingham VR	5DT	Continuum	Immersive	e-minesafe
VR Software	✓	✓	✓	✓	✓
Modular	✓	x	✓	x	✓
Open Architecture	✓	x	✓	x	✓
SWP Platform	x	x	x	x	✓
Machine Interface	x	✓	x	✓	✓
Immersive Environment	x	✓	✓	✓	✓
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	✓

TECHNOLOGY SELECTION

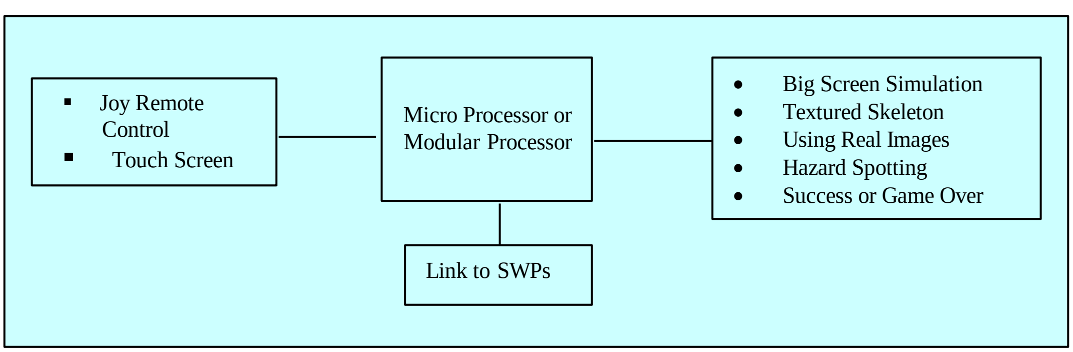
The preferred solution is to build and field test a **MODULAR BASED SIMULATOR** prototype that provides the framework for safety and training simulation across a range of mining equipment. In the first instance, the simulator would be based on delivering interactive training for the operation of continuous miners and the operation and maintenance of roof bolters, including rib bolting. There is an option to 'plug in' a dump truck.

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. Instead of VR 'stick creatures', the simulations must be represented by textures inputted from digital and/or CAD images of the mining machines and surroundings.

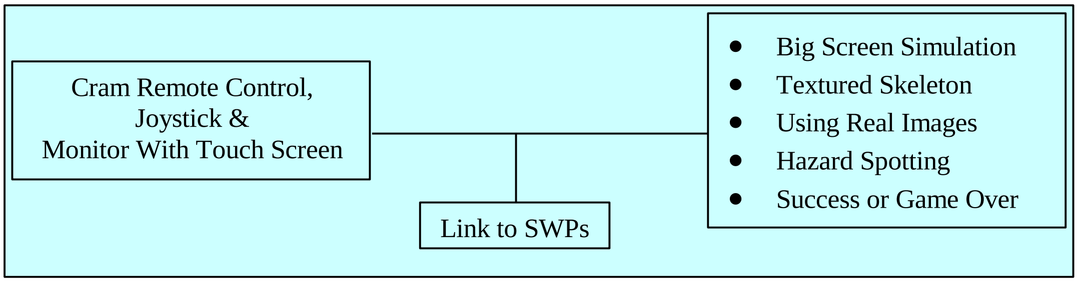
Virtual reality training must be **interactive** and not just an animation of the task. Unlike in many other training forums, people cannot switch off when being trained on an interactive simulator. The training is a real life experience for the trainee. The trainee can receive immediate feedback on the consequences of poor decision making and inept skill, albeit that they do not result in real life penalties.

A key issue identified in the research is the issue of motion sickness when using simulators. The quality of the circuitry comprising the simulator has a significant influence on whether motion sickness occurs. If a person is stationary, motion sickness can develop quickly if the imagery is not refreshed at a high frequency. If the trainee is mobile whilst immersed, motion sickness is less likely to occur. These issues lead to the recommendation that the JCB Simulator should be based on technology that is not solely desktop based. Freedom of movement whilst using a real life control will enhance the quality of the outcome.

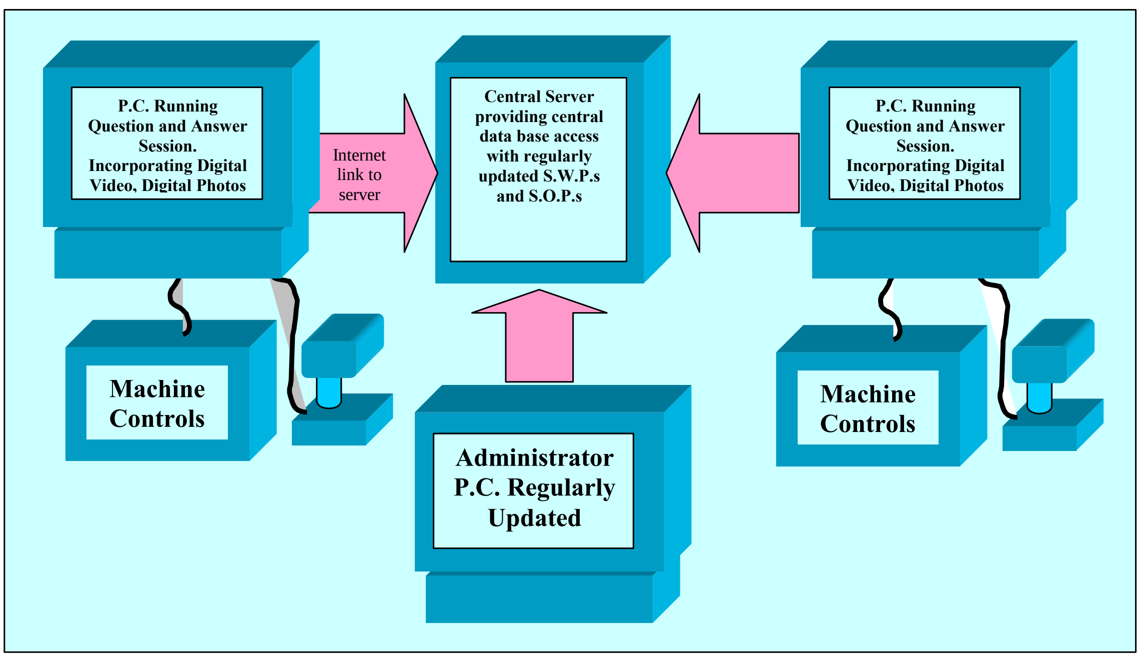
The recommended architecture for operator training and for maintenance training is as follows:
Operator Training



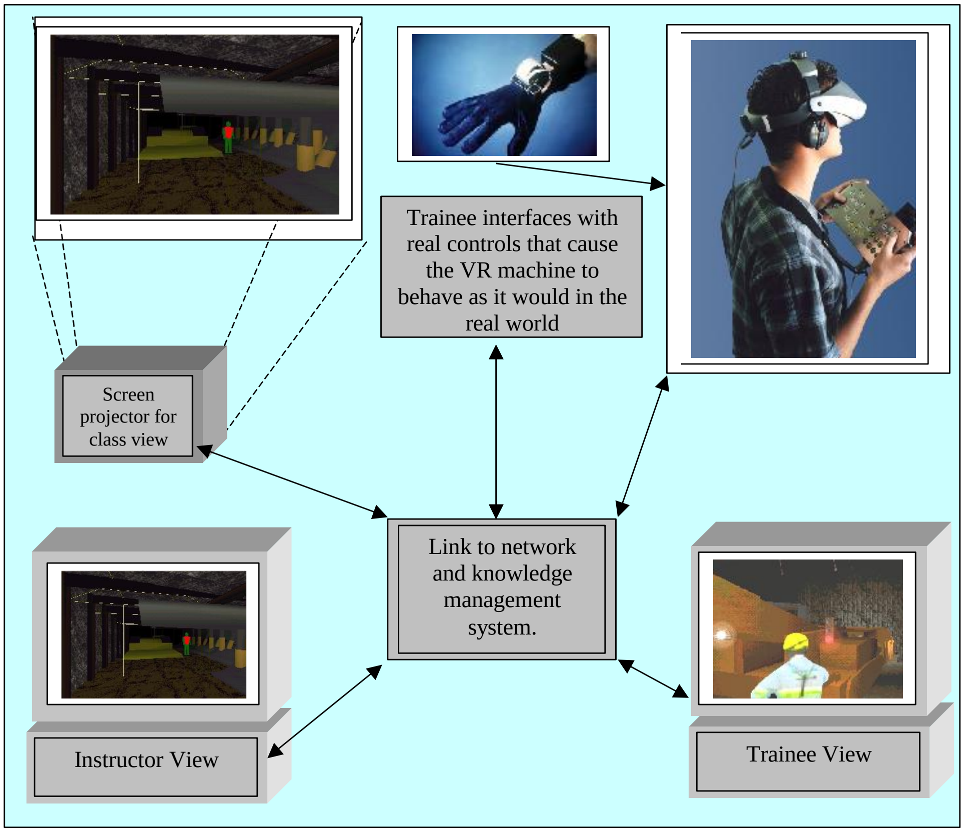
Maintenance Training



Three options that will achieve these desired outcomes are:



Option 1. Desktop P.C. based interactive simulator with real machine controls.

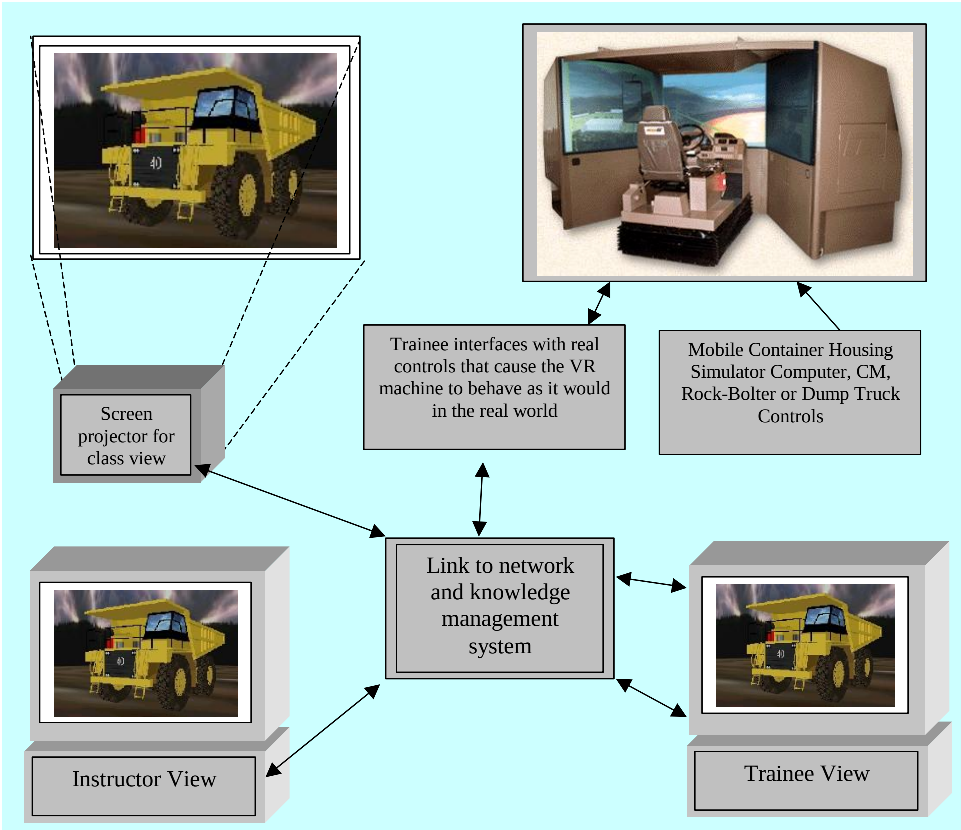


Option 2. Site based, immersive, interactive simulator with real machine controls.

RECOMMENDED TECHNOLOGY

The four main technologies identified all have attributes that can be incorporated into the JCB Simulator. A hybrid simulator is required. The recommended layout of this hybrid system as it applies to the operation of a continuous miner is shown in shown in Option 2. The reasons for selecting Option 2 as the most appropriate layout are that it meets all the identified criteria (see matrix table) and provides the benefits of:

- being site based, making it easily accessible to trainees,
- reflecting reality in the VR simulation,
- propagating site ‘ownership,
- being easier to maintain and keep up to date than a mobile version.



Option 3. Mobile immersive, interactive simulator with real machine controls.

RECOMMENDATION TO JCB HEALTH AND SAFETY TRUST

The project team recommends that the JCB Health and Safety Trust commissions Mine Site Technologies (MST) and the University of New South Wales (UNSW) to design, develop and commission a prototype VR Simulator suitable for safety training of an operator of a continuous miner and operators and maintenance personnel of roof bolters.

The project cost will be $1,540,000 with both UNSW and MST providing considerable in-kind support. In-kind support from UNSW will be in the form of access to the considerable intellectual resources that reside within disciplines in the university, especially in regards to information technology. MST will provide support in the form of their experience in developing and commercialising technological innovation. The proven capabilities of both organisations will be brought to the project.

1. The Concept of the e-Minesafe Computer-based Training Simulator

Key Issues

- A safe, cost effective and efficient, computer-based simulator training system capable of training workers in best practice safe working procedures to reduce the incidence of fatalities and accidents in the industry is required.
- It should train and assess equipment operators and maintenance personnel. It should also be an aid in identifying risk takers.
- The simulators should provide flexible and ready-access for mine-site personnel and permit training and assessment to occur in an environment that is safe, insulated from mine production constraints and is ‘forgiving’ of mistakes.
- A subsidiary aim of training to best-practice Safe Working Procedures is to encourage uniform and consistent high standards of training to improve the transportability of skills between minesites.

1.1 In recent years, fatalities and serious injuries have been associated with the operation and maintenance of mining equipment in the NSW Coal Industry. Two trends underlie these types of accidents:

- Mining equipment has become significantly more sophisticated due to the uptake by manufacturers of advanced remote control and computer technology; and
- the manner in which work is organised and performed in the coal mining industry has changed substantially. For example, workers are now multi-skilled and more extensive use is made of contracts.

1.2 The solution lies in timely and effective training; retraining and improving the skills of operators and maintenance personnel. Simulator training will enhance existing training methods.

1.3 The e-Minesafe concept has crystallised into a requirement for the following four elements,

- Provision of a Knowledge Management System.
- Development of Best Practice Management Plans.
- Development of Best Practice Safe Working Procedures.
- Development of Joint Coal Board Simulators, to:
  - Train production and maintenance workers;
  - Assess competency after training;
  - Identify risk takers; and,
  - Modify behaviour.

This model applies to each major item of underground and open-cut equipment. The e-Minesafe proposal is based on three high-risk items of plant namely, a continuous miner, a roof bolter and a dump truck.

1.4 Issues taken into consideration when developing this approach included:

- The existence of suitable or easily adaptable Knowledge Management Systems;
- The feasibility of undertaking a best practice survey to identify the optimum Management Plan for each item of equipment for input into the simulation model;
- The feasibility of undertaking a best practice survey to identify the optimum Safe Working Procedures for each item of equipment for input into the simulation model;
- How the optimum Management Plans and Safe Working Procedures could be incorporated into a Knowledge Management System available on an industry wide basis;
- How the e-Minesafe system could be kept up-to-date; and,

- How an on-line community could be developed around e-Minesafe.

1.5 This approach will result in a four-stage development and implementation of the e-Minesafe Safety and Training SImulator: -

Stage 1: Scoping Study – Initial Project Assessment (Completed).

Stage 2: Scoping Study – Function and Specification Compilation (Completed).

Stage 3: Prototype Manufacture and Field Trials.

Stage 4: Full product commercialisation.

1.6 Development of the simulator will continue as additional training modules are incorporated into the system as the on-line knowledge base grows.

Simulator Systems suitable for e-Minesafe

1.7 At present, there are a number of existing simulator systems available for training personnel. These systems have been analysed for their suitability for use in the proposed e-Minesafe program, customer acceptance, and technical capabilities, with the view to forming alliances and customising previous work, where applicable. The functions and specifications of available equipment are considered in detail in Chapter 5.

1.8 The proposed Joint Coal Board simulator system is based on identified technologies able to meet the project's objectives. This will allow system prototypes to be built and tested at mine sites to be selected in Stage 3.

The Concept of Simulator Training

1.9 Equipment-related accidents continue to be a source of serious injury and death in both underground and open cut coalmines. These accidents occur in both the operation and the maintenance of equipment. The use of modern machinery and best-practice mining techniques requires multi-skilling of personnel to undertake more complex tasks. These mean that a different approach to training and assessment is needed than in the past. Information Age technology is well suited to meet this new demand for training.

1.10 Mines have a plethora of established procedures for the operation and maintenance of equipment but the continued occurrence of similar kinds of accidents, as recorded by the MSHA web site, indicates that there are deficiencies within these procedures. The procedures are ineffective for a range of reasons which include ease of access or use, cost and not encapsulating learning from accidents/incidents at other sites in Australia and overseas. This information is available, but not in a form which makes it easy to collate, distribute or use. It is evident that current training methods to support safety procedures are inadequate.

Culture of Risk-Taking in the Mining Industry

1.11 Sometimes, both the training and the safety procedures are in order but they are ineffective because of a culture of risk-taking.

1.12 Any considered response must encompass all of these issues.

1.13 It is the Project Team's view that an initiative based on training and assessment of mineworkers in Safe Working Procedures in a simulated environment that is safe, cost effective and readily accessible to mine sites, can be created through using computer-based training. The training and assessment proposed is structured around the approach to mine safety management contained in the Regulations of the N.S.W. Coal Mines Regulation Act – 1999. The concept of mine safety management is shown in Figure 1.1.

1.14 Three elements are associated with this approach to risk management, namely:

- Hazard Identification
- Risk Assessment
- Risk Control

1.15 Figure 1.2 illustrates the conceptual approach adopted by managing risk through simulator based training and assessment.

1.16 The specific steps in establishing the e-Minesafe Simulator Safety and Training System are shown in Figure 1.3. There is a requirement to:

- Establish a system that can manage the web-based knowledge management system and permit it to be shared across the industry.

- Identify and capture the ‘best practice’ Management Plans that have been developed by equipment manufacturers and end users.

- Identify and capture the ‘best practice’ Safe Working Procedures that are driven from these Management Plans.

- Develop a simulator of the mining environment and the mining equipment to train, re-train and up-skill mineworkers in operating and maintenance Safe Working Procedures.

- Identify the ‘risk takers’ who may disregard the Safe Working Procedures.

- Utilise the simulator to modify the behaviour of ‘risk takers’.

- Utilise the simulators to ‘stress test’ and to refine Safe Working Procedures.

1.17 It is proposed that any simulator training and assessment system must have the following features:

- It must be readily accessible – elements having web-based access

- It must be cost effective - to enable operators to purchase or hire in the hardware required.

- It must be realistic – i.e.: simulation must be in “real-time” with quality graphics, audio etc.

- It must be modular – to enable additional training modules to be developed over time.

- It must be designed in conjunction with industry & operators, to ensure that the training objectives and standards are met.

1.18 It is expected that once the system has been developed, tested, and accepted by industry, it will become an essential component in the safe operation and maintenance of all equipment. Similarly, personnel can be accredited on a regular basis to ensure their skills and safety awareness meet specified guidelines. Failure to meet these requirements results in additional training until the standards are met or exceeded.

State of the art Computer Simulation

1.19 Much work involving simulation and remote "equipment control" has been under taken in Australia and internationally. This work spans a broad range of areas, including computer games, military training, civil aviation aircraft pilot training and aerospace simulation, as well as equipment manufacturer's training manuals.

1.20 However, it appears that no one system has been developed to incorporate all the features necessary to bring this technology to the end-user efficiently. In many instances, the emphasis appears to have been on developing technology for technology's sake and not to address a specific problem.

1.21 Similarly, some military and aerospace programs have been over-engineered – in terms of graphics and computer simulation – which requires very expensive hardware to operate the system. Alternatively, other programs do not have the level of sophistication to "mimic" the environment sufficiently to provide adequate training simulation.

1.22 Another common feature is that systems become obsolete, because the Knowledge Management System is neglected.

1.23 This Study has investigated cost-effective State of the Art computer simulation technology to ensure rapid and overall industry acceptance and to increase the likelihood of its implementation.

1.24 To avoid allowing the Knowledge Management System to atrophy, it will be kept up-to-date by incorporating web-based email, chat rooms, swap sites and bulletin boards to encourage inputs from the industry as a whole.

1.25 During the planning of the project, several criteria were identified as being specific to Stage 1. These were:

Safe Working Procedures.

1.26 Safe Working Procedures have become increasingly common in the coal mining industry in the last 15 years, to the point where they are now expected by regulation to exist for each operator and maintenance function associated with equipment.

1.27 However while they are now common, they generally lack best practice input. Some procedures have been developed by equipment manufacturers and some by mine operators. It is logical that Safe Working Procedures provide the foundations of any simulated training and assessment program. It is critical therefore, that these procedures reflect best practice, incorporate a mechanism for ongoing development and refinement and should be readily accessible.

Safety Management Plans

1.28 Safety Management Plans provide a basis for keeping Safe Working Procedures up to date. A Knowledge Management System (eg. utilising an Intranet) provides the tool for sharing the information. While neither of these elements is new, there is no general consistency in how these are applied to training relating to operating and maintaining equipment. Best practice techniques are not being identified and dissipated across the industry.

Computer-based Training Packages

1.29 Computer based training (CBT) packages have been developed for Joy, DMT, Long Airdox, P & H MinePro Services and Caterpillar. Generally these systems are screen based illustrative packages and need to be assessed for this simulation project. We regard most of the functional aspects of these packages as being appropriate to the needs of the Joint Coal Board Simulator albeit requiring some modification.

1.30 Stages 1 and 2 of the Scoping Study have been successful and their findings are described throughout this report. The findings will allow the Joint Coal Board to make an informed decision on whether to proceed through to these next stages.

1.31 The successful completion of the Project to stage 4 will ultimately provide significant benefits to mineworkers and coal producers in terms of improved health and safety, improved technical performance and improved business performance, as indicated in Figure 1.4.

1.32 In particular:

Benefits include enhanced safety

- Safety will be the key benefit of the project. By providing an extra level of safety in the operation and maintenance of equipment the potential for accidents will be significantly reduced.
- Productivity will increase, not only by lowering the risk of productive personnel being unable to work, but by also reducing damage to equipment.
- Production will increase due to equipment availability being higher.
- Human suffering and costs and associated with accidents and injury and poor operational practices will decrease.

Conclusions

1.33 Stages 1 & 2 of the Scoping Study determined the need for using modern training techniques using computer-based simulator training and identified that this could be met by currently-available web-based simulators.

1.34 The continuing level of accidents/incidents in the industry, at any level above zero, is too high. The reasons behind these accidents/incidents include greater complexity of equipment and the need for personnel to be able to handle a wider variety of tasks than before. Accordingly, a requirement for safe, cost-effective training exists which can best be met through the clever use of computer-based training. Once the concepts in this Report have been field-tested in Stage 3, interactive training programs can be offered to the industry.

2. Identification of Appropriate Knowledge Management Systems

Key Issues

Knowledge Management Systems are computer based software programs that provide a facility for the interrogation of and interaction with information. In the case of the Joint Coal Board Simulators, this will be safety information.

Knowledge Management Systems are a powerful medium and correctly applying them in a training medium can only serve to enhance safety.

Personal Computer (PC) based Knowledge Management Systems that access a central server are effective in delivering information and, with some modification, could be an ideal knowledge management system suitable for the Joint Coal Board Health & Safety Trust's training simulator. However, these systems vary in complexity, sophistication and cost. Systems at the higher level of sophistication will increasingly dominate the future market.

The cost of Knowledge Management Systems is dictated by complexity and level of documentation that is to be offered in electronic format.

It would be advisable to establish a basic set of Safe Work Procedures for the three items of equipment that are the subject of this Study. The level of 'user-friendliness' of the procedures could then be effectively assessed before the development of more complex procedures.

Knowledge Management Systems

2.1 The aim of this chapter is to identify and discuss the Knowledge Management Systems that are currently available as a tool for information manipulation and exchange.

2.2 Knowledge Management Systems are intrinsically linked to the World Wide Web (The Web). The Web has revolutionised the way that information is exchanged and accessed over recent years. The idea of the Web as a reliable information source is now approaching a mature stage and it is reasonable to consider using it to deliver training to mining personnel. Indeed, most mine sites now have access to web technology and even remote sites can gain access though modern communications networks.

2.3 In recent years the use and form of Internet-based databases or Knowledge Management Systems has evolved significantly. This Scoping Study found that the pace of change is such that commercial web sites have evolved beyond static pages that link back to billing systems or inventory databases. It was also evident that 90% of enterprises doing business over the Internet were not delivering the kind of services that customers require.

2.4 This criticism about the failure to use the Internet effectively could be applied to the mining industry in respect of the delivery of knowledge, Safe Working Procedures and Safety Management Plans. The potential is there, but it is not being used.

2.5 Personnel who are required to access information such as Safe Working Procedures and Safety Management Plan namely operators and maintenance personnel, should be considered as 'customers' and their information need to be carefully considered to ensure effective delivery of the required information.

2.6 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. To keep the information relevant, the system needs to have a facility for the input of 'customer' experiences. The information also needs to be updated and to be kept relevant as legislation and attitudes change.

2.7 The Scoping Study Team found that companies now realise static content web pages only serve to impress during an initial period and soon loose their appeal. Unless there is a positive financial gain, there is little point in using this form of communication.

2.8 From the Joint Coal Board's point of view, there will be little point in using web-based technology unless there is a gain. In the case of the Joint Coal Board, this gain will clearly be an increase in safety and a reduction in accidents rather than pure profit in a commercial sense. However, a reduction in the number and severity of accidents would reduce the costs of workers compensation.

Development of LAN and WAN Systems

2.9 Historically, personal computers (PC) sat alone on desks and communicated through the use of floppy disks. As multi user applications became more abundant PC applications became more complex. The use of a central file server has become common and data and programs began to be exchanged over a Local Area Network (LAN). This naturally extended to a Wide Area Network (WAN) where PCs were connected over a larger geographical area.

2.10 These LAN and WAN systems worked well for a while but, as data increased, the systems became cumbersome and client-server architecture evolved. The client-server method relieved the network structure of the task of pushing large data streams around the network and through the use of back-end databases that delivered only the required information. This information was deduced through query requests and only the information requested is transferred to the workstation or desktop PC.

Development of the World Wide Web

2.11 The next and current stage in the evolution of computing architecture is the World Wide Web (the Web) whose function may be thought of as the ultimate in client-server computing.

2.12 Users seek information through a web-browser, accessed through their PC, (Figure 2.1 refers). At the same time a remote web-server operating as a 'back-end' database, processes the request for information.

2.13 Instead of the client and server being in close proximity as in the case of a LAN, or at greater distances over a WAN, the client component – for example the trainee at a mine – is any person running an authenticated web browser anywhere on the Earth. The server is a 'back-end' database system running on a Web server – potentially anywhere on the Earth, but in the case of the Joint Coal Board Health Simulator, the server would probably a central server in an agreed location.

2.14 From Figure 2.1 it is easy to recognise the natural progression from an isolated desktop computer to 'webtop' computer. The effects of this transition are now only coming to fruition and many organisations now require capitalisation of the global nature of the web.

2.15 This approach is also relevant to knowledge management. Safety information from mine sites other than those in New South Wales or Queensland can be potentially be accessed and a knowledge base with inputs from many sources is possible. The key is co-operation and collaboration to achieve an information source which is constantly being regenerated. The International Committee for the Coal Research may be a vehicle to facilitate co-operation and collaboration across the international coal mining industry.

2.16 An excellent example of such a knowledge management system that is already up and running effectively is the Australian Standards web site, which is accessed through subscription. The cost of subscription depends on the information to be accessed or be downloaded AS3000, for example, costs around $70. Subscriptions are based on an 'as-used' basis and data may only be accessed through a recognised password.

2.17 An example of an interactive web site 'log in screen' presented to a subscriber[1] is shown in Figure 2.2a. The sequence undertaken by the User to access the training program would be:

- The first screen asks the user for a password and user name. This information is passed back to the central server running the backend database. If the parameters are correct the user is forwarded to the next screen.
- At the next screen the user is presented with a series of options that allows the type of search that is required to be determined. For example there is a keyword search, subject search or a power search that allows a combination of criteria to be entered that will result in a more efficient 'scan' of the available information.
- Finally, the appropriate information is displayed as regulation number and headings. The user can then select the appropriate heading and display the full documentation associated with that heading on the local PC.

1 UNSW/ Australian Standards 2001.

Access to a Simulator System by Mine Personnel at Remote Sites

2.19 Clearly, this type of search is extremely powerful and only limited by the information that is in the database and the bandwidth of the link between the central server and local machine. Modern communications systems and Internet links are becoming faster all the time. In the longer term, access and capacity constraints are not considered an impediment to the development of this type of system.

2.20 A present, modem links to remote sites are between 14kbps and 56kbps. Modern technology, such as microwave radio technology, is used by Telstra to provide reliable modern telephone, fax and dial up data services to customers located in areas too sparsely populated for the use of copper cables. This technology uses chains of radio towers or masts to pass radio signals to a radio structure installed on a customer's property. The radio equipment is connected to the telephone; fax machine or computer by a copper cable, similarly to an urban service. It is a tried and proven system with over 10,000 services in operation across remote Australia.

2.21 Telstra claims that even in the most remote site, dial-up data rates of at least 14.4 kilobits per second will be achievable. Faster Internet speeds will be possible using Telstra BigPond™ broadband 2-way satellite Internet.

2.22 Considering the technology discussed above, it is feasible that the plethora of Occupational Health & Safety documentation described in Figure 2.3. could be accessed in the manner described.

2.23 Subsequent chapters in this report describe the non-standard approach to the development of Safe Working Procedures (SWP) and Safety Management Plans (SMP). Using a Knowledge Management System, such as that described above would present an opportunity to present a forum to mine sites and manufacturers through which they could collaboration and develop 'best practice' safety documentation.

Interactive Knowledge Management System

2.24 The Knowledge Management System developed by Standards Australia is a well-presented, logically-arranged web site. However, the system only delivers knowledge. 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. The information is presented to the user but is not ‘interactive.’

2.25 In the Study Team’s opinion, what is required in the case of the Joint Coal Board Simulator project is a means of stimulating the user into absorbing the relevant information.

2.26 Typing-in a query is fine and, with enough variation on a theme, the user will receive the appropriate information. The limit is that when the user receives the information it is effectively static. It may be functionally correct and a good procedure, but if for example, the operator identifies an unforseen hazard or a safer way of doing things the operator cannot easily exchange that information with the Knowledge Management System or other interested parties such as other mine sites within a collaborative group.

2.27 In addition, the Knowledge Management System should be in a form that encourages interested parties to exchange ideas. This facility is now readily available through chat rooms that are offered through Internet Service Providers or through the use of ‘Add-on’ software for Microsoft Internet Explorer and Netscape Navigator. The program that is very commonly used is Microsoft Messenger. Microsoft Messenger MSN Messenger Service is an instant messaging program that lets a user:

- See who else is online and show that the user is online.
- Send an instant message.
- "Chat" with a group.
- Invite someone to an online meeting.
- Get notified of new e-mail.
- Post warnings or new ideas to improve safety.

2.28 To use MSN Messenger Service on the Internet, a ‘Passport’ is required and an email account. Logging on to the service enables information to be exchanged between interested parties and allows them to browse relevant information posted on the web site.

2.29 A highly simplified example of the sort of functions the site offers is shown in Figure 2.4.

2.30 Essentially, a user with a valid subscription can log on to the site and join the forum. If the user has a problem a request can be sent in real time to the chat room. Any of the other subscribers that are on line can respond and provide appropriate advice. This advice is transparent to all that are online and even to those not online. This is achieved through the use of email. If the advice still needs developing other online or offline subscribers can contribute.

2.31 Eventually this has the potential to become a self-perpetuating system of developing Best Practice. If this type of facility is incorporated with the type of knowledge management system described in Figure 2.2, a very powerful medium for knowledge management and exchange of safety procedures will be possible.

2.32 An important consideration is the use of a purely text based forum. Reading text on a complex task can be daunting. The transfer of the written word, particularly if the subject matter is very ‘dry’, is not always successful, particularly to those lacking literacy skills. Often a more effective approach - particularly where time is limited or attention skills are lacking – is the use of pictorial representation.

2.33 Using images, static photographs, short video clips or computer generated graphics, can provide a much more effective means of communication over text based information. Also, in the case of Knowledge Management Systems that would be used in the mining industry, the use of familiar icons as interfaces and links to appropriate information will almost certainly be more acceptable to mine personnel.

2.34 In modern production environments, typing-in long strings of text may be unacceptable. For example, in the case of a continuous miner, after the interested party has logged on, he or she should be presented with a screen showing icons of the equipment used on site. For example, a roof-bolter, a continuous miner, dump truck and shuttle car. Touching the screen on the appropriate icon will bring up a larger view of the piece of equipment. This view could be rotated on the screen and gradually zoomed in upon until the required operation or component is visible. The interested party could then bring up the operation and maintenance procedures directly related to a specific task. There is also the opportunity to continue to interact with the online community. Using touch screens and images will almost certainly be more successful than keyboard and text interaction.

Advanced Knowledge Management Systems : VITOS and MUSE

2.35 The examples shown above are essentially PC-based Knowledge Management Systems that access a central server. They are very effective in delivering information and with some modification could be an ideal knowledge management system suitable for the Joint Coal Board Health & Safety Trust's simulator.

2.36 However, Knowledge Management Systems may be taken to another level of complexity. While considerably more expensive than a PC based knowledge management system, systems such as VITOS will almost certainly gain more and more market share over the next ten to fifteen years. These systems are discussed briefly below.

Visually Integrated Team Operating Space (VITOS)

2.37 The main feature of VITOS is that it revolves around a plugin-design that enables access to any number of third-party applications. VITOS accesses data and applications, and controls and presents data objects by means of plug-in applications. The plug-in architecture allows application developers to focus on application functionality, while VITOS provides the infrastructure to catalogue, manage, and present the data objects. Plug-ins can be developed to support any proprietary workflow a company might have.

2.38 VITOS integrates data and applications in a collaborative visual team operating space. It is designed to provide access to all data collected during a project. The data may be geological, geophysical, engineering, production, Computer Assisted Design, or safety information such as SWP.

2.39 VITOS allows integration regardless of the original software format that is currently being used, and allows operators to interact with and visualize data in a single virtual environment.

2.40 With VITOS it is possible to simultaneously view and interact every aspect of the data. The components in the models can vary in scale from less than an inch to thousands of kilometers and be represented in the same visual operating space. The ability to view all data in a single space enables true collaboration between disciplines. This would be particularly useful for visualizing the impact of poor operation of mining equipment on a mine.

2.41 VITOS uses a voice command and control as the user interface. This removes the need for keyboard and mouse interaction and allows the user to easily navigate a data model. All cognitive efforts are focused on understanding the model and gathering information. The aim is to remove the boundaries between the user and the data.

2.42 Ultimately, it may be possible for VITOS to combine the Joint Coal Board Simulator and knowledge management system into one seamless product. An example of the architecture is shown in Figure 2.5. An example of merged geological, mining and ore body data is shown in Figure 2.6.

2.43 VITOS provides a shared workspace solution to problem solving and training. It achieves this by allowing a user to assimilate data efficiently and completely. Once the user has developed a mental model of the data, and its implications – for example cutting coal and hitting sandstone – the user may wish to communicate ideas and recommendations to obtain a sanction for the proposed course of remedial action.

Knowledge within the Mining Industry Should be Used

2.44 In the coal mining industry there is a great deal of knowledge and experience to be tapped and each user may have certain skills and knowledge. The aim of VITOS would be for the user to have access to this ‘Horizontal’ team. One of the horizontal team members may have knowledge that can be used to relieve the initial users problem. VITOS also uses the concept of the ‘Vertical’ team where multi-disciplinary modelling is commonplace, allowing data such as mine-plan, ventilation, electrical and production data to be merged to compliment safety data.

2.45 VITOS presents a very powerful tool for the merging of interdisciplinary data. If considered, it may offer a method of integrating not only SWP and SOP but also data derived from other disciplines that ultimately impact on safety if managed incorrectly.

Synthetic Environment

2.46 MUSE is described by Continuum Resources as a Multidimensional User-oriented Synthetic Environment. The system has been around since 1993 and has been used to solve extremely complex problems in the worlds of manufacturing, science, engineering and even government. Continuum Resources comment that for both software and computer users, MUSE provides a better way of experiencing analysing and understanding all types of data using sight sound and even touch to unlock hidden trends in data.

2.47 Continuum Resources also state that in nearly every application created with the MUSE Development System, users have reached important and rapid conclusions by discovering trends that were completely unexpected, yet clearly visible when presented in the MUSE environment.

2.48 MUSE presents a full set of built in features that facilitate the rapid discovery of meaning in complex data. MUSE offers “Craft” a function that allows users to easily navigate and explore quantities of complex and disparate data. In the case of mine safety this could be the correlation of data such as time dependence, areas of the mine in which accidents occur and identification of the areas of a mine in which risk takers operate. This may identify ‘clusters’ of risk takers.

2.49 MUSE provides a platform for interoperability between UNIX and WindowsNT platforms. This facility allows Users to move easily from conventional desktop PC to full multi-pipe theatres or immersive Visual Reality (VR) such as the system envisaged as being developed by the Joint Coal Board.

2.50 MUSE provides software developers with a full-featured set of development tools. This allows the software developer to be free to focus on problem solving and the method presentation. The result is faster development of more robust applications.

2.51 According to Continuum Resources within the MUSE environment is a comprehensive software application that fuses together advanced data visualisation, virtual reality and networked collaboration capabilities into a single environment. An example of this is shown in Figure 2.7.

2.52 MUSE allows developers to create custom applications that integrate nearly every type of data with powerful visualisation capabilities. Data may be controlled using voice response, head tracking, voice command and other motor skills.

2.53 Continnuum Resources explains that the MUSE System was developed with humans in mind – not computers.

2.54 MUSE exploits the team environment that is often required for humans to solve problems. MUSE permits the comparisons of discoveries and thoughts from several users and also for these thoughts and discoveries to be split into smaller more manageable components where necessary. As the ‘building blocks’ of the problem are manufactured, they can be brought together at a later date or immediately in real time.

2.55 A MUSE-based application permits multiple users to be connected over any type of compatible network and allows simultaneous exploration of the shared environment regardless of their own hardware platform. It is a truly collaborative environment and one in which safety documentation could be manipulated over many mine-sites. Figure 2.8 (see Appendix 1), shows a typical network arrangement.

2.56 MUSE technology is a very powerful knowledge management system. It allows disparate data to be brought together and exchanged. Control of the data is based on the concept of human interaction across many disciplines.

2.57 The nature of MUSE and VITOS is such that the architecture allows unrelated software to be plugged together to form a common application. MUSE is also platform-independent and networked users can all interact with the data. This may be particularly pertinent to mine-sites. Some may operate UNIX systems others Wintel (Microsoft, Intel).

2.58 An advantage that MUSE may have over a database system is that it would allow user visualisation of safety documentation specific to their mine site through the integration of data obtained at that mine-site. It would also provide a means of drawing and visualising experiences of other mine-sites.

Costs involved in developing Knowledge Management Systems

2.59 The preceding sections have discussed the use of interactive database Knowledge Management Systems and more complex integrated Knowledge Management Systems.

2.60 Generally, the costs of these systems depend on their complexity and the level of documentation that has to be handled and the stage at which the documentation is with respect to being offered in electronic format.

Standards Australia

2.61 To develop a web-based system such as that offered by Standards Australia requires the following, components. This list is not exhaustive.

- Central Server
- Dedicated P.C.s at ten Mine sites
- Windows 2000 Server:
- Web Developer Software
- SQL Server Database Management
- Database Development and Programming
- Hardware set up
- Transferring S.W.P. to ‘Best Practice Format’
- Project Management
- Internet Service Provider
- Administration person
- Product updates
- Administration
- Dedicated Phone Line

Continuum Resources

2.62 In the case of Continuum Resources technology, due to the complexity, hardware components would also include:

- VITOS system
- 3D Studio Max
- MUSE software
- Mainframe computer
- Graphics Projector

- Development Costs
- Theatre

*

Conclusions on Knowledge Management Systems

2.63 Knowledge Management Systems are powerful tools for information visualization and management. They may be presented in the form of a simple web page database that provides links to static pages or they may contain a search engine through which the user may interrogate a database of information through the use of a keyword, subject or power search. The complexity of the Knowledge Management System essentially dictates the cost. The more complex the information and more complex the functionality, the greater the cost.

2.64 In the case of the Joint Coal Board Health & Safety Trust, the use of text based data searches may be inappropriate. There may be a requirement for the use of a digital image or video representation of the specific SWP or task. Developing a web site that is interactive and that stimulates the user appears to be the key to successful assimilation of information by the user. Presenting pure text based information may not provide this stimulation.

2.65 Knowledge Management Systems are also appropriate to the integration of information from many - multi disciplinary – sources. Continuum Resources provide a system that has an open architecture that allows the information from several incompatible platforms to be assimilated. From the point of view of the Joint Coal Board, assimilating and visualizing data from several disciplines may be advantageous. Approaching safety in this manner will allow the factors that affect safety and that are not readily identified to be flagged.

2.66 Overall, Knowledge Management Systems are a powerful medium and correctly applying them can only serve to enhance safety. The question is how far does the Joint Coal Board Health & Safety Trust wish to take Knowledge Management Systems. The Study Team believes it would be advisable to establish an effective SWP database for the items of equipment that are the subject of this study. The level of 'user-friendliness' of the system and its safety documentation could then be assessed.

2.67 The Research Team also believes that as the system is stress-tested by the industry and gradually becomes the ‘norm’ for safety management, the knowledge management system will continue to grow through the collaboration between minesites.

2.68 Eventually the ideal ‘best practice’ format will be developed and relevant information identified and collated in a central knowledge database. More and more procedures will be developed through the collaborative efforts of many sites and many individual experiences. This can only serve to improve safety and reduce accidents and benefit the Coal Mining Industry.

3. Safety Management Plans and Safe Working Procedures

Key Issues

- The formulation of a "Best Practice" Safety Management Plan (SMP) and Safe Working Procedures (SWP), requires a decision as to the format and content of a generic system.
- This generic system could be based around an approach to safety already in operation, augmented by examples from elsewhere in the industry. If this approach is combined with the recommendations made by this Report, it is realistic to expect that a truly effective Safety Management Plan and Safe Working Procedures relevant to the Coal mining industry can be created.
- In reaching this conclusion, the Report has canvassed widely across the industry and has drawn upon a variety of models and approaches to SMP and SWP currently in use. Assistance was sought from eight underground mines, six opencut mines, and eight equipment suppliers.
- It is evident that enough suitable material exists to form the base of a coherent computer-based simulator training program

Need for multi-skilling

3.1 The complex nature of modern mining machinery and the modern methods of organising tasks within the mining industry present a need for multi-skilling of operator and maintenance personnel. Multi-skilling inevitably exposes workers to a wider range of tasks and hence risk.

3.2 This requires that effective Safety Management Plans and Safe Working Procedures be in place to minimise risk and to meet Occupational Health and Safety legal obligations.

3.3 This type of safety documentation is already in place at mine-sites. However, injuries and fatalities associated with mining machinery operation and maintenance still occur, suggesting that these procedures and plans can fail, or, may have flaws in their design and application.

3.4 An examination of Figure 2.3, shows that mine managers and personnel are required to be aware of a great deal of regulatory information. The complex nature of this regulatory information and that it is mostly in ‘hard-to-read’ manuals, mitigates against their use. This may also account for the occasional failures.

- It was proposed by the Research Partners that part of the e-Minesafe Scoping Study should collect, examine and critically assess the SMP and SWP from numerous New South Wales coal mines, to identify the more effective documentation and to critically assess and evaluate it with the aim of a best practice approach.
- As expected, choosing three disparate pieces of equipment has revealed the inherent complexities of safety documentation associated with the operation and maintenance of each type of machine.

Sourcing Safety Management Plans and Safe Working Procedures

3.7 The Safety Management Plans (SMP) and Safe Working Procedures (SWP) discussed are those that apply to the operation and maintenance of a roof-bolter, a continuous miner and a rock-truck.

3.8 The initial proposal required that the safety management information obtained for this Report would be acquired from a number of sources and it was anticipated that the information would be in many formats. That is, there would be probably be documentation available at each source that was based on a generic Safe Work Method Statement such as that developed by N.S.W. Work Cover. The interpretation of the generic statement differed from mine to mine, as expected.

3.9 The main source of SMP and SWP was found to be mining companies, machine manufacturers, minerals councils and mine regulators. It was found that the documentation obtained from each source was the result of each site, operator or manufacturer’s interpretation of the guidelines of 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. As mentioned above, this has resulted in many employers developing their own SWP as one of the measures to control hazards associated with the tasks being undertaken by their employees.

3.10 To present information obtained by the study, a simple method of presentation has been developed and this simple matrix is shown in Appendix 1. A system that could rank the SMP and SWP from different sources was also required. Ranking of the information is also shown in the Appendix 1 of this Report.

3.11 The SMP and SWP discussed in this Report have been and are currently being developed with input from the people who actually perform the tasks as well as the equipment suppliers who design and supply the equipment.

3.12 This research found that industry-endorsed competency standards for machinery operators include reference to work procedures and manufacturer's directions in their assessment criteria, suggesting that trainees must be familiar with and able to interpret the appropriate safety documentation before they are considered competent.

3.13 Figure 3.1 shows that across the ten mines that provided information, the operators of a continuous miner may be exposed to a minimum of nineteen SWP. At mine 'G' the operator may be exposed to seventeen. At mine 'Q' the operators' exposure to SWP may be zero.

Identification of appropriate Safety Management Plans and Safe Work Procedures

3.14 One of the considerations of the original proposal for the Joint Coal Board e-Minesafe Simulator project was that for any training simulator to be acceptable to the Coal Mining Industry its foundations should be based firmly on "Industry Best Practice".

3.15 In order to establish the criteria for "Best Practice" it was necessary to critically assess as many SMP and SWP as possible for a rock-bolter, continuous miner and rock-truck. Evaluating the documentation would thus identify the criteria required for "best practice".

3.16 Figure 2.3 reflects the complexity of information and it quickly became clear that the volume of documentation was massive even though the scalability of the task had been restricted to the N.S.W. Coalmining Industry. Nevertheless, it was encouraging that such a quantity of safety documentation was in place in the industry, showing that most companies had embraced the concept positively.

3.17 Due to the massive volume of information, it was decided that at this stage of the e-Minesafe Project it was necessary to be further selective with respect to which procedures should be reviewed. Being selective was not considered to have an impact on the validity of the findings, as the ultimate aim of sourcing safety documentation was to identify:

- Any variation in format of SMP and SWP between sources;
- Any variation in the methods of delivery of SMP and SWP between sites;
- Any parity between sites and procedures identified as needing an SMP and SWP.
- Any disparity between sites procedures identified as needing a SMP and SWP.

3.18 The study compared ‘like’ with ‘like’. This Report includes the compilation of all SMP and SWP contributed by the NSW Coal Mining Industry and equipment suppliers to 15th May 2001.

3.19 Assistance was sought from eight underground mines, six Opencut mines, and eight equipment suppliers. While most mines and equipment manufacturers were pleased to provide copies of their documentation, some mines declined. Overall, the response was good and the reasons for non-participation varied from confidentiality clauses to simple reluctance to participate. The mines and manufacturers that did participate provided enough information to proceed.

3.20 Several mining companies requested that their information be kept in confidence and not be distributed within the industry. This material is correctly seen as being proprietary exclusive copyright. Companies or mines that have contributed material were informed in writing that any information will be held within this project and will not be made public. Due to confidentiality issues it was therefore necessary to not identify a particular mine or company in the process of comparison of the material analysed in this study. The contributors will be referred to as Mine A, Mine B etc in the Report to maintain confidentiality.

3.21 A significant list of SWP has been developed by some mines for both operating and for maintenance tasks. These documents are then incorporated in the training and assessment process for operators in their production tasks. Thus the assessment documentation directly reflects the application of these SWP for a person to demonstrate competency.

3.22 Maintenance task SWP documentation, however, is treated somewhat differently. Some mines use them as part of their training for maintenance personal while others issue them as a job instruction and require the maintenance person to tick each step in the procedure as they complete it and return completed check sheets at the completion of the task.

3.23 Some mines do not write separate production procedures but prefer to develop a “training” manual for the production tasks which, when examined, reveals a whole series of what could be described as procedures within the tasks. The competency assessment process similarly reflects the application of each of these sub tasks.

3.24 Despite the excellent quality and response of the contributors it was found that there were large gaps in the responses.

3.25 For example, there is a lack of contributions of SWP and SMP for maintenance of Rear Dump Trucks. The reason for the lack of procedures for maintenance of Rear Dump Trucks - other than isolation of energy - has been given by industry contributors that most major repair and maintenance work is performed by specialist personnel employed by the equipment suppliers. Further requests, made to the equipment suppliers for this material went unanswered.

3.26 From the information received it was apparent that a focus on the perceived higher risk activities had received most attention by industry. This information is readily available from the employers in the industry but is less available from equipment suppliers. Some equipment suppliers are currently reviewing the procedures that they do have to ensure the “duty of care” obligations will be met by them for their own employees who go to mine sites, as well as client employees who operate or maintain equipment supplied by them.

Summary of Responses

3.27 The information provided by the manufacturers and mines was found to be comprehensive and covered a wide range of activities. Criteria common to each SMP and SWP was identified for the Continuous Miner, Mobile Roof Bolter and Rear Dump Truck and placed in a matrix. An example of the matrices is shown in Figure 3.2. . A complete set of matrices is also shown in the Appendix 1.

3.28 The SWP and SMP were subdivided into operator tasks and maintenance tasks for each machine. As stated previously, not all contributors had developed separate SWP for each task associated with the machine. The matrices differentiate between those SWP that have been specifically written as such, and those which can be inferred from the training/assessment materials.

3.29 However for the purpose of the Joint Coal Board Study they have all been referred to collectively as SWP. Operator tasks are presented separately and maintenance tasks do not differentiate between electrical and mechanical tasks in the presentation.

3.30 Examining Figures 3.1, and 3.2 shows that the level, number and method of delivery of SWP and SMP between mines are variable. The format is also variable. Some SWP and SMP are electronic and some are paper-based. In the case of a continuous miner, the safety documentation is greater in the area of maintenance than operation.

3.31 Most mines have some documentation. Some mines, however, do not have any suitable documentation. For example, from the 'Operator Tasks Matrix' it would appear that there is little correlation between mines in identifying which tasks require an SWP even though as discussed earlier, industry and safety legislation expects that this documentation be in place.

Continuous Miner

3.32 Six out of the ten mines have a procedure for start up. In the case of continuous miner maintenance, only three out of the ten mines have a comprehensive list of SWP for maintenance tasks. The remainder are sporadic. Some mines would appear to place emphasis on particular tasks. Mines 'G' and 'P' have many SWP for replacement of components. This may be related to what is conceived as an operation requiring an SWP or simply that the person responsible for those operations is more ‘risk’ aware.

Mobile Roof Bolter

3.33 In the case of the Mobile Roof Bolter, some contributors did not use these machines and hence the information is limited. Despite this, a similar circumstance to the continuous miner arises in that some operations have SWP for certain operations at some mines and not others. This is the case in both operation and maintenance.

Rear Dump Truck

3.34 In the case of the rear dump truck, operator tasks have numerous SWP and most tasks are considered worthy of an SWP by most mines. In the case of maintenance however, only one mine has one procedure. This may be due to maintenance work on these machines being performed by specialist personnel employed by equipment manufacturers.

3.35 The information provided by the contributors was comprehensive and the procedures that had been addressed were generally of high quality. The safety documentation received, was presented in several electronic formats as well as printed matter. Figure 2.3 shows the depth of the problem in the form of the sheer volume of information that has to be disseminated to the work force. Controlling this documentation through a mine-specific Safety Management Plan is clearly a challenge

3.36 To demonstrate this point and to attempt to identify the most favourable method of delivering safety documentation, it was decided to rank a number of the SMP and SWP acquired during the Study.

3.37 To achieve this a simple numerical method of ranking was used with the aim being to rank the ease with which the SWP could be interpreted. The ranking was performed on a scale of 0 to 10 with zero being poor and 10 considered as excellent. The purpose of the evaluation of the documentation was to be able to determine a “best practice” model on which to base the computer simulator program.

3.38 It was not possible to evaluate all of the material presented for each machine. Therefore the procedures that were selected were those considered most appropriate to satisfy the objectives of this Project.

The two selection criteria were: -

- High level of risk associated with the procedure.
- Common need for procedure recognised by contributors.

3.39 The criteria on which each contributor's material was compared were identified by reference to the common basis on which the SWP and SMP were developed by the contributors.

3.40 The complete results of the evaluation are presented in table form in the Appendix 1. The contributor who achieved the highest score for a particular SWP may be considered as the most suitable industry procedure for this project. In many cases this was Mine B. An example of the rankings and associated bar charts for several procedures are shown in Figure 3.3.

Conclusions

3.41 Sourcing SMP and SWP from the Coal Industry was successful. Most manufacturers and operators were very co-operative and the data supplied was extensive. However, to meet the requirements of this Report, only the more commonly occurring tasks were selected.

3.42 Examining the information and placing the common procedures into a matrix revealed that only some procedures at some mines are considered robust enough for the requirement of an SWP. At some mines these same tasks do not have an SWP. Overall, it is apparent that most of the contributors to this Study have attempted the problem of developing SWP. This suggests that all the sites studied have Safety Management Plans and have developed these independently.

3.43 A number of selected SMP and SWP for each of the three machines under study have been evaluated and have found to be suitable as the basis for a computer simulator-training program and a foundation for the collaborative development of SMP and SWP.

3.44 To obtain an "Industry Best Practice" it may be necessary to include aspects of a number of SWPs. For example, there is a lack of contributions of SWPs for maintenance of Rear Dump Trucks.

3.45 The following considerations should be taken into account when developing computer simulator training programs that incorporate SMP and SWP:

- There is no standard format that the industry has adopted to develop their procedures.

- The standard for risk analysis issued by the DMR could be widely adopted in the industry.
- There is significant support in the Industry for risk analysis processes which provide for the development of SWPs to manage safety.
- The simulator approach to training would enhance the focus on hazard control by focussing on “industry best practice” safe work procedures.

Mine B appears to have a well developed SMP and the SWP provided by Mine B are some of the easiest to use. It is recommended that the basis for ‘Best Practice’ should revolve around Mine B’s approach. However, the ‘Best Practice’ should reflect input from all the contributors to provide a system of ‘hybrid’ SMP and SWP. It should be inclusive and not exclusive of positive points ascertained from the inspection of as many SMP and SWP as possible.

4. Practical Training Requirements and the Identification of Risk Takers

Key Issues

- Simulator training could be used effectively to reduce the unacceptable fatality and serious injury rate that continues to occur in the high-risk areas of Continuous Miner, Roof Bolter and Dump Truck operations on mine sites.
- A simulator training system should take into account the human characteristics of operators, supervisors and maintenance personnel in the areas of risk-taking and making errors.
- As far as the literature on risks and errors in industry in general and mining in particular is concerned, there appears to be two divergent views; that as many as 90% of accidents are caused by human errors, mistakes and violations, or the real causes of these accidents are organisational, systemic or latent. Hence, while simulator training could reduce risk-taking, errors and violations, not all accidents and incidents may be eliminated because human frailty is inherent.
- Employees' perception of risk can be regarded as one of the most powerful influences on behaviours, and without a concerted effort focusing on this, no amount of procedures will affect risk-taking at the coal-face.

Characteristics of Human Behaviour and Risk

4.1 Much of the literature suggests that most accidents have at least some cause due to human error. This chapter summarises contemporary understanding of why accidents occur and how simulator training could be used to lessen the likelihood of these occurring.

4.2 Simulator training provides the environment whereby new operators can be trained on a piece of equipment in a realistic setting, encountering unusual or rare events that would be too dangerous to attempt if learning was taking place on the actual machine. Experienced operators, supervisors and maintenance personnel can also have their skills refreshed. An advantage of the system is that instruction and assessment can be on a one-on-one basis.

4.3 Simulator training is a better way of communicating the mass of rules, regulations and procedures that govern the operations of risky processes. (See Figure 2.3).

4.4 Simulator training can also provide an opportunity to:

- train personnel in the operation and maintenance of mining equipment;
- assess their propensity for risk-taking;
- determine an individual's error-proneness as well as their understanding of any rules, regulations or procedures governing the use of the equipment; and,
- indicate a tendency for violating rules and procedures.

4.5 The Study Team believes that simulator training is a means to reduce the unacceptable fatality and injury rate attributed to "operator error" or risk-taking. Identifying and correcting risk-taking behaviour before the individual is permitted to operate a real machine must reduce the accident and incident potential.

The Need for Action

4.6 Despite strenuous efforts within the Mining Industry, fatal accidents and serious injuries still occur. Two recent fatal accidents in the Australian underground sector have involved falls of ground associated with operations trying to recover remote controlled continuous miners that have broken down. Other fatalities and serious injuries have been caused during maintenance work, causing the Queensland Chief Inspector of Mines to state in 2000 "that all mines, as a matter of urgency, review their maintenance procedures. These incidents are not restricted to Australia.

4.7 A random study of the Web, for fatal accidents, showed that in West Virginia in 1998 and 1999 many accidents were from continuous miner operators and roof bolters and resulted in a call by regulators that "all employees must be retrained on the approved roof control/deep cut mining plan before returning to work".

4.8 Simulator training would appear to have the potential to reduce these incidents by the retraining of operators and training of inexperienced personnel to be able to detect roof and rib hazards; appropriate roof support procedures; no standing zones; correct maintenance procedures and so on.

Errors and Risk Takers

4.9 The Study Team found that a significant body of literature exists on human error and risks. The most recent and relevant work in relation to the Mining Industry is provided by researchers such as Joy, Hopkins, Reason, Pitzer, Shaw and others. Relevant findings are summarised in the following section.

4.10 One Researcher[2] examined 24 serious mining losses that occurred mainly in Australian coalmining over the past 10 years and found that 80% or more of incident and accidents were caused by human error. Of 75 accidents in NSW mines that caused serious injury, 71 of these had an element of active human error. In most cases human error was the end point of poor decision making. That is, the accident was already programmed to happen and all that was required was a place and a time for it to occur.

4.11 Fatality rates, while decreasing in Australian mines in the past 10 years, are far higher than in comparable "safe" industries. The risk of a fatality is about 1 in 2,300 compared with a "safe" industry fatality rate of 1 in 100,000.

4.12 Another analysis of 24 accidents came up with the following conclusions:

- Active human error is a major issue (85% of cases) but is not usually intentional – the person intended to do things correctly (eg slip/lapses; mistake; deviations from known requirements); and,
- Management systems failures or latent errors (eg mine planning/maintenance) are at least as significant an issue as active human errors.

4.13 The role of the individual in accidents also received scrutiny. A report into this aspect of safety stated that humans can act as both the hazard itself, through for example slips, lapses, mistakes and violations as well as a defence to the hazard by adjustment, compensation, recovery and heroic improvisation [3]

4.14 Elimination of human error is seen as a primary goal by many system managers; as with technical unreliability, they strive for greater consistency of human action.

[2] Joy (1999)
[3] Reason (2000)

Well-trained Operators with Good Procedures should not Make Errors

4.15 There are two views of error as a contributor to system failure. Firstly, that errors are rare but sufficient to cause accidents. They arise from delinquency by the front-line operator. A second view is that errors are commonplace and are only very occasionally necessary to complete an accident sequence that usually has a long history. The best people can make the worst mistakes.

4.16 The aviation industry acknowledges for example that, in any one year, there are more than 100 million errors translating into 100 major incidents and 25 accidents

Unsafe Acts

4.17 Unsafe acts can be divided into:

- slips, lapses, trips and fumbles;
- rule-based mistakes;
- knowledge-based mistakes; and
- violations (often a sub-class of rule-based mistakes).

Rule-based mistakes can be further classified into

- misapplication of a good rule ;
- application of a bad rule; and,
- failure of a good rule (violation).

Violation

4.18 Violation Incidents include:

- routine violations – cutting corners;
- optimising violations – for kicks;
- necessary violations – to get the job done; and,
- exceptional violations – ‘one-offs’.

4.19 The following reasons give some examples of why people violate good rules:

- illusion of control: “I can handle it”;
- illusion of invulnerability: “I can get away with it”;
- illusion of superiority: “I’m very skilled”;

- feelings of powerlessness: “I can’t help it”;
- feelings of consensus: “everyone does it”; and,
- feelings of consent: “they’ll turn a blind eye”.

4.20 Situational factors provoking violations include:

- time pressure;
- high workload;
- unworkable procedures;
- inadequate equipment;
- bad working conditions; and,
- supervisors turning a blind eye.

4.21 Ninety percent of violations are blameless and include system-induced violations and errors. However, ten percent are culpable and include sabotage and reckless violations involving ‘dare devilry’ and concerns about being teased by workmates for an inability to operate machines properly. [4]

Blaming the Victim and Blaming the System

4.22 There are two perspectives on the causes of illness and injury. The first blames the personal characteristics and behaviour of the workers themselves. The second holds the wider social, organisational or technological environment responsible. Each perspective demands a different strategy for combating the illness or injury

4.23 Accident proneness, ignorance/carelessness, a culture of masculinity and malingering fall under the first category. System(ic) failure, company violations of safety regulations, production imperatives and physical/technological environment come under the second.

4.24 The two approaches concept is useful. It brings into focus just where the onus for the prevention of accidents lies; with the employee or with the management. If one takes the approach that one or other is mostly responsible, then it also means that the majority of accidents/incidents are the responsibility of either the employee or management.

[4] Hopkins (1984)

4.25 One Australian mining manager told a mine safety seminar he believed that the great majority of accidents (up to 97%) were due to unsafe acts and very few to unsafe conditions. He concluded that effort must be focussed on changing behaviour.

4.26 Unsafe acts in the workplace may have organisational or systemic causes.[5]

- Active failures are those errors or violations which have an immediate adverse effect. These are generally associated with the activities of 'front line' operators: control room personnel, ships' crews, train drivers, signalmen, pilots, air traffic controllers, etc.

- Latent failures: these are decisions or actions, the damaging consequences of which may lie dormant for a long time, only becoming evident when they combine with local triggering factors (that is active failures, technical faults, atypical system conditions, etc).

4.27 Industrial accidents can be described as organisational accidents where latent failures, arising mainly in the managerial and organisational spheres, combine adversely with local triggering events (weather, location etc) and with the active failures of individuals at the sharp end (errors and procedural violations). It is misleading to suggest that accidents can be attributed to either unsafe acts by workers or to unsafe conditions or systems in which the work is carried out. It is more commonly a combination of both.

4.28 Managers are also responsible for meeting the challenge to control human risk factors and to improve the overall safety of operations under their control. Most accidents involve a chain of events often involving management decisions at the very beginning. Accordingly, it would be useful to look at the risk of error in all stages of an organisation's operations.

Culture of Risk Taking

4.30 In 1999, a survey of mine sites carried out for the Minerals Council of Australia found, among many issues, that risk taking among operators was endemic in the industry (metalliferous and coal).

[5] Hopkins 1995

4.31 Violation is a class of human error that has often escaped public scrutiny but in mining for example, where legislation, rules, codes, guidelines, procedures and other mechanisms, aim to control behaviour, it is one of the most significant in terms of its contribution to accidents.

Most underlying Causes of Violations are Caused, Accepted or Condoned by Management

4.32 Often, violations have become the normal methods of working rather than the laid down procedures. Solutions open to management for reducing the potential for violations include improvements to design, training, supervision/management and organisation. An example was given of an unrealistic maintenance schedule where a manufacturers preshift check on a large piece of machinery was estimated to take longer than the shift itself! This leads of course to a breakdown in following any of the rules.

4.33 Violations can be classified as either routine, situational, exceptional or optimising.

Routine Violations

4.34 Routine violations are behaviours in opposition to a rule or procedure that has become the norm in a group. The violating behaviour is usually automatic and unconscious (but recognised by the individual if questioned. There are a number of factors causing routine violations:

- cutting corners and saving time and energy
- overly restrictive rules
- rules seen as no longer applicable
- rules aren’t enforced

4.35 Routine violations can be minimised by assessing the risks and reducing risk-taking behaviour; increasing the probability of detection and rationalising the work systems to reduce the numbers of unnecessary rules

Situational Violations

4.49 Situational violations often occur when a rule is impossible or extremely difficult to work to in a particular situation. They often lead indirectly to other violations – rules in general command less respect. Can be overcome by improved job design; improved hazard reporting systems; improved working conditions; more appropriate supervision.

Exceptional Violations

4.50 Exceptional violations occur when, attempting to solve a new problem, a rule is violated to achieve the desired goal. They are often high risk because the consequences of the action are not completely understood. One of the means of addressing exceptional violation is ensuring defences are in place to prevent such violations resulting in accidents.

'Optimising' Violations

4.51 'Optimising' violations are created by a desire to increase excitement in jobs, and/or pure inquisitiveness. These incidences can be reduced by job redesign and a removal of rules considered restrictive.

4.52 In general, a high workload and the pressure to do the job quickly increases the likelihood of all types of violation occurring. Perceived risks can be very different from actual risk; the organisational culture and the rules themselves can increase the likelihood of such an even occurring.

4.53 The combination of motives behind any violation is likely to be complex and specific to an individual. The key, therefore, is to change the factors that influence these attitudes ie the organisational, training, management and supervision, job design and equipment design factors which are present in the working environment. This is where the Joint Coal Board Simulator offers potential and will be invaluable as a training tool.

4.54 The assessment of hazard awareness and risk perceptions is therefore central to an understanding of the reasons behind some rule violations; and therefore any training mechanism designed to redress them. There is, however, a further dimension to consider. The decision to commit a violation is often derived from a conscious decision which balances the perceived risk against the perceived benefits The benefits may be both personal as well as for the company and may be short or long term.

4.55 In any program of change, it is important to measure changes of attitudes. However, a problem exists in determining which behavioural factors need to be measured. Designers have a duty of care to design plant and equipment that is safe. Poor design features can provide a strong motive for operators to violate safety rules. This is area where simulators can be used to stress test systems to assess machinery before production of the real item.

4.56 There is a strong body of evidence to suggest that an approach to OHS improvement built on reinforcing total compliance with procedural rules and regulations is likely to be counterproductive. Blindly following safe work procedures can actually increase risk. Behaviourist approaches, which rely on rewards and punishment on an individual basis, could be counter-productive if they reduce group cohesion.

4.57 Other findings include:

- While there is a general risk-taking disposition – it varies within the individual from task to task;
- risk-taking measures have generally failed to provide the subject with a true atmosphere of risk – assessment devices may fail to generate the atmosphere of risk which is necessary to tap risk-taking tendencies; and,
- risk taking can be divided into various components where the individual may show different dispositions to risk. These are:
    - monetary – willing to take chances where financial gain is involved
    - physical – enjoys adventurous activities – a thrill seeker
    - ethical – willing to compromise either own or society's standards
    - social risk-taking – willing to express himself freely, socially brash.

4.58 Some commentators maintain that a training program should not aim to entirely eliminate error. Eliminating the opportunity for error severely limits the range of possible behaviour. Error can be creative and there is a role for creative error. Operators who need to exercise critical skills at regular intervals, will benefit by refresher training with an associated reduction in error-making.

4.59 The relationship between skills and knowledge is not well understood. Skill is the ability to carry out a task and knowledge is the possession of information, facts and understanding about a task. The designers and authors of the procedures may have an enormous amount of knowledge about the system and its components but that does not always translate into useable information at the operator level.

Risk taking in Underground Coal Mining – Recent Studies

4.60 The NSW Department of Mineral Resources commissioned a study[6] in 2000 into the risky positioning behaviour of underground coal mine employees using remote controlled continuous miners

4.61 This study[5] had its origins in an alarming number of fatalities of miners using and maintaining this equipment. A focus of the study was to be on the behaviour of employees in using the equipment and the degree of compliance with rules and procedures. The use of large equipment such as continuous miners is risky due to the need for operators to constantly position themselves near moving equipment in confined spaces in less-than-ideal working environments.

4.62 This report observes that it is not just sufficient to concentrate on engineering aspects; human or behavioural issues must also be taken into account.

4.63 Relatively little is known about risk-taking behaviour in a mining context. Operators are often well informed of the risky or even life-threatening nature of their behaviour but they still jeopardise their personal safety to make gains. This can be for production purposes but often it is only for comfort or convenience.

4.64 This Study had two specific aims:

- To measure the extent that operators and other personnel enter “No Standing Zones” at underground coal mines; and,

[6] Corrie Pitzer

- To assess and analyse possible causal factors for this behaviour.

No Standing Zones

4.65 The NSW Department of Mineral Resources Report[5] (the DMR Report) found that during routine coal cutting operations, continuous miner drivers tended to select their positions primarily for line of sight, then comfort, then out of habit, and only then in terms of their perception of danger. Rarely did they report that they selected the position because it was the "correct" position as per the rules. Similar observations were made during tramming and non-routine cutting (flitting) operations. This is an example of area where VR simulators can be used.

4.66 The time that operators stood in no-standing zones varied from 10% in routine coaling to 18% for tramming to an average of 55% of the time during flitting operations and up to 80% while handling cables. Other risky behaviours were observed including:

- An operator using the cutter head as a work platform when the continuous miner was operational;
- an engineer commenced working on a part of the continuous miner while the driver was tramming the miner; and,
- hazardous pick changing on the continuous miner head;

4.67 The causal factors were found to include:

- information processing needs – the operator judges that the no standing zones are inappropriate;
- motivational issues – including incentives,
- risk awareness deficiencies – being unaware of the risks;
- risk tolerance/ignorance – operators were starting to ignore risks; and,
- risk assessment limitations – underestimating probability or consequence of risks.

4.68 At the heart of these causal factors was conscious risk taking. The DMR Report found, disturbingly, that most of the employees questioned routinely enter dangerous works areas, such as unsupported roof areas. Maintenance personnel indicated that they would routinely carry out maintenance under unsupported roof.

Knowledge of "no standing zones"

4.69 The majority of drivers had very limited knowledge of no standing zones. Clearly there is a communication issue here

Awareness of rib spall

4.70 Operators were aware of rib conditions and the potential for rib spall.

Physical fitness

4.71 Again in a disturbing finding, the study indicates that workers tended to take more risks towards the end of the shift. These tasks included standing out under under-supported roof while bolting and meshing in a measure to reduce the strain and bodily discomfort.

Motivation to take risks

4.72 The DMR Report found that the reason employees took risks could only be investigated to a limited extent because they tended to become defensive when questioned about it. Pressure to get the work done is considered to be one of the major reasons.

Risk Ignorance/ tolerance

4.74 It was found that operators are usually aware of the risks, particularly of roof falls, but often underestimate or tolerate them. This phenomenon often occurs in high-risk environments, where a belief develops over time that risks are under control, because of an over-confident reliance on procedures, controls and back-up safety systems. It is for the same reason that mine disasters often happen in organisations where good safety management apparently exists[7]. A correlation can thus be drawn between the DMR Report study and the findings of the Challenger disaster where it was apparent that the engineers and managers became tolerant or ignored the risk of O-ring failure over time. Risks are normalised over time due to routine nature of risk-taking.

[7] Pitzer

Risk-takers' behavioural profile

4.75 The correlation of risk-taking personalities with accident data has generally been discounted in scientific and behavioural science literature. Those employees who described themselves as risk takers also regularly breached safety rules, routinely go into unsupported ground and are less likely to wear personal protective equipment. There may be some substance to the idea that the risk-taking personality is more likely to become involved in risk-taking behaviour, which may warrant further research. It was, for instance, observed that certain workers who more regularly breach general rules of safety in the underground work environment are the same workers who more readily described risky behaviours in themselves and others, and generally tend to be the ones who stated that they would routinely go under unsupported roof. These workers were also less compliant about wearing required personal protective equipment[8].

External sources of Risky Behaviour

4.76 Poor equipment design such as the placement of trip/isolation switches can contribute to the positioning of workers in risky positions. It can also lead to risky behaviour due to the additional effort required to isolate machines.

Behaviour of Cable Hands and Maintenance Staff

4.77 Unlike continuous miner operators that are skilled in recognising poor roof or rib conditions, the same could not be said of ancillary employees such as maintenance workers. Maintenance workers would more readily enter no standing zones and would work on machines without properly isolating them.

4.78 The DMR Report observed that it was the unusual, non-routine periods of operation around a continuous miner that posed the highest level of risk. The lack of guidelines and procedures during these tasks is an issue here. More guidelines or procedures may not be very effective in dealing with the issue. "It was noted for instance that there was little observable difference in risky behaviours between operators of mines where an abundance of procedures are issued and mines where procedures are hardly available or known to the operators". The challenge is to make training on the procedures and the rules, more effective.

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8 Pitzer

Perceptions of rules and procedures

4.79 One of the most significant sections of the NSW Department of Mineral Resources Report looked at employees' perceptions of safety procedures, managers' rules and standard operating procedures. "Most employees (above 90% of all those interviewed) expressed misgivings, doubt and outright criticism of the value of these procedures. Any mine that operates 100% within the rules will not produce a single tonne of coal." It stated that possibly the majority of underground employees operate every day with the assumption that safety rules are "irrelevant, superfluous, non-essential or excessive".

Routine Risk Taking

4.80 Miners develop habits in relation to task execution based on a compromise between the need to carry out a task in a certain sequence and practical circumstances, which results in risk taking to such an extent it is routine.

4.81 The Report developed a draft conceptual model of risk taking behaviour, as shown in Figure 4.1 (Appendix 1), based on the premise that risk taking is either preceded by a decision to take the risk or it is done automatically due to the employee's state of mind.

4.82 The Report included the inputs of drivers and operators in the design of standard operating procedures, which is common in a structured risk assessment approach. This may also be the key to the creation of good and effective legislative controls. Workplace rules can have a significant effect on the safe behaviour of employees, but only if those rules are seen as relevant and practical.

a. Employees' perception of risk can be regarded as one of the most powerful influences on behaviours, and without a concerted effort focusing on this, no amount of procedures will affect risk-taking at the coal-face.

b. The large variety of risky situations that employees encounter in the workplace makes it impossible to design and implement procedures to govern every possibility. It is crucial that regulators and the management of mines achieve a realistic and "intelligent" balance in the scope and level of intended control for such procedures – otherwise employees will continue to find ingenious ways to perform tasks effectively, but not necessarily safely.

Requirements for the simulator

4.85 The requirements for any development of a training simulator for the Mining Industry can be grouped under the following subheadings:

- The Training Environment;
- The Trainee; and,
- The Training Program

The Training Environment

4.86 The Training Environment should:

- Reflect real life environment/conditions;
- incorporate real-life controls;
- be close to reality as possible – need for operators to immerse themselves in the virtual world;
- provide for trainer-trainee interaction;
- a variety of systems should be available;
- interaction should be kept simple ;
- interactivity should overcome inattention during normal learning situations;
- be suited to Australian conditions; and
- back up service should be available.

The Trainee

4.87 Several issues surround the issue of trainees. These include, but are not limited to:

- To what extent is a particular person trainable?
- Do the trainees have a bias for production over safety issues?
- What is the rate of learning of the trainee?
- How much training is required to achieve mastery of a particular task?
- What are the effects of changes in the training regime on rate of learning?
- How often is refresher training required?

4.88 Personality tests for Trainees. This is important its own right and is examined further in Appendix 2.

The Training Program

4.89 The Training Program should take into consideration the following factors,

- The system must be robust or resilient to overcome the possibility of errors;
- training on a simulator transfer must be as realistic as possible to performance in a mining situation;
- elimination of corner-cutting and other undesirable behavioural traits;
- reducing the error rate;
- the system should be forgiving and should absorb errors at least for a time;
- the Trainee operator should be trained to admit the possibility of error and acknowledge it;
- in the event of error some kind of feedback must be given so that it is possible for the operator to recognise that an error has occurred;
- contain routine plus unusual hazards and risks – both high probability, low consequence and vice versa; and
- Variability of underground environment needs to be incorporated.

5. Review of the Software Techniques available for Illustrative and Interactive Virtual Reality (VR) Simulation.

Key Issues

- Simulators are effective training tools and allow trainees to make decisions and to have the opportunity to see the consequences of their decisions.
- Interactive technology has the capacity to greatly improve safety through improved training of operators in a safe environment.
- VR-based training is now an affordable technology. Desktop PCs are powerful enough to manage VR and their performance is continually increasing. Also, as the market for VR software increases, the price of the development, and thus the software itself, will decrease.
- VR based training is currently in use in other industries. Flight simulators are the most advanced VR systems, and these show increased retention of information by students because of the visual and interactive nature of VR simulators.
- VR has the potential to become a bridging method of training between the classroom and on-the-job training.
- This Study has identified three potential suppliers. These have well-developed and functional systems that can almost certainly be developed further to suit the needs of the Joint Coal Board Simulator. The most cost-effective of these is the AIMS *SAFE-VR* Simulator package.

Review of the Application of Virtual Reality to Training

5.1 This Chapter details the results of a review of literature on the application of illustrative and interactive Virtual Reality (VR) simulation technology. It also assesses 'demonstration' versions and literature on these simulators - where available.

5.2 The literature reviewed is selective and concentrates on systems that are applicable for use in the Joint Coal Board Simulator. Other more peripheral systems are discussed in less detail. This Chapter also discusses some of the issues associated with the delivery of VR, the development of different systems and the functionality that is required to present effective VR training.

Literature Review

5.4 Due to the volume and complexity of the safety information and legislation considered by the Scoping Study, it was decided that a comprehensive review of literature on simulator-training software packages and developments was required in order to make an informed decision upon an appropriate simulator for training miners in continuous mining, rock bolting and haulage.

5.5 The scale of the VR system literature reviewed ranged from simple PC based question and answer simulators to sophisticated immersive VR simulators that use a combination of computer graphics, digital images and real machine controls to deliver the system.

5.6 There are many varieties of simulator-training packages, from PC-based systems, to cabs that simulate every aspect of driving a truck. This review attempts to address the issues associated with each type of simulator; in particular simulator training systems available, their functionality and relevant issues associated with using simulators as training devices.

5.7 The use of simulators for training has been common practice for many years in areas such as driver, military and aircraft personnel training. The sophistication of these devices has increased with the advances that have taken place in computer technology over recent years.

5.8 The Study also evaluated PC-based demonstrations of VR software to discover what makes them effective or ineffective as a learning tool.

AIMS Research Unit University of Nottingham

5.9 The AIMS Research Unit[1] has been active for over a decade matching advanced computer techniques to engineering problems. The purpose of the Unit is to act as a technology based centre for advanced computer applications in the engineering sector.

5.10 In the past, mine planners, surveyors and geologists all relied on the two dimensional presentation of information. Using Virtual Reality, the user can interact with 3D computer generated models. In this virtual world they can operate objects that respond to their actions in real time.

5.11 AIMS believe that this technology can be used to:

- Visualise new designs, techniques and methods.
- Assess hazardous items of equipment for their safety.
- Train users to use complex pieces of machinery in a safe and cost effective environment.

5.12 To improve safety, operators need to understand and apply the techniques of risk assessment. Managing risk involves identifying a hazard, identifying that it has potential for harm, estimating the probability that harm will occur, thus calculating a risk rating, and importantly, identifying the methods to reduce the risk.

Virtual Reality Systems

5.13 In 1998 AIMS undertook a Desktop Study of how VR could be used to train operators in risk assessment and hazard recognition, in mining.

5.14 AIMS adopts the view that VR has the potential to become a bridging method of training between the classroom and on-the-job training. VR based training is currently in use in other industries, like aviation. Some flight simulators are the most advanced VR systems, and these show increased retention of information by students because of the visual and interactive nature of VR simulators.

[1] Much of the technical content of this section is derived from the AIMS Research Unit of Nottingham University. The Scoping Study Team wishes to place on record its appreciation for the use of this material generously made available on the Web.

5.15 AIMS insists that simulators, to be effective training tools, should not just involve navigation around a virtual world, but should include the facility for trainees to make decisions and the opportunity to see the consequences of their decisions. That is, interactive technology has the capacity to greatly improve the training process of operators.

5.16 A VR system could be used by a trainer to demonstrate to the trainee correct and incorrect procedures and routine and infrequent/unusual operations. Alternatively, the computer could be used to 'advise' the trainee during a simulation, to be used as a competency based testing system, and a place to train staff for hazardous environments and situations. Through VR based training there is a record of decisions made by the trainee. Sessions can be stopped at any time for the trainee to investigate other possible decisions, allowing a trainee to learn by trial and error in a safe environment. AIMS, however, believes that conventional classroom training and work experience are still vital.

5.17 PC based VR systems are relatively new and reflect the advances technology has made primarily due to the high investment in the computer games market. PC VR systems typically use joysticks or steering wheels as input devices. Increases in processing power have allowed VR to become PC based, especially with the availability of low cost 3D accelerators which remove some of the effort in processing from the main processor.

5.18 Examples of output devices are Head Mounted Displays (HMDs), which are continually improving in quality and provide stereoscopic vision, and PC projection systems, that are only semi-immersive. Normal monitors have the potential to be just as effective if the software is of a good quality.

Customised Training

5.19 AIMS intends to develop VR systems that are all desktop based and can run on a £1000 (AU$ 3,000) machine. These systems can be customised to different environments and scenarios and can be easily modified.

5.20 They can be made more beneficial as a training tool by the introduction of hazards which can be introduced in a random or controlled manner. These VR systems can have a logging mechanism for the post-training review of scenarios, hazard recognition and decision making.

Types of Simulator Environments

5.21 The systems that AIMS are designing include a surface mine haul simulator, a processing plant walkthrough, and an underground mine fire and explosion simulator. The truck simulator is designed to train truck drivers driving in and out of a surface mine or quarry.

5.22 The ‘world’ is created by the importing of layouts from CAD systems, and models of equipment. This system has an interface of a steering wheel, pedals and levers, and the trainee can either drive the truck or run it in auto pilot and focus on hazard spotting and risk assessment. The trainee simply has to target the cursor on the hazard and choose the hazard from the list. The trainee also has to select from lists what the most important potential consequence from this hazard, the level of risk, and the method of reducing the risk.

5.23 The trainee continues the simulation and the logging facility allows a report to prepared at the end of the simulation, giving the trainee a final score. This system is designed to be as realistic as possible by, for example, by introducing atmospheric conditions which affects the visibility and the traction of the truck. Sound is also available.

5.24 The processing plant walkthrough is similar to the truck simulator. The trainee, a process plant operative or a supervisor, as the case may be, ‘walks’ through a process plant using a joystick. The underground mine fire and explosion simulator, once fully developed will be able to train mine workers, supervisors, engineers and managers in rescues involving hazardous situations.

5.25 Future improvements in PC VR simulators are expected. Faster hardware, especially 3D graphics processors, and better methods of representing virtual worlds by improving software and increasing artificial intelligence integration are under development. Interfaces will be improved so that users will be given a true immersive feel, by improving stereoscopic viewing, and perhaps developing body sensing and voice actuation. The development of the Internet has the potential, with a sufficient bandwidth, to allow remote mines to train employees where there are no major training centres.

The University of Virginia

5.27 The University of Virginia addresses similar issues to that of the AIMS team in Nottingham. However, their emphasis is on the need for safety in surface mines

5.28 Trucks have a high level of risk, because of handling and visibility problems due to their large size. By 1995, industrial trucks were the second leading cause of fatalities in the private sector. The Occupational Health Safety Authority (OHSA) found that the industrial truck training standards were not adequate to reduce the number of accidents.

5.29 Reducing the number of accidents involving industrial trucks, from a financial perspective, is significant because haulage trucks are the largest cost item in the operating costs of a surface mine.

5.30 The University of Virginia's study paper discussed two applications, a VR surface mine truck driving simulator and a truck inspection scenario. They explain that the driving simulator runs on a PC platform, with a screen for visual and 3D audio output. This simulator recognises that detail is important for training because it is the hazard spotting of details that results to safe operation of any equipment.

5.31 The performance of the driving simulator depends on the size of the VR environment. A large environment results in a larger mesh. However, improvements in graphical accelerators have increased the retention of high frame rates. The application uses currently available pit data to create the VR world, thus reducing the cost of developing the world. Mesh data from standard modelling packages, such as Vulcan or Surpac, can be imported into the VR world. All objects, including importantly the haul roads, are added in a 2D system, and the third height dimension is automatically calculated.

Hazard Spotting

5.32 The pre-shift truck inspection training system involves the trainee's navigation around a single truck and identifying hazards with components of the truck. Once the hazard is spotted, the trainee needs to identify the type of hazard from a list of options, and then correctly identify the risk reduction strategy. The trainee navigates around the truck using a mouse, joystick or 3D control device. Every decision is logged, and a score is given at the end of the simulation.

5.33 Both these training systems have drawn favourable comment. The hazard spotting system was tested at some South African gold mines, and both systems were demonstrated to a large number of mining institutions. The ease in creating scenarios from existing CAD and hazard data impressed the institutions. It is expected that both these systems will become commercially available.

5.34 AIMS has also included haulage-truck hazard-identification system, the safety inspection training system, and the mine incident training system in its training systems.

Potential Use of VR for Training Mining Personnel

5.35 University of Nottingham's AIMS also briefly describe the methods to build VR worlds. They emphasize that CAD systems can be used to build objects for the virtual world, and most CAD software allows the export of these objects into VR systems. VR shells can also be used to build a VR world, however, they lack flexibility for complex scenarios. Alternatively, VR toolkits can be used for more complex systems, but toolkits need more programming skills than shells.

5.36 VR-based training is now an affordable technology. Desktop PCs are powerful enough to manage VR, and their performance is continually increasing. The price of a PC is also continually decreasing, and a PC may be used for other purposes than just training. Also, as the market for VR software increases, the price of the development, and thus the software itself, will decrease.

5.37 VR system cans be used for both training and testing purposes. In the training mode, the trainee is alerted by the system of a hazard. The hazard is highlighted and the response of what danger this hazard poses, how severe the hazard is, the probability of occurrence, and perhaps the course of action to remove or reduce the hazard. In the testing mode, the trainee has to identify the hazards, and rate their potential severity and probability of occurrence. In the results of the testing session, hazards and answers can be ranked according to their importance and correctness, and those hazards missed are listed.

5.38 VR's advantage is its flexibility in regards to creating scenarios and adding hazards. This makes it possible to continually create unique situations, making learning by repeated trial and error impossible. Passing a test by trial and error, would not be testing knowledge retention.

5.39 Importantly, Virtual Reality-based systems can also be used for competency-based testing. At mine sites where drug and alcohol abuse are problems, operators are sometimes unfit to carry out their duties. Operators may also be unable to perform their jobs effectively and safely due to domestic problems associated with these abuses. A test on a VR system can determine a person's "fitness" to operate certain equipment by checking their concentration levels.

VR only Part of the Training Experience

5.40 Virtual Reality is unlikely to replace on-the-job or classroom training as it cannot train for all the skills needed in many jobs, such as human interaction. VR should be only a part of the total training experience.

5.41 Virtual Reality feedback is useful for evaluating the training process on an individual and group basis. Individually, VR tests can identify which types of hazards are repeatedly being missed or inaccurately identified, and these areas can be the focus of future training sessions. On a group basis, if there is a failure to spot certain hazards by many of the trainees, this indicates that there is a systematic training problem that needs to be rectified.

5.42 Adding a variety of static and mobile equipment, incorporating realistic truck queues, using noises to represent engine noise or warning sirens, and changing the light and road conditions to simulate other weather conditions are all possible.

5.43 Ultimately, this training system tests the procedures drivers take when operating a truck, rather than the accuracy in controlling a truck. One major part of this simulation is the identification of hazards. This simulation can offer both types of hazards, static and dynamic, despite dynamic hazards being more difficult to configure.

5.44 Two examples of the safety-inspection training software are a processing plant and an underground room-and-pillar mining operation.

5.45 The room-and-pillar simulation is described as a typical load-haul-dump sequence in which the trainee does not click on potential hazards; rather he/she ensures that they are in a safe position at all times. This simulation has equipment moving randomly, and hazardous situations only arise when the trainee positions his/herself incorrectly.

5.46 AIMS reveals that their mine incident training software is still in preliminary development. This simulates an incident in a VR mine, and with a real-time ventilation model in this simulation, the user is given statistics on the direction and speed of the ventilation. The user can be anyone: from a mine worker, to a supervisor, to a mine rescue team member. These users will have different objectives when an incident occurs, and all users will be tested according to their role. During the simulation, likely physiological effects are given to the user when atmospheric conditions worsen.

5.47 VR training is no longer expensive nor difficult to create and use.

Safe-VR

5.48 AIMS research has produced *SAFE-VR*, a tool that allows training applications to be easily created, without programming. Through a graphical user interface new objects can be introduced, and can be associated with hazards and sounds. Next a user defined query list needs to be formed that gives lists of solutions to the trainee, and each answer needs to be given a score according to the insight that the trainee displays. Sounds can be associated with the presence of hazards, and interactivity, such as turning on buttons, can be incorporated into the virtual world and its hazard logic.

5.49 AIMS states the software is easy to use, and no literacy is required because all text entries can be associated with pictures or a sound file that provides a spoken version of the text. Navigation around the VR world can be achieved by keyboard, mouse or joystick, and identification of hazards requires a mouse or a touch screen.

5.50 Hazards are given probabilities, ensuring that each hazard spotting session is not identical, and each session is a challenge and a learning experience. Hazards can also have multimedia files associated with them that provide more information about that hazard, if the trainee wishes to know more.

5.51 At the end of the training session, the trainee is provided with a final score and a comprehensive summary of which hazards where correctly/incorrectly identified and which hazards were missed.

5.52 *SAFE-VR* can show the trainee the location of the missed hazards in the virtual world, and the best replies for those hazards identified. This is discussed in more detail below.

VR is an indispensable addition to training packages

5.53 Virtual Reality training systems are now an indispensable addition to any training package. The use of high quality three-dimensional graphics, spatialised sound and dynamic simulation combine to form a uniquely engaging experience. New recruits can be trained on the latest equipment without taking valuable resources out of production. Their ability to handle hazardous situations can be assessed without actually putting them at risk. The computer-based nature of the training means that recruits can learn at their own rate, but the interactivity ensures their active participation, whist the automatic scoring tracks their individual progress.

5.54 AIMS comments that virtual reality systems have traditionally been very expensive. Each application was programmed from scratch and needed high-end Unix workstations to run. This is no longer the case.

5.55 AIMS *SAFE-VR* allows creation of individual training applications quickly and simply on a PC (Figure 5.1,). *SAFE-VR* software uses a graphical user interface to allow the import of new objects and sounds that can be associated with relevant hazards without any programming whatsoever.

5.56 Each hazard can be associated with a user defined query list. Trainees may only be required to identify a hazard and choose the best solution, or they may need a more formal hazard assessment structure. In *Safe VR*, this is not a problem. A list can be defined and new hazards created. For each criteria a list of answers is presented, that can be scored individually. This gives the opportunity for a sliding scale of answers, with more marks available for the trainee with more insight, instead of a simple yes or no.

5.57 All that's left is to choose which objects belong to that hazard. Each object can have a sound, and that sound can even depend on whether a hazard is present or not (hissing air for leaking pneumatics, for example).

5.58 The hazards in a particular scenario such as a continuous miner, may not be that easy to spot; they may need some investigation on the part of the trainee. In *SAFE-VR* the user can interact with objects in the virtual world, such as turning on buttons and flicking switches. *SAFE-VR* provides the ability to respond to these actions, and include troubleshooting trees and dynamic simulations using a simple PLC-type logic tree as shown in Figure 5.2.

5.59 According to AIMS, although *SAFE-VR* makes creating training worlds easy, it's even easier for the trainees to use. There's no need for computer expertise or even for literacy to learn on this software. Moving around the virtual world is achieved using keyboard, mouse or just a joystick, and a mouse or touchscreen is used to point out suspected hazards. Real machine controls can also be interfaced to the simulation.

5.60 Where literacy or language could be a problem, all text entries can be supplemented with user-defined pictures. Alternatively, a sound file can also be associated with the text, providing a spoken version, for example.

5.61 The ability to associate the probability of any hazard occurring ensures that each training session presents the trainee with a new challenge. This variability ensures that the trainee takes care to inspect the entire equipment, instead of simply learning the software, even for repeated training sessions. An example is shown in Figure 5.3.

5.62 AIMS explains that the end of the hazard spotting session is not the end of the learning process. The system provides a comprehensive summary of the training session. However, rather than just providing a simple score, the opportunity is provided for the trainee to learn from any mistakes. The software shows how the total score has been calculated, where any marks have been dropped, and what the best replies would have been. The trainee can see a list of any hazards that were missed (Figure 5.4), and can get the program to point out their locations. Each hazard can have additional files associated with them, so that when the trainee requests more information about any hazard, various multimedia files (video, audio, text etc.), and even other applications, can be automatically displayed.

SAFE-VR, a Training Enhancer.

5.63 *SAFE-VR* provides a unique opportunity to use specific models and multimedia files to develop a PC-based VR trainer that enhances existing training packages. AIMS already produce many VR training programs that vary in complexity and function. AIMS also produce visualisation material suitable for accident reconstruction, demonstration and planning. VR simulations include:

Safe-VR Shell	Truck Simulator
Mk II 650 Drill Rig Inspection	Truck Inspection
Underground Roof Support Demo	Shuttle Car Hazard
MOL Pump Operation	Shuttle Bar Hazard
Chemical Plant Demo	Room and Pillar Simulation
Waste Inspection Site	Opencast Pit
Drilling Rig Inspection	Face Salvage

AIMS' VR Visualisation includes:

Mine Accident Reconstruction	Joint Assembly
Mine Safety Training	Free Steered Vehicle
Mine Fly Through	Construction Site Training

5.63 Three VR simulation and one visualisation demo are evaluated here. They are all of a high quality.

- Underground Roof Support Demo
- Room and Pillar Simulation Demo

- Truck Inspection Demo.
- Mine Accident Reconstruction.

SAFE-VR requires a PC with a Windows 95, 98, or 2000 platform. It also requires DirectX and HTML Help, and a recent PC with a good quality graphics processor.

Underground Roof Support Demonstration

5.64 This demonstration was developed using AIMS Research's *Safe-VR* software and allows the trainee to walk through an underground mine and spot various hazardous situations. Hazards include missing and badly positioned roofbolts and geological hazards.

5.65 The underground roof support demo initially provides a diagram for correct bolt placement (see Figure. 5.5). The trainee is then introduced to the underground simulator, in which he/she needs to identify the hazards, such as missing or incorrectly placed bolts and dislocated blocks. Clicking on the hazard gives a window in which to identify the type of hazard and a choice of what should be done about the hazard. At the completion of the simulation a report of what hazards were correctly/incorrectly identified, and which hazards were ignored (see Figure 5.6).

5.66 This demonstration provided reasonable well-patterned graphics, easy navigation using a mouse or joystick, and the speed of navigation was adequate.

Room and Pillar Simulation Demonstration

5.67 The room and pillar demo contains a dynamic simulation of a room and pillar mining operation. The simulation contains a continuous miner, shuttlecars, conveyors and roof bolters and is fully customisable. It also provides performance information.

5.68 The room and pillar simulation allows the whole operation to be experienced in VR and users can travel throughout the mine and witness how machinery interacts. The room and pillar simulation demo does not allow the user to spot hazards, rather it allows the user to observe the practices of room and pillar mining, by navigation or by observing from preset viewpoints. It does, though, show the user where an operator should not stand. Hazard spotting could be easily incorporated.

5.69 In its current form it presents the amount of coal mined and the distance of roof bolted (see Figure 5.7). The graphics are reasonable, and for enhancing the reality of the underground environment, the degree of darkness can be altered. If a Head Mounted Display was used, it could immerse a trainee in the environment in 3D. Detail is only used where necessary, to reduce file size. For example, the continuous miner has very little detail except for the picks. In this demo, however, the user can navigate through solid objects and walls. This saves time when moving from site to site.

Truck Inspection Demonstration

5.70 AIMS is developing a generic hazard spotting training system. This demonstration is an early application, which allows the user to spot a variety of hazards on a haulage truck

5.71 The hazards are randomly generated and the user is scored on their ability to correctly define the hazard and choose the best solution.

5.72 To identify a hazard (e.g. gashed tyre) the 'eye' hazard-spotting button is chosen on the tool bar, then double clicking on the object or hazard reveal further information. The user is then presented with a dialog box asking them to specify the hazard. When the user has identified all the hazards the red 'stop' button is clicked to reveal a score (Figure 5.1).

5.73 A range of options are presented to fix the hazard. These actions are spoken and together with pictures, this simulation is suitable for all literacy standards of trainees. Additionally, this demonstration provides instructional videos (Figure 5.8) about hazard detection and maintenance for some parts of the truck. This allows the trainee to learn at his/her own pace, and provides information for assistance prior to an assessment of the truck hazards.

5.74 Graphics in the demonstration are reasonable but less textured than the underground demonstration and navigation around the truck with either mouse or keyboard is quite challenging without a joystick. Navigational speeds are adjustable, but this helped very little. This could be a result of the graphics processor used in the evaluation, and perhaps a faster processor would lessen this problem.

Training Simulations Assessed

5.75 All the AIMS VR simulators except the room and pillar demonstration, give a score and details of which hazards were identified, correctly or incorrectly, and those that where missed. This allows the identification of areas of weakness in the hazard-spotting trainee.

5.76 Overall, the *SAFE-VR* system is a very powerful 'shell' in which VR worlds are placed, making this a flexible VR tool. Further flexibility is offered by the full versions that allow the addition, removal, and modification of hazards, which would be useful in the Joint Coal Board simulator. This type of technology is probably the most cost effective and with some further development may provide a means to deliver combined VR and web-based training.

Mine Accident Reconstruction

5.77 The VR visualisation representing a mine accident reconstruction produced by AIMS is excellent. The Mine Accident Reconstruction demonstration is a cut down version of a large VR visualisation. The scene shows the impact of a runaway coal wagon underground. It clearly shows how one of these trucks can be easily derailed through a series of events. The consequences for two of the animated characters are severe. This type of VR would be excellent for the reconstruction of events and for the demonstration of the consequences of poor management or risk taking behaviour.

5.79 Using these VR visualisations is preferable to film or animation. Filming this type of event would be very expensive and require special effects and filming expertise. These sort of skills are very expensive and the range of scenarios that it is envisaged would be encountered by the Joint Coal Board Simulator would make video production costs very expensive indeed.

5.80 Access to underground mines for filming events presents challenges. The VR simulation also has the advantage of looking more realistic than 'cartoon' animation.

5.81 A sketch of the proposed system is shown in Figure 5.9, Some of the commercial issues are that the system needs to address are:

- The use of a Big Screen 3mx2.4m

- The use of a Touch screen –say 20” monitor to start/stop big screen 3D models (biggest touch screen is 4ft x 3ft and is too small to gain a 3D experience)
- The need to interface between real control panels and VR Software
- The need for sounds (surround)
- The possible need for smell
- The need for digital images - essential
- The need for video shots where appropriate
- The need for machine general arrangement drawings
- The need for layout drawings of mine roadway and roof support plans
- Use of a Joystick – rotational type.

5.82 In conclusion, AIMS offer a fully customisable system that can be modified to the needs of the Joint Coal Board Simulator.

Continuum Resources

Continuum Resources – VR visualisation[2]

5.83 Continuum Resources explores and manages corporate knowledge via a Visually Integrated Team Operating Space (VITOS). VITOS is designed to encourage and enhance multidisciplinary collaboration, eliminating the barriers between users and their data. VITOS is discussed in the section that covers Knowledge Management Systems.

5.84 Continuum aims to take this technology beyond visual and audio immersion to total sensory immersion, where all the senses are fully engaged in virtual operating space. Continuum's products and services focus on enabling clients to integrate their workflow, data and applications, decrease cycle time, and increase return on investment.

5.85 Continuum Resources is a recognized leader in the commercial application of multi-sensory, immersive virtual modelling tools in a true collaborative environment as a means to fully explore multidimensional, many-faceted data sets.

An Immersive Environment to Suit Different Training Needs

5.86 Continuum Resources takes users beyond mere visualization into a real immersive environment where users can experience the data and thereby capture knowledge from a data set to an extent never before possible. This can be accomplished either on a workstation or PC, in a team room with a wall-size projector, or in one of our human scale immersive visualization facilities. For the first time, all data for a project can be viewed in a single space, allowing full interdisciplinary collaboration among team members, whether on-site or in remote locales.

5.87 Continuum design, source, install and maintain immersive visualization systems ranging from desktop size to theatre. The systems provided by Continuum Resources are comprehensive data visualisation systems. Continuum Resources also develop immersive images for training visualisation and interaction.

[2] The Study Team gratefully acknowledges the kind support provided by Continuum Resources in preparing this Report.

5.88 Continuum Resources have provided many visualisation demonstrations. Some of these include:

• Jaw Crusher Simulation	• Submarine Rescue
• B Valve (Interactive)	• Geophysical (Interactive)

5.89 The graphics in Continuum Resources simulations are excellent. An example of a scene from the Crusher Simulation is shown in Figure 5.10. In the Crusher Simulation, the scenario shows the interaction of a dump truck and the crusher. The simulation is aimed at visualisation. However, discussion with Continuum Resources confirms that it would be possible to have interaction with this type of scenario.

5.90 Figure 5.11 shows an example from Continuum Resources Submarine rescue simulator. The demonstrations provided also include an example of an underground truck fire and mine ventilation simulations. Unfortunately, screen shots of these are unavailable at present.

5.91 Overall, the VR products presented by Continuum Resources are of high quality and are suitable for the Joint Coal Board Simulators. However, the interactivity and method of programming is not as straightforward as AIMS.

Fifth Dimension Technologies

5.93 Fifth Dimension Technologies (5DT) is a high technology company specializing in Virtual Reality (VR). 5DT develops, produces, and distributes affordable VR hardware, software and related systems. 5DT also develops complete custom 'turnkey' systems. 5DT are located in South Africa and the United States and produce a range of VR training simulators. In recent years they have worked with Sasol Coal in the development of a VR continuous miner.

5.94 5DT claims their Virtual Reality Continuous Miner Training Simulator, developed with Sasol Coal, teaches the continuous miner trainee how to control the machine in such a way as to "increase productivity while maintaining a high safety standard." The trainee controls the continuous miner in a virtual coal (or potash) mine with controls that accurately resemble those of a real CM (remote control version).

Training Scenarios

5.95 The trainee works through a series of training scenarios that vary in complexity from simplistic training scenarios to very complex and challenging scenarios. The trainee receives a complete training report at the end of each training session. The system may be used for the training of new operators or for evaluation and re-training of experienced operators. Training is performed in a "safe and controlled environment." Figures 5.11a-b outlines the system components.

5.96 5DT describe the system as having two computers that are networked together. The first computer is connected to a Big Screen Projector and is an Instructor Computer that shows the virtual instructor on the monitor. The second computer is used by the trainee.

5.97 When an event occurs, or if the trainee makes a mistake, event messages and/or error messages will be superimposed on the instructor's view. These messages will not be visible to the trainee; However, it will be visible on the Big Screen to benefit the rest of the class. The trainee wears a Head Mounted Display. The Head Mounted Display contains two miniature computer screens and two headphones. This enables the Trainee to view the virtual mine, virtual Continuous Miner and virtual Shuttle Car.

Head Mounted Display

5.98 As well as hear different sounds created in the virtual environment, a Head Tracker is fitted to the Head Mounted Display. For example, when the trainee looks downward, the Head Tracker measures their head orientation and relays such positioning information to the trainee's computer. The computer then calculates the image that the trainee would have seen when looking downward in an actual coal mine. This image is displayed on the two miniature screens inside the HMD.

5.99 The computer calculates new images approximately thirty times every second. The result is that the trainee is totally immersed in a virtual environment. The trainee's view through the HMD is also displayed on the monitor of the trainee's computer. The trainee controls the virtual Continuous Miner with a Remote Control Unit that accurately resembles a real remote control unit.

5.100 The 5DT system was originally co-developed by 5DT (Fifth Dimension Technologies) and Sasol Coal, one of the leading coal producers in South Africa and over the past two years more than four hundred Continuous Miner operators have been trained, evaluated or re-trained with the system.

Applications

5.101 The type of applications that the Virtual Reality simulators can be used with are described by 5DT as:

1. **Training of new Continuous Miner operators**.

   The simulator allows the instructor to train new Continuous Miner operators in a controlled and safe environment. A trainee's skills are developed systematically with the Continuous Miner.

2. **Evaluation and re-training of existing Continuous Miner operators**.

   The simulator is ideal for the evaluation of qualified Continuous Miner operators, since all actions performed by the operator are recorded. The skills of a qualified Continuous Miner operator may be analysed in detail, where re-training or corrective training may be applied to sub-optimal skill areas. For example, a supervisor in an operational coalmine may find faults in a particular operator's performance, and can then schedule corrective simulator training for the operator.

3. **Research and Development.**

The simulator may be used to try new procedures in a virtual realm first, before validating these procedures in reality and is also an ideal tool for the development and implementation of 'best practices'.

4. **Familiarization and Introduction tool.**

It is often the case that a majority of coalmine personnel have not experienced any time underground. This can lead to an unsatisfactory understanding of the coal mining process, which can result in sub-optimal mine management and administration. The simulator is ideal to expose administrators and managers to the "cutting edge of their industry."

5. **Marketing and PR**

The simulator could be used to show visitors what it is like to work in a coal mine, without exposing them to the real environment.

5DT claim that:

- Loss of Continuous Miner production time during training can be reduced significantly.
- It is unnecessary to interrupt actual production to perform basic skills training with the simulator.
- Shorter Continuous Miner operator training periods are possible. The simulator has been designed to minimize the training cycle while maintaining a very high standard in terms of skills development and safety awareness. The pre-simulation module teaches the user how to optimally manipulate the controls of the Continuous Miner. The trainee is then exposed to several training scenarios, ranging from simple to complicated scenarios. The system continuously evaluates the trainee so weaknesses in performance are quickly identified.

5.102 During training enhanced Continuous Miner operator skills development is possible. Trainees are exposed to a wide variety of conditions and environments, some which may be life threatening in reality. A trainee can be prepared for much more than average/normal conditions. The simulator can exactly measure trainee performance, which can lead to an enhanced skills development.

5.103 The application of ‘best practice’ is also considered by 5DT. Through the improved application of best practices the simulator enables a mining group to evaluate and optimise their best practices. Once these have been identified and established, they may be used during workplace implementation.

5.104 5DT describe many of the simulator’s features and comment that the simulator has:

- Realistic Visuals: the virtual world and objects look like the real thing.
- The Continuous Miner is a fully functional computer generated Continuous Miner and all the relevant parts move, pivot, and/or rotate correctly.
- A computer generated Shuttle Car with lens-flared headlights and a moving conveyor belt, supplements the Continuous Miner.
- The mine itself has a very realistic feel with cutting marks on the walls (vertical marks on the forward faces and circular marks on the sidewalls), a realistic roof and floor textures, roof bolt streamers, and shiny slip sections.
- When the Continuous Miner is trammed backwards, a virtual cable handler ensures that the cable is not in danger.
- The trainee can see the virtual instructor. Additionally, a surprise visitor may be programmed to transgress the area in which the trainee is in control of.
- Special effects are present, the purpose of which is to make the simulation as realistic as possible. A few examples are:

  a. Sparks, when cutting into the roof

  b. Roof bolt streamers that move in accordance with the ventilation system. The streamers cease to move when there is a ventilation system failure.

  c)Coal, that falls down when cut from the face.

5.105 According to 5DT the simulator also presents realistic sounds and a dynamic model. For example, cutting speed is reduced when cutting into rock rather than coal. Cutting speed is increased when cutting into burnt (devolatised) coal. There is a change in the density of the coal when it is cut ($1m^3$ of coal in the coal face [in situ] corresponding to $1.5m^3$ of coal once it has been cut).

5.106 The simulator offered by 5DT offers a Pre-Simulation Training Module and before a trainee can operate the continuous miner in the virtual world, they first need to know the associated terminology; as well as how to control the continuous miner with the remote control unit. The pre-simulation module serves to prepare the trainee to operate the continuous miner.

5.107 The simulator also offers a realistic control interface and the remote control unit used in the simulator accurately resembles the real remote control of the corresponding reality-based continuous miner. It looks, feels, and weighs the same as the real remote control unit.

5.108 To allow the instructor to create, edit and save different virtual mine-sections, editing is done on a plan view (top view) with assistance of two side-section views. The mine section editor described by 5DT consists of several modules:

1. There is a Volumetric Pixel [voxel] editor. The virtual mine is constructed with volumetric pixels [voxels] of approximately 250mm x 250mm x 250mm (10" x 10" x 10"). The instructor/administrator may edit the mine to determine exactly where air (tunnels), rock, soft coal and hard coal appear. The relative hardness and density of the above voxels are also variable. The instructor may lay down realistic strata, e.g. a thick coal seam with a thin layer of rock at a specific height within the seam.
2. There is a floor and ceiling editor and the instructor may edit the floor and ceiling (roof) heights. These heights are normally chosen to reflect the dimensions of the mine where the trainee will be working after training.
3. The instructor may position cracks and slips (step-shifted strata) with the mine section editor.
4. Roof bolts and other objects may be placed with the editor.

Range of default training scenarios

5.109 The simulator also offers a training scenario editor that allows a sequence of events to be created that the trainee has to negotiate. According to 5DT, the simulator contains a range of default training scenarios and the object of the exercise is to expose the trainee to the scenarios in the order of increasing difficulty to develop the trainee’s skills. The scenarios contain numerous events that the trainee has to react to. These events include time dependent and position dependent events.

5.110 During the simulation a log that logs all activities during a simulation and a mining operation report is produced. The mining operation report contains the date, time, training scenario, mine, name of instructor, name of the trainee, total coal mined and a list of events that occurred. It also lists the response of the trainee to each event, as logged by the computer or instructor.

5.111 The simulator offered by 5DT (2000) may be operated in one of two modes:

1. Stand-alone mode
2. Networked instructor/operator mode

5.112 The normal mode of operation is the networked mode, where both the instructor and operator computers are active. The simulation may however also be run on a single computer (stand-alone) mode. This mode is normally used for system demonstrations. It also offers a convenient back-up solution if one of the computers may fail.

5.113 The system can be customised to represent a Continuous Miner or Shuttle Car and can offer a Remote Control Unit and Cockpit Controls. The basic simulator was designed for Remote Control operation.

Technical specifications

5.114 The technical specifications of the simulator are listed by 5DT as:

1. **Hardware**

   Computers 2x Pentium III 700MHz computers (1 for instructor, one for trainee) with Geforce2 graphics accelerator cards. Network interface, 100Tx Ethernet, Head Mounted Display, 5DT's HMD 800-35 (Full colour 800x600 SVGA resolution, 35° Diagonal Field of View [FOV]). Head Tracking *Ascension's* 3-D Bird orientation tracker. Remote control unit / Radio Unit Manufactured by 5DT to mimic the control unit of the CM manufacturer. Big screen projector In Focus DMD (1024x768 resolution, 1,200 ANSI lumens).

2. **Software.**

   Operating system Microsoft Windows 98SE. Rendering engine Microsoft Direct 3-D. Software language.

Microsoft Visual C++ 6.0. Voxel rendering 5DT's Dynamic Real Time Voxel Rendering [DRT-Vex].

5.117 The information presented by 5DT (2000) show that virtual reality training of mine personnel is a realistic opportunity that is available now. While the information presented by 5DT is really a sales brochure, the information is worthwhile and the following conclusions may be drawn.

5DT has trained 400 + miners using their system

5.118 From the information provided by 5DT it appears that the system has already evaluated, trained and retrained some four hundred miners in a safe environment without risk of injury over the past two years.

5.119 It appears that it may be possible to identify poor performance or unsuitability to training in trainees at an early stage. This may allow a system for behaviour modification to be employed that can demonstrate to a trainee the impact of risk taking or not adhering to best practice without exposing the trainee to the dangers of risk taking.

5.120 5DT suggest that its system could be used to identify and test new mining methods and scenarios and familiarise personnel with these. This could be very cost effective.

5.121 There are some obvious benefits outlined by 5DT in the form of improved productivity through effective training and shorter and higher quality training periods of consistent standard. Trainees may be exposed to scenarios that rarely present themselves but are nevertheless crucial to effective training. Apart from increased tonnages, there are other benefits, such as less damage to machines, and increased safety awareness.

Summary

5.122 5DT appears to be one of the market leaders in Virtual Reality Systems aimed at the mining sector. 5DT claim that VR training can increase productivity through more effective training of personnel. The simulator offered by 5DT offers training and virtual coal and potash mine simulations that expose trainees to a series of training scenarios of varying complexity and difficulty.

5.123 Overall, 5DT appear to produce an effective realistic VR training simulator that utilizes ‘off the shelf’ and easily upgradeable software and hardware. The system is aims to be as realistic as possible through the use of real machine controls that familiarise the trainee with the ‘feel’ of the controls and the interaction between the machine and controls. 5DT also has the advantage of offering a pre-simulator training module to familiarise personnel with no mining experience with the environments that exist underground.

5.124 The output from the simulator is quickly available through the training report presented after each training scenario. This is invaluable when appraising trainees and identifying risk-takers.

Immersive Technologies (Caterpillar)

Truck Simulators

5.125 Immersive Technologies provide high quality manufacturer fitted truck simulators for operator training. Current truck fittings are for Caterpillar, Komatsu, and other truck manufacturers.

5.126 Immersive Technologies (2000), provides simulators that entirely replicate operations inside a truck. They provide large 4.5 m long high quality 195° wrap around displays, side rear view mirrors, an operator's console where all controls are functional just like a real truck, a 3D motion base that simulates the road conditions and grades, and surround digital sound. Together, these features make this simulator as real as possible.

5.127 The Immersive Technologies brochure and the Caterpillar Inc. video, identify some of the advantages in using a simulator, which include:

- assessing a person's skills prior to employment;
- providing information on how an operator may respond in an emergency;
- providing a safe learning environment for the trainee and other workers,
- minimum to no risk of damaging valuable equipment,
- trucks are not taken out of production for training,
- truck cycle times are not decreased.
- This simulator can also test any braking or other practices that may abuse brakes, tyres, transmissions or engines. The procedures can be corrected before an inexperienced driver operates a truck, thus reducing maintenance costs.

Training Suitable for all Levels

5.128 Immersive Technologies explain that for fresh trainees, lessons are available that include all possible truck error warnings. Multi-media is used in these lessons, including voice-over animations and graphics. Languages other than English are available. Alternatively, experienced operators undergoing refresher training, receive no guidance from the simulator. All levels, Beginner, Intermediate and Advanced, are given detailed reports at the end of the simulation. Important parameters shown in the reports include:

- travelling time;
- reaction time;
- loading position;
- incorrect use of the park and service brake;
- high/low RPM when retarding;
- failure to stop at stop signs;
- not sounding the horn when required; and
- number of collisions.

5.129 Simulator session data can also be formed into plots from certain criteria. This is for more technical analysis, which can be useful for checking aspects like operator errors.

Supervisors, according to Immersive Technologies, find the simulator easy to manage. The parameters the supervisor can change are:

- Selection of loading implements, i.e. shovel, excavator, or front-end loader
- Load and dump location
- Number of circuits to be completed by the trainee
- Hazardous events eg fires, failures, loss of steering, and bogging
- Driving conditions eg dust, fog, night driving, wet weather, road traction
- Path and number of additional trucks on a circuit.

5.130 Supervisors can also print trainee reports and playback a trainee's session. Supervisors need only point-and-click computer skills to operate and maintain the simulator. They are provided with full documentation and training.

Truck Models can be Changed

5.131 Immersive Technologies explain that the simulator can also be changed from one truck model to another. If the controls are the same, the software can be changed so that the simulator handles like a different truck. Software exists for Caterpillar and Komatsu trucks. For those truck with different controls, conversion kits are also available, and can be installed easily by the client in about 20 minutes. Conversion kits for excavators and front end loader will be available soon.

5.132 There are two available installations of the Immersive Technologies simulator: the transportable and the freestanding (permanent installation). The transportable installation is the same size as a standard 20 foot sea container, weighs about 3.5 tons can easily be transported from site to site, and is operational 10 minutes after connecting the container to the power.

5.133 For permanent installation, Immersive Technologies recommend a dry, secure room with solid floor, at least 6m by 3.5m in size. The room should have air conditioning to ensure the temperature does not exceed 28°C when the simulator is operating. Access doorway needs to be at least 140cm wide, a 110V or 240V AC power supply is essential, and a telephone line is useful for any remote maintenance and software upgrades via a modem.

5.134 The Immersive Technologies simulator comes with two generic mine models, however, for an additional cost, depending upon the complexity, a virtual mine can be custom built according to an individual mines computer data.

5.135 Ultimately, this performs like a real truck, the realism is provided through full screens, rear view mirrors, surround sound, controls like a real truck and the 3D motion base simulates grades, skidding, and other road handling sensations associated with driving a truck.

Most Appropriate Type of System

5.136 This is a high quality simulator and an expensive option, however, the quality of the realism, as seen in the Caterpillar video suggests it is the ultimate truck simulation system.

CSIR Stope Training – The South African Experience

5.137 CSIR Have developed a simulator that is designed to introduce miners to hazard spotting in a gold mine stope.

5.138 According to CSIR of South Africa, a reduction in mining accidents can be achieved by using VR as an approach to training miners. The top two categories for mine accidents in South Africa are falls of ground and mining and transport.

5.139 Traditionally, the approach taken to reduce fall of ground accidents was the improvement of support units and systems, and improving mining layout design. The additional approach of improving the level and effectiveness of training to underground workers should also be taken, where training emphasis should be on hazard identification and the subsequent safety action.

5.140 VR training has already been successful in a wide range of other industries that have a strong emphasis on safety, such as the aviation and medical industries. Some of the advantages include lower costs than physical models, flexibility, the creation of situations that are rare or have never been encountered before, the repetition of scenarios, monitoring of trainee progress during sessions and trainee interaction.

5.141 CSIR found that computer-based training, compared to traditional instructor-led training, has a cost saving of as much as 50% with an equal or higher quality of learning in 40-60% less time. This type of training ensures that there are no hazard to the trainees from hazardous equipment, and no damage to valuable equipment during training.

5.142 Low levels of education and literacy, particularly in South Africa, and a lack of employee enthusiasm to be trained, are problems that need to be overcome in mine training. Traditional training methods taught ‘knowledge’, rather then ‘skills’, this can be ineffective when training workers with poor education. Effective hazard recognition requires both knowledge and skill, and VR allows these skills to be developed. VR, therefore, primarily uses skills based training, allowing the training method to be more effective for those workers that have low levels of education and literacy.

5.143 The training simulator used is Windows/PC based and requires a joystick for the trainees' movement through, for example, the main working area of a stope. The exercise involves recognising hazards, primarily loose rock in the roof. To prevent the virtual 'death' or 'injury' of the trainee, he/she must remedy the situation by selecting a corrective action on the touch-screen monitor, represented graphically. This graphical approach ensures language boundaries and different literacy abilities are overcome. The training instructor has keyboard access to load and reset hazards, move to different viewing positions, activate the scoring and evaluation module, and can make minor adjustments to the module. The trainee receives a score at the end of the session, but is also made aware of the likely injury they receive when he/she has an 'accident'.

5.144 The training simulator was evaluated by CSIR Miningtek and SIMRAC. This investigation compared classroom training with VR based training. The findings show that there was little difference between the ease with which trainees could understand visual material, as the VR and video material was ranked as easy or average. This shows that poor literacy and computer literacy skills did not affect comprehension. Realism of VR and video ranged from good to poor, with video realism ranked better. However, the participants all liked or had a high liking of VR, and this included an older group of subjects.

5.145 Some of the positives of the VR training included a feeling of empowerment for the trainees, feeling at ease, practicality and the less 'theoretical' nature of VR and, most importantly, its requirement of attention through participation. VR does not allow lack of attention, while 22% of the subjects were asleep during the video, and 28% were not paying attention to the screen. The only negative aspect of the VR training was the extra time some trainees needed for familiarisation with the use of a joystick, but no one rejected the use of a joystick.

5.146 Although this simulation was a gold mine stope hazard scenario, this technology could also be applied to other hazards and environments. The experiment used one-on-one interaction with the PC. However, it could be applied to a group situation, where one member interacts on behalf of the group by looking at a large wall mounted screen, rather than a monitor. Training personnel in the mining industry have shown enthusiasm about the prototype VR training simulator, but not many have applied this technology.

5.147 VR with further development and take-up of the technology, has the potential to be relevant to and improve, training. The effectiveness of VR training of workers with low levels of education and literacy is higher than traditional methods. VR particularly appropriate for safety training.

The smaller players in VR and Knowledge Management are Shown in Appendix 3.

6. The Driver and Operator Assessment Battery.

Key Issues

- 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, is of great benefit to the mining industry. Computer-based technology such as the Driver and Operator Assessment Battery (DOAB) appears to be one system that may be applicable for this task.
- An estimate of the applicability of DOAB to continuous miner operations, roof bolting operations and off-road truck operations suggests that DOAB would be applicable to the Mining Industry.
- There is some concern that the former promoters of the product are no longer in existence and the licence is for sale.
- It is recommended that further research be carried out on the applicability of computer-based assessment batteries to the coal mining industry. There may be superior systems with a mining orientation that may be more relevant.
- It is further recommended that a field trial be conducted at one or several mine sites to test the system.

The Driver and Operator Assessment Battery

6.1 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 places 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.

6.2 The Study Team 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. This chapter summaries independent studies on DOAB's effectiveness in detecting risk-taking, error proneness and other adverse behavioural traits and its suitability to the Australian Mining Industry.

6.3 It should be noted, however, that DNS Business Solutions, the company that strongly promoted the product in 2000, is no longer in existence. The licence is for sale. Connect Personnel has the international copyright for DOAB and is currently trying to sell it. This sequence of events would seem to cast some doubt on the product and the promoter's belief in its success in the market place. This development notwithstanding, the DOAB Battery has enough merit to warrant consideration.

6.4 Generally speaking, computer-based technology, such as DOAB has 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 these are static and skills-based.

6.5 Before this system is acquired, it is recommended that further investigations be carried out, including a survey of safety and mine managers, to determine the current usage of aptitude and behavioural testing and whether they see DOAB as being of benefit in their organisation. Secondly, a field trial at a mine site is recommended to assess the performance in a real life situation.

Overcomes Static Tests

6.6 The Driver and Operator Assessment Battery was developed to overcome some of the drawbacks of the numerous conventional, static "paper and pencil" aptitude tests.

6.7 Driving and operating is an "over learnt" skill. It is the wrong use of these skills, due to attitudinal and behavioural factors, that cause the majority of 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):
  - Both too-slow and too-fast reaction times are correlated with accident causation. In particular, "complex" reaction time involving stimuli and the response to the stimuli is highly relevant and is measured by DOAB.

- Impulsiveness:
  - Impulsivity is defined as the "tendency to respond quickly to a given stimulus, without deliberation and evaluation of consequences." It is linked with the concepts of extroversion, sensation seeking, risk taking and field dependence.

- Appropriateness of risk-taking:
  - Risk-taking is a difficult area to assess. DOAB uses an overtaking scenario incorporating incentives and punishment for correct and incorrect decisions.

- Tracking or fine motor skills deficiencies:
  - Tracking measures directional control; and,

- Division of attention:
  - Division of attention is measured by having simultaneous sources of stimuli present while tasks are being performed. It measures the ability to differentiate between relevant and irrelevant stimuli.

6.8 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.

6.9 The specifics of the system are simple and include a PC (486 or above) with a 2 button mouse, a steering wheel, accelerator and a brake pedal.

Trainee Assessment

6.10 The Trainee is assessed in a one-on-one situation in a non-threatening environment. The instructor aims to put the trainee at ease before the trainee sits at the desk to carry out the tasks.

6.11 The DOAB is not designed to test operating skills and is not a simulator. The promoters suggest it should be used in conjunction with skills and knowledge testing and operator record evaluation to increase its effectiveness.

Measurement of Risk Taking and other Behavioural Traits

6.12 There is little available information of actual field investigations on the use of the DOAB or any other similar, computerised battery testing system. There have not been any tests carried out in the mining industry. Nor can it be said that testing has been carried out on truck drivers, bus drivers or others.

6.13 The results of a test in Newcastle earlier this year using DOAB and a full driving simulator, CYBERCAR, were subjected to analysis and it was found that four factors were significant. These were risky behaviour, goal attainment, efficient perception and fast driving. CYBERCAR predicted two of these factors. To the lay reader, the results appear to be inconclusive.

6.14 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.

6.15 The current General Manager of Connect Personnel, and a former director of DNS, believes that DOAB would be suitable for the mining industry itself to licence or even a University. There is no equivalent product in Australia.

6.16 The DOAB aims to assess individuals to find out what their learning capacities are and if they have weaknesses or problems. Before they do generic training the DOAB can be applied in the recruitment and selection phase but also at other times such as moving to new rosters. A person may be well suited to 8-hour shifts but entirely unsuited to 12-hour shifts. Another use is in post-accident investigations and the assessment can reveal where the weak spots are.

6.17 As far as fitness-for-duty is concerned, Connect Personnel indicates that the 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. The consumption of amphetamines will result in increased brain activity thus manifesting itself in other criteria.

6.18 The point was stressed that all personnel on a mine site, regardless of their literacy skills in both the written, verbal or computer area can use the battery. Furthermore, the assessment is suitable to non-English speakers as well. Clearly this has advantages over the conventional paper-and-pencil tests.

Use of Assessment Batteries at Mine Sites

6.19 The Cadia Hill Gold Mine operates one of the largest fleets of off-road haul trucks in the mining industry. The Safety Manager at Cadia indicated that Cadia uses the recruitment and selection procedure to "weed out" the risk takers.

6.20 This mainly consists of an interview and written (psychometric) testing. He is quite happy with the present process but acknowledges that this alone will not determine the risk takers. He was unaware of the DOAB but believes computer-based assessment has some merit. The cost of the simulator training was an issue. It is expensive but on the other hand they have quite high personnel turnover and maybe that would have helped retain them.

6.21 The Safety Manager believes that human behaviour is helped by having the culture right – as the "old school" diminishes then new operators will assist in bringing in the right culture. Another major issue is fatigue and fitness for work – when people are tired, then they cut corners and take risks.

Applicability of DOAB to the Mining Industry

6.22 Computer-based assessments of human behavioural traits such as those offered by DOAB could have a positive role to play in the mining industry.

6.23 It appears that there are advantages over the traditional, static paper and pencil aptitude tests although the literature has not confirmed this aspect. This can be and 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.

6.24 Table 6.1 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.

6.28 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 safely operating a truck.

6.29 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.

6.30 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.

6.31 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**.**

7 Integration of Virtual Reality and Multimedia Technologies into Interactive Simulators

Key Issues

- The Joint Coal Board Simulator should embrace available technologies completely and customise them with the aim of integrating VR technology, multimedia and safety legislation and rules within the one training simulator.
- In the first instance, the procedures used by the simulator should be carefully selected and related to a training needs analysis. It is preferable to have a basic set of rules that work well and that can be tested for efficiency rather than have a top heavy and complicated system that is difficult to manage.
- For the first simulator, the SWP should be generic and presented in a form that can be developed through interaction between mine sites, with the ultimate aim being to develop an effective safety management plans through collaboration.
- Best endeavours should be made to obtain footage for video clips and photographs from a range of mine sites for use in simulations.
- Care must be taken to ensure that Safe Working Procedures written for mining equipment maintain there currency and are updated to allow for modifications to that equipment
- Components technologies that are used to develop the simulator should be of high quality and the latest specification to reflect the real world to be encountered and to avoid 'Simulator Sickness'.

7.1 The principal findings of the Stage 1 and Stage 2 Scoping Studies are:

- The task of collecting and collating SWP from minesites and producing a system of 'Best Practice' and expanding this beyond the NSW industry was greater than envisaged due to differing practices at mine sites;

- Developing a generic system of ‘Best Practice’ may not be appropriate for some operations or maintenance tasks. Different ground conditions at different mine sites do not lend themselves to generic procedures in some areas of work.

- Some tasks may be better represented through the use of video clips and digital images rather than pure computer graphics simulation.

- Limitations are associated with identifying and achieving interactive work place experience.

- The maintenance of equipment by a range of bodies has resulted in SWP that can be different to those of the original manufacturer. This situation is compounded by modifications to equipment without the knowledge of the original manufacturers who raised the initial maintenance work schedules, making manufacturer’s SWP inappropriate;

- There are already Dump Truck Simulators available;

- There are already Continuous Miner Simulators available;

- There will soon be a Rock Bolter Simulator available;

  However, None of these satisfy the requirements of the Joint Coal Board Simulator.

- Poor quality simulators can have adverse side effects such as creating nausea through ‘simulator sickness’. It is important to ensure that only sophisticated equipment be used.

The above topics are addressed in more detail in the following subsections.

Duplication of existing Simulators

7.2 The Project Evaluation Study identified existing simulator technology in the form of Dump Truck simulators, Continuous Miner simulators and potential Rock Bolter simulators. Many other types of simulators were also found to be readily available.

7.3 The existence of this technology and the varying levels of sophistication within it, suggested that much of the development work has already been performed. It is considered that the existence of these technologies presents the Joint Coal Board with the building blocks with which to build a leading edge simulator. Using these current technologies and arranging the building blocks into the form required by the Joint Coal Board will be more practical than developing a system from scratch.

7.4 This Scoping Study recommends that the Joint Coal Board Simulator should embrace these technologies completely and customise them with the aim of raising the sophistication of simulator training to the next level. The next level is a simulator that integrates VR Technology, Multimedia and Safety legislation and Rules within the one training simulator.

Collecting and collating the SWP from Many Mine Sites

7.5 The Scoping Study found that the volume of material that was provided by the mines quickly became unmanageable due to the variation between formats and methods of delivery. For the Scoping Study to be effective in the time frame required, the evaluation had to be selective. The disparity between formats is something that a system of generic SWP would relieve but it was also found through discussion with existing mine operators and equipment manufacturers that the use of generic SWP for some tasks was inappropriate. Factors such as, ground conditions dictate whether information in an SWP is appropriate.

7.6 For the system of 'Best Practice' SWPs and SMPs to be truly effective, there would almost certainly have to be a unilateral decision by participating mines to adopt the system. There would also be a requirement for the system of 'Best Practice' to allow a variation within 'Best Practice' that accommodates parameters such as ground conditions.

7.8 Overall, collecting and collating the safety documentation from all mines was a massive undertaking. If the system begins to acquire and assimilate experience from outside New South Wales, the volume of information increases again.

7.9 The Study recommends that, in the first instance, the procedures used by the simulator should be carefully selected and related to a training needs analysis. It is preferable to have a basic set of rules that work well and that can be tested for efficiency rather than have a top heavy and complicated system that is difficult to manage. For the first simulator, the SWP should be generic and presented in a form that can be developed through interaction between sites with the ultimate aim being to develop an effective safety management plans through collaboration.

Digital Images, Video Clips and Computer Graphics

7.10 At the outset of the Study, one of its primary aims was to review computer based training and multimedia packages currently available from machinery manufacturers and multi-media suppliers for both illustrative and interactive simulation.

7.11 It is now evident that there is no one ideal multi-media solution. For the effective delivery of safety documentation and operator and maintenance training all types of multi-media should be embraced. An example of this is shown in the University of Nottingham's Safe-VR program where the trainee moves around a VR truck. The aim of the scenario is to hazard spot. When the trainee spots a hazard, interaction with the VR truck brings up a video clip explaining the hazard and how to remedy it. Supporting documentation is also available.

7.12 For the Joint Coal Board Simulator to be effective, it must embrace multi-media technology such as digital photographs, video clips and computer generated simulations to provide as much flexibility and realism in the simulator as possible.

7.13 The Study Team recommends that the simulator should ultimately be a hybrid system that exploits computer graphics, video and digital images to develop and maintain the required levels of realism.

Achieving Interactive Work place Experience Proved Difficult.

7.14 The Study Team found that achieving interactive work place experiences might present a problem. It was found that manufacturers are generally open to conversation and exchange of information provided that the information is not made public or passed onto third parties.

7.15 Developing a generic SWP requires experience of as many systems as possible to provide a balanced system.

Refits

7.16 A point picked up though discussion with equipment manufacturers was that some equipment is not always serviced by the original supplier or manufacturer. This can result in variations from the manufacturers original specifications and hence an SWP that was written for the equipment at the time of manufacture or commissioning, may not be applicable to the re-furbished equipment.

7.17 A system would have to be devised to monitor maintenance or upgrading of equipment so that appropriate changes can be made to the SWP. This is a serious point as a simulator that represents a certain machine could teach a trainee an operation that is safe on a 'standard' machine that complies with the manufacturers specifications but which in real life is not safe due to the 'non-standard updating' of a machine by a subsequent contractor or maintenance section.

Adverse effects of Poor Quality Simulators

7.18 One purpose of the Scoping Study was to evaluate integrating VR simulator and multi-media technologies into simulators. During the study, a phenomenon emerged that presented a problem in the early days of computer-based simulators. Known as 'Simulator Sickness', this problem has the potential to manifests itself in all simulators regardless of whether they are purely computer graphics based or video clip based if the components of the simulator are not of sufficient quality.

7.19 Simulator sickness is the manifestation of motion sickness experienced in moving vehicles by some people. In computer-based simulators, its effects can be acute due to the effect that simulator images have on the retina of the subject's eyes. In the real world the image on the retina moves instantaneously as the head or body is moved. In simulators, if the system speed of design is inadequate, the change in the image is not instantaneous and is detected by the central nervous system. The brain reacts by assuming there is some undetected toxin in the system and this can lead to vomiting and other nauseous effects. 'Simulator Sickness' within populations can be as high as 70%.

7.20 It is extremely important that the simulator technology used by the Joint Coal Board, delivers images to the trainee immersed in the world at ''refresh' rates sufficiently fast enough so that the image presented to the retina acts as though it was an image of the real world.

7.21 The Study recommends that the components technologies that are used to develop the simulator are of high quality and the latest specification.

Conclusions

7.22 The major conclusions that can be made from the Study are that there are many simulator and multi-media technologies available to the Joint Coal Board. From the Study it is apparent that technology suitable for training simulators is variable in quality, functionality and cost. There are already Dump Truck and Continuous Miner Simulators on the market. The level of sophistication of these depends largely on cost. None of the simulators meet the specifications for the JCB Simulator

7.23 For simulators to be effective they must be developed from a 'training needs analysis' rather than the blind application of technology to the training of operators and maintenance personnel. Using a 'training needs analysis' will identify whether the trainee requires immersion in a VR world to provide experience of operating machine controls or whether the trainee could be sat in front of a P.C. based simulator that uses video clips and question and answer sessions to assess understanding or personality traits.

7.24 Clearly, integrating VR and multi-media technology into a system that can be used to train personnel is no mean feat. However, with careful consideration, planning and control of scale, there is no reason why VR and multi-media technologies cannot be brought together successfully to provide a simulator that represents a continuous miner, a roof-bolter and a dump truck.

8 Design Specification for an Interactive Simulator

Key Issues

- A recommendation of this report is that the University of Nottingham's AIMS software be used for the construction of the simulator. The University of Nottingham have considerable mining experience and experience in applying VR to mining situations.
- Safe-VR is produced by AIMS and is a modular programming environment that allows easy and rapid modification of scenarios. Ownership of the scenarios developed in Safe-VR remains with the customer.
- The system also allows VR and digital images to be combined easily to provide a multi-media training system. Internet Access, real machine controls and immersive headsets can be easily incorporated.
- A system such as Safe VR may ultimately be easier to modify and update than more complex systems offered by Fifth Dimension Technologies and Immersive Technologies.
- Developing the simulator using Safe-VR will keep control of the simulator within the domain of the J.C.B. Health and Safety Trust.

Suitable Technologies Available

8.1 This Study has found that technologies are available for the development of a simulator suitable for training mine operator and maintenance personnel.

8.2 There are many methods of delivering virtual training. These range from simple question and answer programs using 'click and drag' options and true/false answer sessions to desktop PCs running programs such as the University of Nottingham's Safe-VR program that uses hazard spotting in a Virtual Reality (VR) world and digital video clips as its main medium of communication. The next level of sophistication is the fully immersive VR technology developed by Fifth Dimension Technologies and Immersive Technologies. These companies have developed fully immersive VR worlds into which the trainee is placed.

8.3 The study has found that much of the development of VR has been driven by developing software without any specific goal in mind. The opportunity now exists to develop a powerful training simulator tailored to the training and development needs of the Coal Mining Industry, that will reduce the number and frequency of accidents and incidents. Several levels of complexity and different levels of skills training may be incorporated into this system.

8.4 It is important that a 'Training Needs Analysis' is performed before the development of the simulator. A Training Needs Analysis will identify the Trainee's needs and what the system requires from the Trainee. Once this is established, the building 'blocks' that are available in the form of disjointed VR technologies can be brought together into a VR simulator adapted to meet a specific training need. The arrangement of the building 'blocks' will be such that they can be easily pulled apart giving the simulator flexibility though its modular form. There may also be 'spin offs' into other industries.

8.5 The design specification for an interactive simulator is discussed below. Essentially, the preferred model is a modular system that can be easily adapted to the training requirements of a roof-bolter, continuous miner or dump truck. This Study has shown that there are three levels of sophistication and they are presented in order of increasing expense.

8.6 The key to the success of all three options is ease of interaction. Interaction removes the possibility of inattention on the part of the trainee. Also, the systems should be fun to use and the trainee should consider that the experience to be positive.

Option 1.

Desktop P.C. based interactive simulator with real machine controls

8.7 Of the three options presented here, option one has the lowest cost per unit. The option is essentially P.C. based and uses software run on the Wintel platform. A diagram of the proposed system is shown in Figure 8.1.

8.8 The basic function of this option is the access to a central server that controls the relevant information included in the simulator. The increasing bandwidth of computer communications allows the Virtual Reality Training Software to be delivered over the Internet.

8.9 An example of such a system maybe one that incorporates the University of Nottingham's Safe-VR program, digital video streaming software such as Apple Quicktime, Microsoft Internet Explorer or Netscape Navigator and question and answer software such as Questrak. However, where a large quantity of video data are required it may be that a slightly different approach is required where software and data alike are pre-loaded onto the local P.C. via the server and each time the program is used, a check is performed to validate the current document version and perform an update where necessary.

8.10 This type of system maybe useful where training in safe working procedures, re-training or risk-taker identification is required. It would be very useful as a second-level simulator that compliments any full-blown immersive simulator. Delivering this type of system over the Internet could be the key to providing remote mine sites with up to date training when the full-blown simulator is unavailable.

8.11 This option provides a solution that can be delivered relatively quickly to a large number of sites. The nature of the system is such that competency based training and assessment is easily delivered. A trainee's progress through a training program can be assessed at the central server. Also, any trainee that has qualifications that are becoming dated can be tracked using this system. The errant trainee can then be advised of the situation and remedial action taken to enhance and update the appropriate training.

8.12 Set up Tasks:

▪ Safe-VR Programs	▪ Project Management
▪ Central Server	▪ Dedicated Phone Line
▪ Dedicated P.C.s at ten Mine sites	▪ Internet Service Provider
▪ Windows 2000 Server	▪ Administration
▪ Web Developer Software	▪ Product updates
▪ SQL Server Database Management	Hardware set up
▪ Database Development and Programming	Transferring S.W.P. to 'Best Practice Format'

Option 2. *Site based, immersive, interactive simulator with real machine controls*	8.13 This option is used by Fifth Dimension Technologies (5DT) and CSIR in their training simulators. A diagram based on the type of configuration used by 5DT and CSIR with some proposed modifications that consider the parameters defined by the J.C.B. Scoping Study is shown in Figure 8.2. 8.14 The proposed system is more sophisticated than Option 1 and the standard simulator offered by 5DT in that it utilises two-networked computers, a Head Mounted Display, a large screen view and a link to a knowledge management system described in Option 1 and Figure 8.1. It is anticipated that the simulator would be installed in a $3m^2$ room or a mobile container that may be transported on a truck.

8.15 The main attraction of this type of simulator is that it can immerse the trainee in a virtual world that is an accurate representation of the environment into which the trainee will be placed. The concept is that the trainee can interact with the machine controls in the VR world as would occur in the real world. When the trainee looks up, he or she sees the roof, when the trainee looks down, he or she sees floor and so on. It is proposed that during the training session information such as safety documentation would be accessed by the trainee in ‘real time.’ This would be achieved by the trainee ‘touching’ the appropriate area of the machine or environment and the central server delivering the relevant documentation or video stream to the to the Trainee and Instructor Screens.

8.16 This level of sophistication raises the simulator from a Option 1 where system of networked PCs are communicating over a network to a system where the trainee can be immersed in a virtual world that contains as much realism as is required. This level of realism can only be identified by a training needs analysis. However, from Figure 8.2 it can be seen that it would be possible to use this type of technology to train inexperienced personnel in the operation and maintenance of mining equipment. The system could expose the trainee to hazards in the VR world without suffering physical injury.

8.17 The estimated tasks involved in developing this type of system are:

Central Server:	Safe-VR Continuous Miner Immersive Simulator
Dedicated P.C.s (10 sites)	Safe-VR Roof Bolter Immersive Simulator
Windows 2000 Server Sftwr:	Safe-VR Dump Truck Immersive Simulator
Web Developer Software	Project Management
SQL Server DB Management	Dedicated Phone Line
DB Development	Internet Service Provider
Hardware set up	Administration
Transferring S.W.P. to 'Best Practice Format'	Product updates

Option 3.

Mobile immersive, interactive simulator with real machine controls

8.18 This is the most expensive option. The idea is based on the concept of the Immersive Technologies Dump Truck Simulator. A layout of the proposed system is shown in Figure 8.3. The proposed system of Figure 8.19 system is more sophisticated than Options 1 and 2. It is anticipated that the simulator would installed in a mobile container that can be transported on a truck. The simulator could also be located in a training room. The main attraction of this type of simulator is that it can semi-immerse the trainee in a virtual world.

8.20 The world may represent that of a roof-bolter, a continuous miner or a dump truck. The world will be an accurate representation of the environment into which the trainee will be placed.

8.21 The concept is that the trainee can interact with the machine controls in the VR world as would occur in the real world. The feed back from machine controls such as bumping, and jolting of the seat in response to virtual movement provides another dimension to the simulation into which the trainee is place. Similar to Option 2, when the trainee looks up, he or she sees the roof, when the trainee looks down, he or she sees floor and so on.

8.22 In this simulation the interaction between the trainee's machine and other machines or personnel in the session is possible. (This is also possible with Option 1 and 2). It is proposed that during the training session information such as safety documentation would be accessed by the trainee in ‘real time.’ This would be achieved by the trainee ‘touching’ the appropriate area of the machine or environment and the central server delivering the relevant documentation or video stream to the to the Trainee and Instructor Screens.

8.23 This level of sophistication raises the simulator from Options 1 and 2, where system of networked PCs are communicating over a network to a system, to one where the trainee can be immersed in a virtual world that contains the maximum amount of realism in that it has an extra dimension in the feedback presented to the trainee’s seat. Whether this level of realism is genuinely required can only be identified by a training needs analysis. However, from Figure 8.3 it can be seen that it would be possible to use this type of technology to train inexperienced personnel in the operation and maintenance of mining equipment. Similarly to Options 1 and 2, the system could expose the trainee to hazards in the VR world without suffering physical injury.

8.24 The tasks involved in this type of simulator are:

Central Server:	Safe-VR Roof Bolter Immersive Simulator
Dedicated P.C.s (10 sites)	Safe-VR Dump Truck Immersive Simulator
Windows 2000 Server:	Truck and Container
Web Developer Software	Project Management
SQL Server DB	Dedicated Phone Line
DB Development	Internet Service Provider
Hardware set up	Administration
Transferring S.W.P. to ‘Best Practice Format’	Product updates
Safe-VR Continuous Miner Immersive Simulator	Transport running costs

8.25 Developing a truly interactive simulator that encompasses safety legislation, safe working procedures, and trainee evaluation is the next step in the evolution of simulator technology.

8.26 The Interactive Simulator presented in Option 3 will almost certainly place the Joint Coal Board at the cutting edge of safety and training and result in the reduction in accidents and fatalities in the mining industry.

9 Conclusions and Recommendations

The two Scoping Studies have established that virtual reality simulation offers benefits relating to:

Flexible

- Flexibility in time, place, rate and privacy of learning

Understanding

- Developing understanding and retention of learning

Induction

- Staff induction
- Customised 'on the job' training in a safe environment
- Refresher training
- Fault-finding
- Equipment assembly and maintenance training

Visualisation

- Visualisation of the hidden
- Visualisation of the future
- The literacy level of the trainee

Evaluation

- Evaluation of consequences of an action
- Communicating complex data
- Identification of risk takers

Competency

- Tracking of learning progression and understanding
- Competency assessment
- Consistency of training and assessment

Accident investigation and reconstruction

Training Needs Analysis

The research has also identified that for simulators to be effective, their development must be based on a 'training needs analysis' rather than just on the blind or spot application of technology. In order to achieve the potential benefits of VR simulation for operator and maintenance training in the coal industry, the simulator needs to have the following characteristics:

- Interactive
- Immersive
- Realistic to actual environment, not just stick creatures
- Built on best practice SMP and SWP.
- Allow trainees to make decisions and to experience the consequences of these decisions
- Embedded hazard spotting
- Identification of attitudes and reactions to risk taking
- Simply and quick to keep up-to-date
- Affordability relative to the small size of the market

IMPS	Nevertheless, it must be appreciated that the difference between a person knowing how a task should be done versus how they actually undertake the task will remain. The attitudes and aptitudes of a person will still determine how they apply the knowledge and skill imparted by simulated training. The IMPS will still apply:

IMPetuous – act without thinking of consequences

IMPatience – knows better but cannot wait

IMPunity – cannot happen to me

IMProvise – contravene SWP

There is potential for VR simulators to assist in identifying persons prone to these IMPS.

The research has considered the design and application of a number of simulators and technologies. The technology and framework for a JCB Simulator certainly exists. However, it is fragmented and there is no one combination of technologies in the market place that satisfies the requirements of a JCB Simulator. Simulators have generally been purpose designed for operator training on one specific piece of equipment. The developers of the technology have not realised the true potential of VR simulators with respect to mine safety.

Four Technologies

Four leading technologies have emerged. They are

AIMS Technology

1. The AIMS Safe-VR, University of Nottingham. This offers the following features:

- Interactive
- Modular construction
- Graphical programming
- Hazard spotting embedded in the software
- Environment can be textured to a degree
- Links to video clips
- AIMS is experienced and has a track record for producing VR simulations
- Can be effectively linked to a web based database
- Cost effective

Continuum Resources Technology

2. Continuum Resources offering:The AIMS Safe-VR, University of Nottingham. This offers the following features:

- Platform independent architecture for the Knowledge Management System.
- Interactive
- Immersive
- Modular construction
- Graphical programming
- High quality computer based images

Fifth Dimension Technologies

3. Fifth Dimension Technologies offering:

- Continuous miner operator simulation
- Interactive
- Immersive

- Real machine controls
- Field experience - already trained 400 miners in operations in South Africa

Immersive Technologies

4. Immersive Technologies offering:

- Dump truck simulator
- Interactive
- Immersive
- Real machine controls
- Field experience – already trained drivers in operations

Feature	Nottingham VR	5DT	Continuum	Immersive	e-minesafe
VR Software	✓	✓	✓	✓	✓
Modular	✓	x	✓	x	✓
Open Architecture	✓	x	✓	x	✓
SWP Platform	x	x	x	x	✓
Machine Interface	x	✓	x	✓	✓
Immersive Environment	x	✓	✓	✓	✓
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	✓

These four main players offer high quality simulators. However, the accompanying table shows none of the four systems satisfy all of the requirements of the JCB Health and Safety Trust with respect to the integration of knowledge and skills to achieve safe human responses. The JCB *e-minesafe* Simulator needs to incorporate a combination of the positive attributes of the four main technology options.

Modular

The preferred solution is to build and field test a **MODULAR BASED SIMULATOR** prototype that provides the framework for safety and training simulation across a range of mining equipment. In the first instance, the simulator would be based on delivering interactive training for the operation of continuous miners and the operation and maintenance of roof bolters, including rib bolting. There is an option to 'plug in' a dump truck.

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. Instead of VR 'stick creatures', the simulations must be represented by textures inputted from digital and/or CAD images of the mining machines and surroundings.

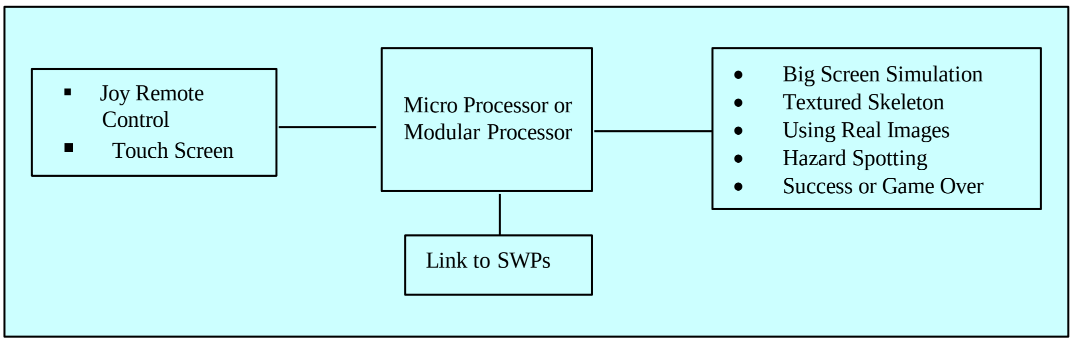
Interactive

Virtual reality training must 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 is a real life experience for the trainee. The trainee can receive immediate feedback on the consequences of poor decision making and inept skill, albeit that they do not result in real life penalties.

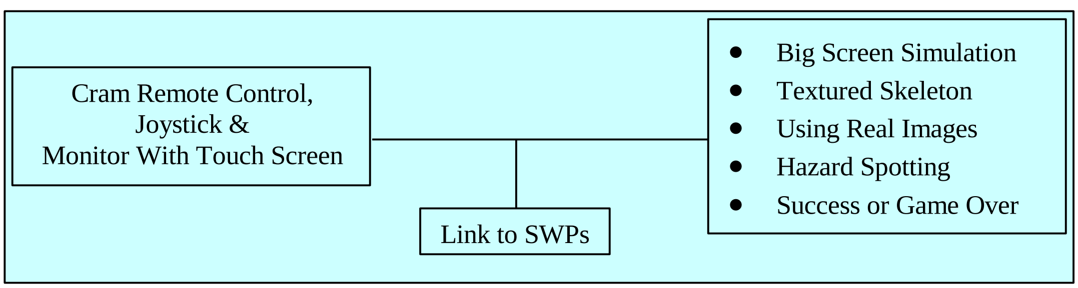
A key issue identified in the research is the issue of motion sickness when using simulators. The quality of the circuitry comprising the simulator has a significant influence on whether motion sickness occurs. If a person is stationary, motion sickness can develop quickly if the imagery is not refreshed at a high frequency. If the trainee is mobile whilst immersed, motion sickness is less likely to occur. These issues lead to the recommendation that the JCB Simulator should be based on technology that is not solely desktop based. Freedom of movement whilst using a real life control will enhance the quality of the outcome.

The recommended architecture for operator training and for maintenance training is as follows:

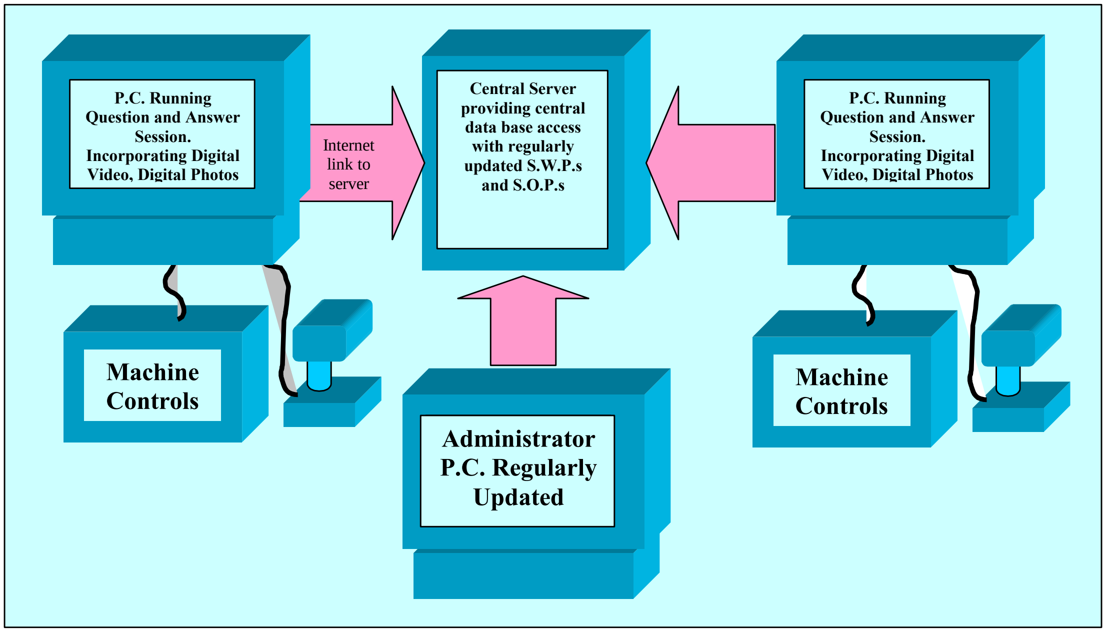
Operator Training



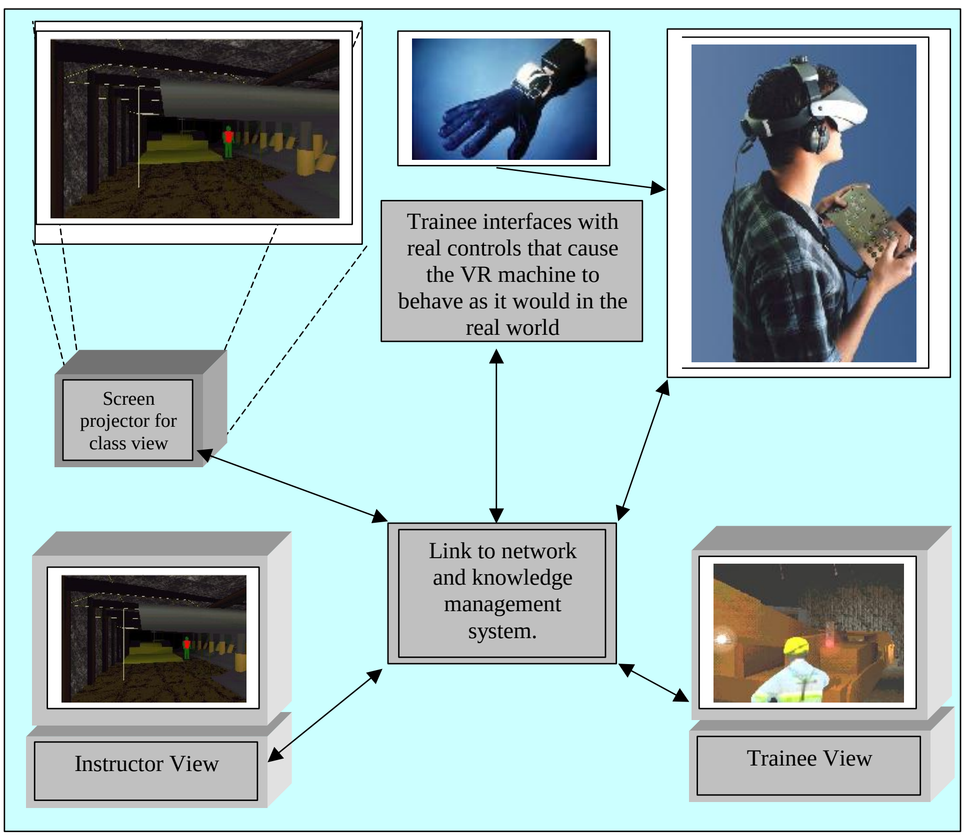
Maintenance Training



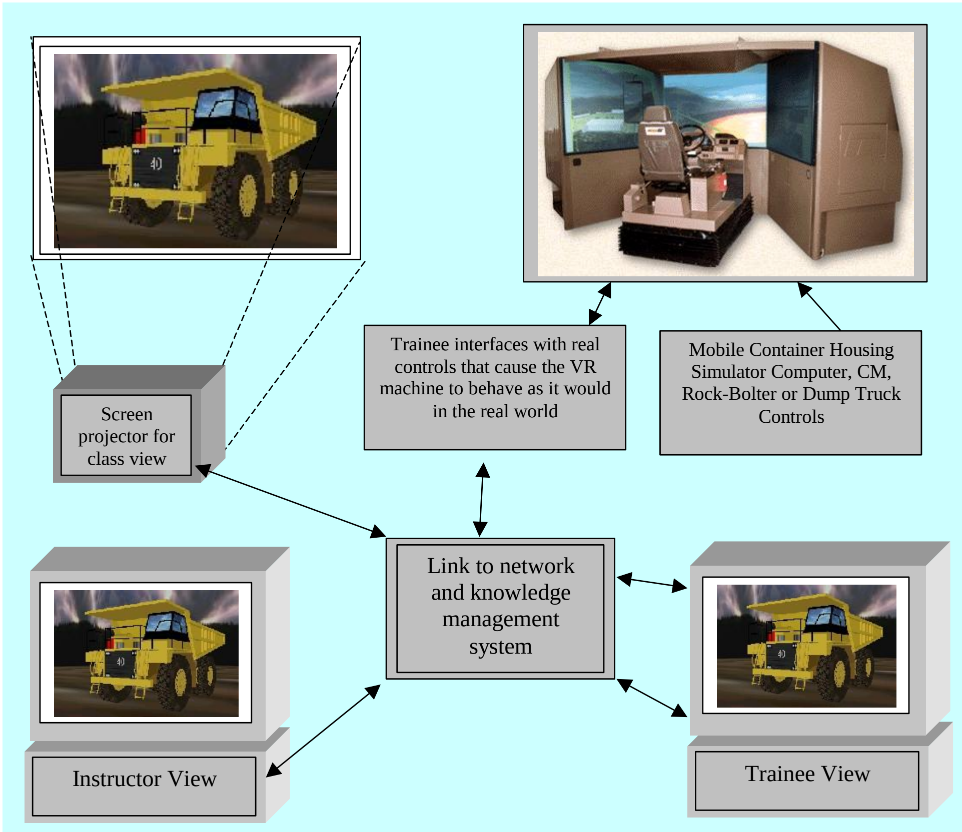
Three options that will achieve these desired outcomes are:



Option 1. Desktop P.C. based interactive simulator with real machine controls.



Option 2. Site based, immersive, interactive simulator with real machine controls.



Option 3. Mobile immersive, interactive simulator with real machine controls.

Hybrid SImulator

The four main technologies identified all have attributes that can be incorporated into the JCB Simulator. A hybrid simulator is required. The recommended layout of this hybrid system as it applies to the operation of a continuous miner is shown in shown in Option 2. The reasons for selecting Option 2 as the most appropriate layout are that it meets all the identified criteria (see matrix table) and provides the benefits of:

- being site based, making it easily accessible to trainees,
- reflecting reality in the VR simulation,
- propagating site ‘ownership,
- being easier to maintain and keep up to date than a mobile version.

The project team recommends that the JCB Health and Safety Trust commissions Mine Site Technologies (MST) and the University of New South Wales (UNSW) to design, develop and commission a prototype VR Simulator suitable for safety training of an operator of a continuous miner and operators and maintenance personnel of roof bolters.

Commercialisation and Technological Innovation

The project cost will be $1,540,000 with both UNSW and MST providing considerable in-kind support. In-kind support from UNSW will be in the form of access to the considerable intellectual resources that reside within disciplines in the university, especially in regards to information technology. MST will provide support in the form of their experience in developing and commercialising technological innovation. The proven capabilities of both organisations will be brought to the project.

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THE UNIVERSITY OF
NEW SOUTH WALES

MINE SITE TECHNOLOGIES

e-minesafe SAFETY AND TRAINING SIMULATOR
The Integration of Knowledge and Skills to Achieve Safe Human Responses

APPENDICES

Joint Coal Board
Health and Safety Trust

By

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ISBN No. 0 7334 1844 9

Appendix 1

		Underground Equipment					Open-cut Equipment		
Equipment Type		Continuous Miner		Roof Bolter		Etc	Dump Truck		Etc
Mineworker Function		Operation	Maintenance	Operation	Maintenance		Operation	Maintenance	
Continuous Improvement by Web Based Community Input	Knowledge Management System								
	Management Plans	Best Practice Surveys							
	Safe Working Procedure	Best Practice Surveys							
	Simulation - Training, Up-Skilling - Assessment - Identifying Risk Takers - Modifying Behaviour								

Figure 1.1 ‘The Integration of Knowledge and Skills to Achieve Safe Human Performance’

MINE SAFETY MANAGEMENT PLAN (MSMP) ↓	• "Umbrella" document that includes all matter policy and structure. • Provides the framework for the operation of the mine's Safety Management Systems
MINE SAFETY MANAGEMENT SYSTEMS, ENGINEERING STANDARDS OF PRACTICE ↓	• Management Systems designed to manage risks associated with mine hazards. • Hazards identified from risk assessments.
SAFE WORKING PROCEDURES	• The working elements of the process. • Standards of work and work procedures developed to control the risk to an acceptable level.

Figure 1.2. Approach to mine safety management encapsulated in the N.S.W. Coal Mines Regulation Act – 1999 Regulations.

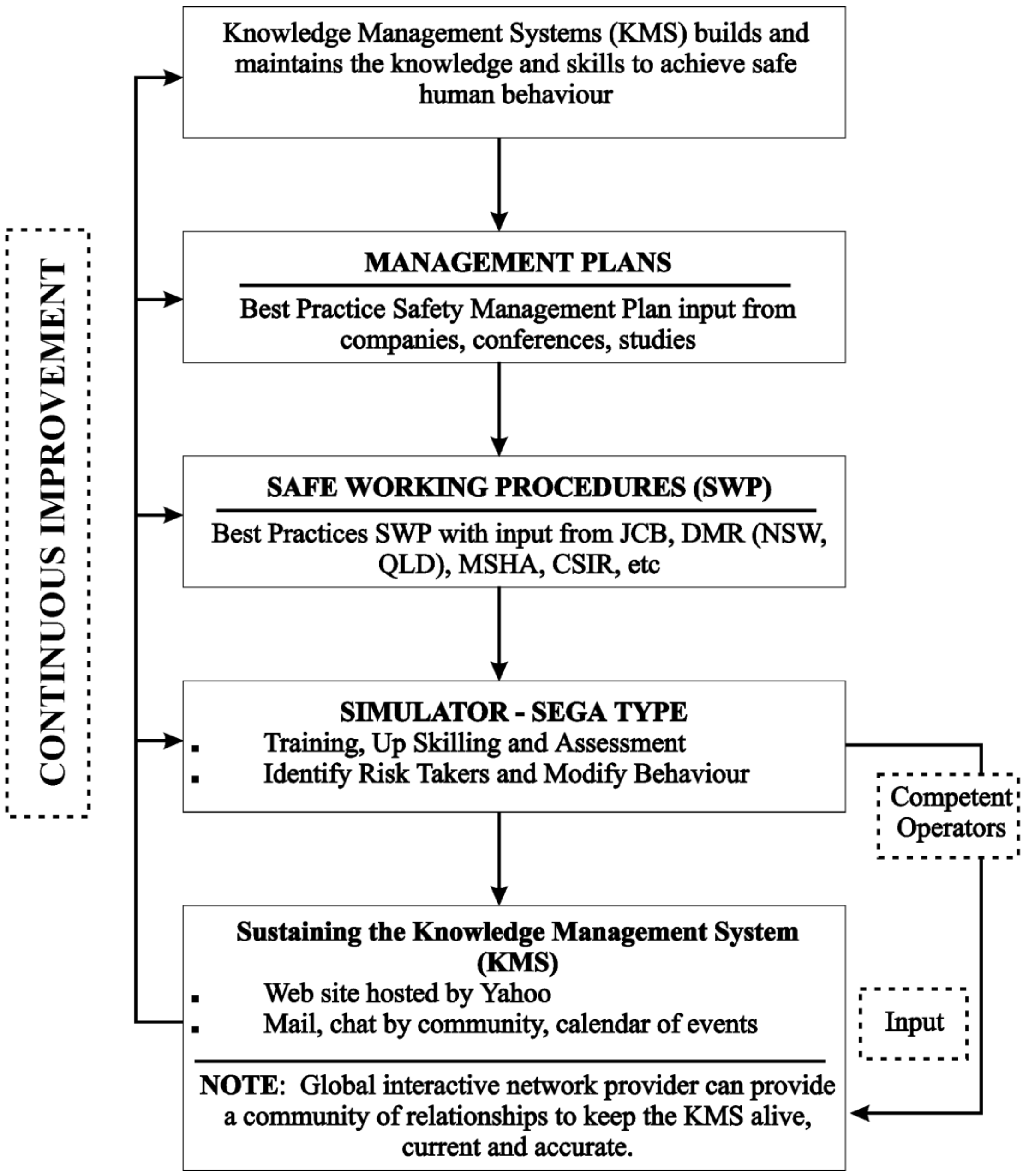

Figure 1.3 Conceptual approach adopted by the Joint Coal Board in managing risk via simulator based training and assessment.

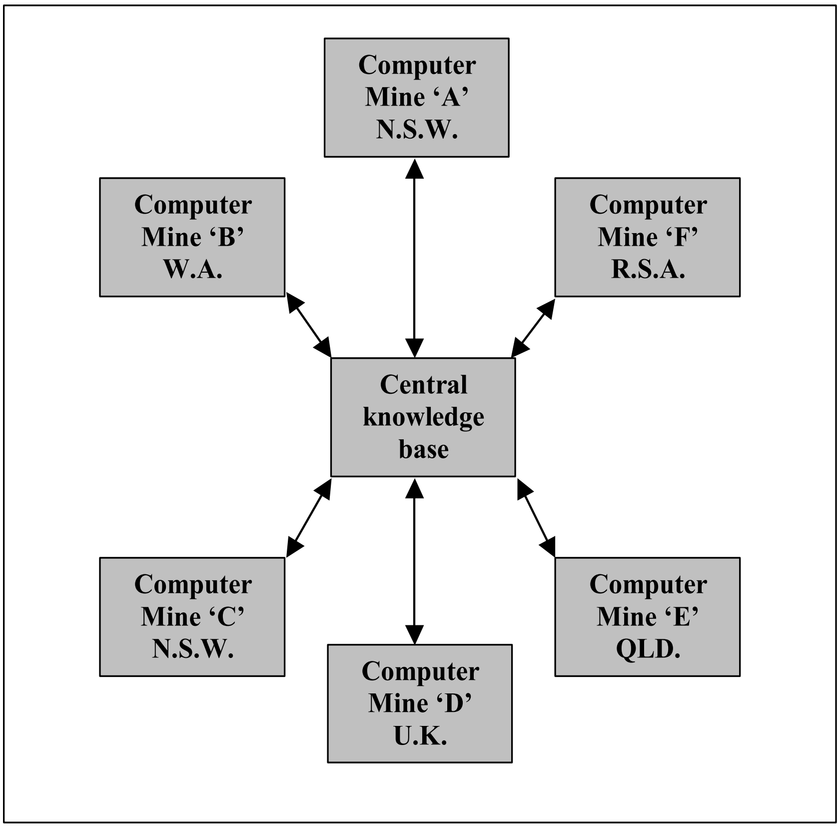

Figure 2.1 Example of Networked Mine Sites

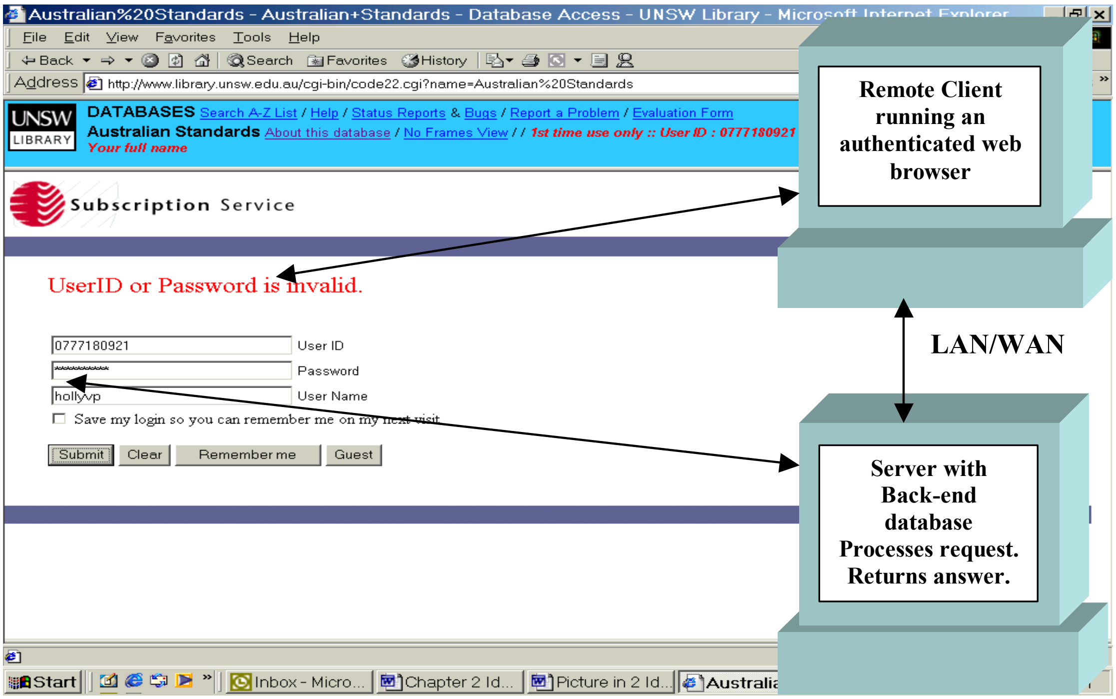

Figure 2.2a. Example of an interactive web site 'log in screen' presented to subscriber (After UNSW/ Australian Standards 2001).

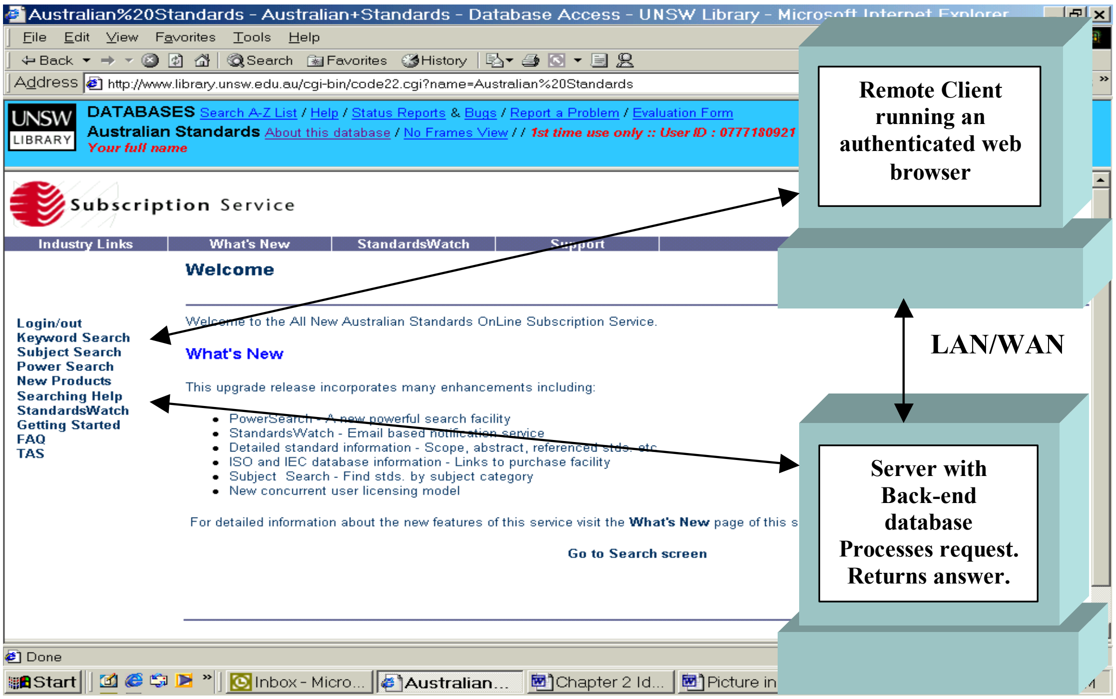

Figure 2.2b. Query screen options selected by user. (After UNSW/ Australian Standards 2001).

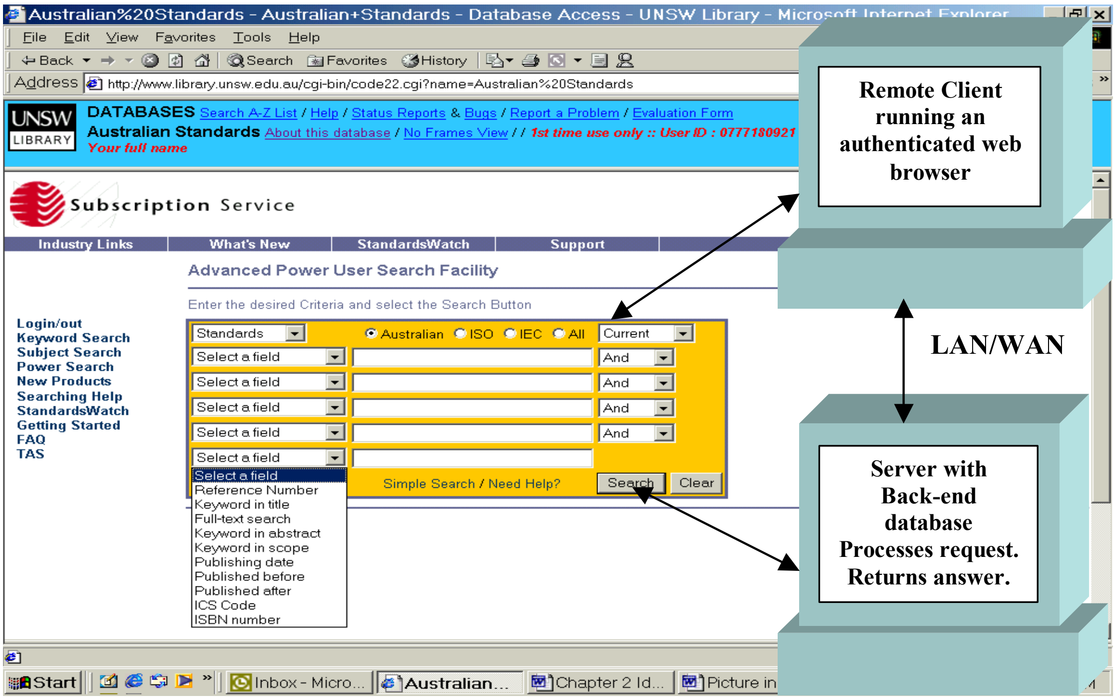

Figure 2.2c. A 'power search' for information particular criteria can be applied to the search (After UNSW/ Australian Standards 2001).

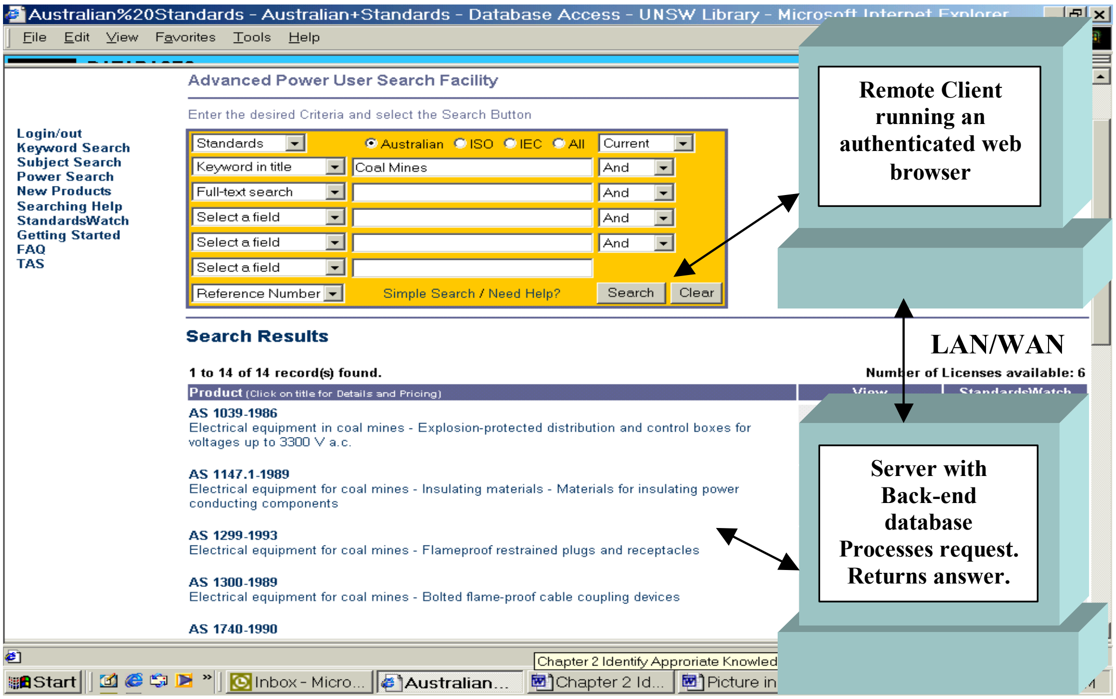

Figure 2.2d. Data base returns information that meet search criteria (After UNSW/ Australian Standards 2001).

Figure 2.3. Complexity of rules and regulations

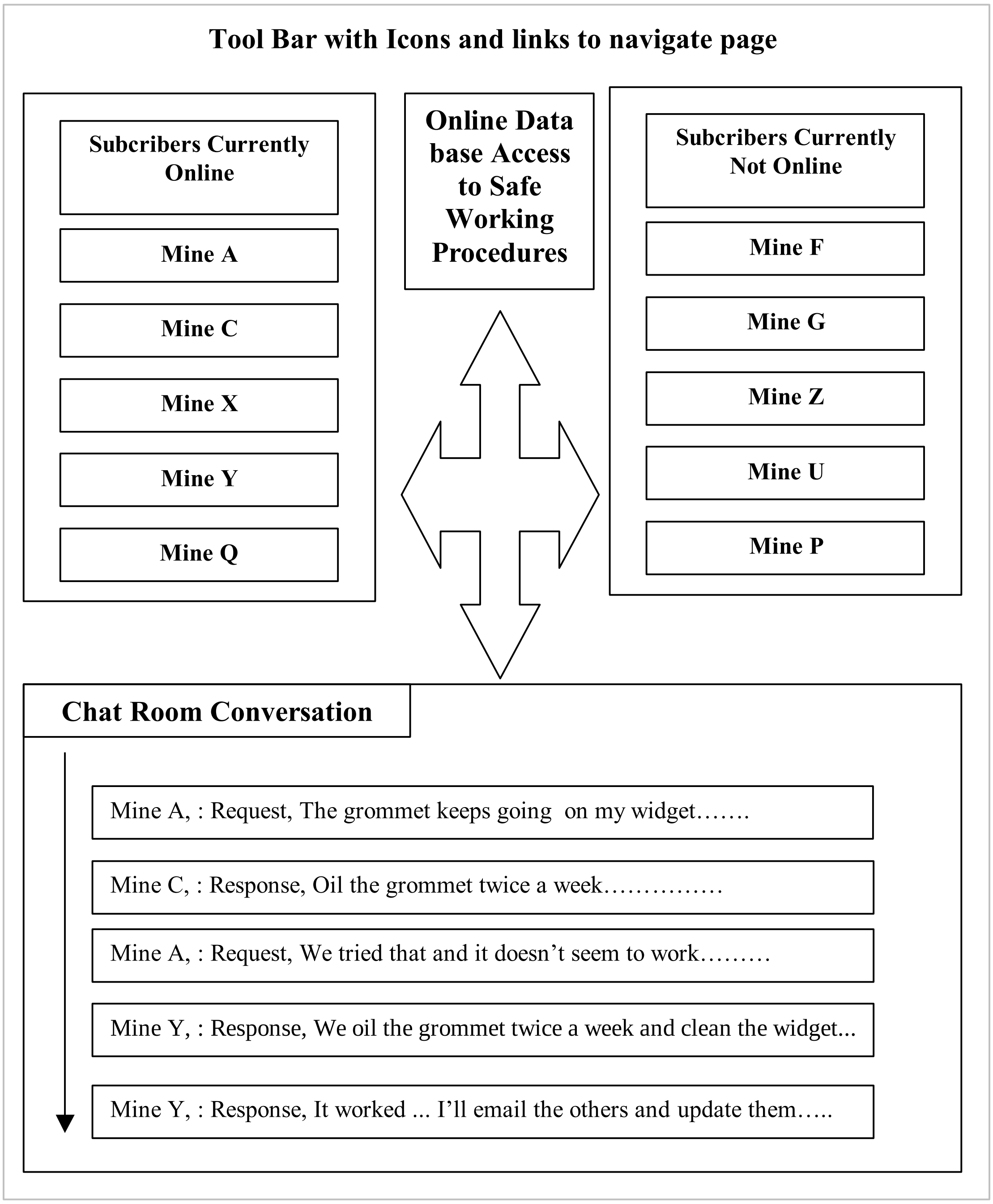

Figure 2.4. Simplified example of an online community discussing maintenance tasks.

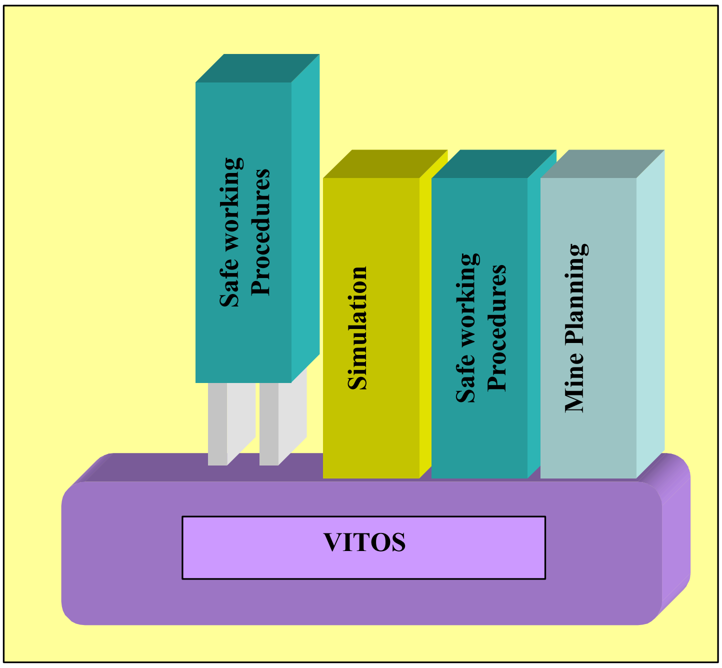

Figure 2.5. VITOS Plug in Architecture.

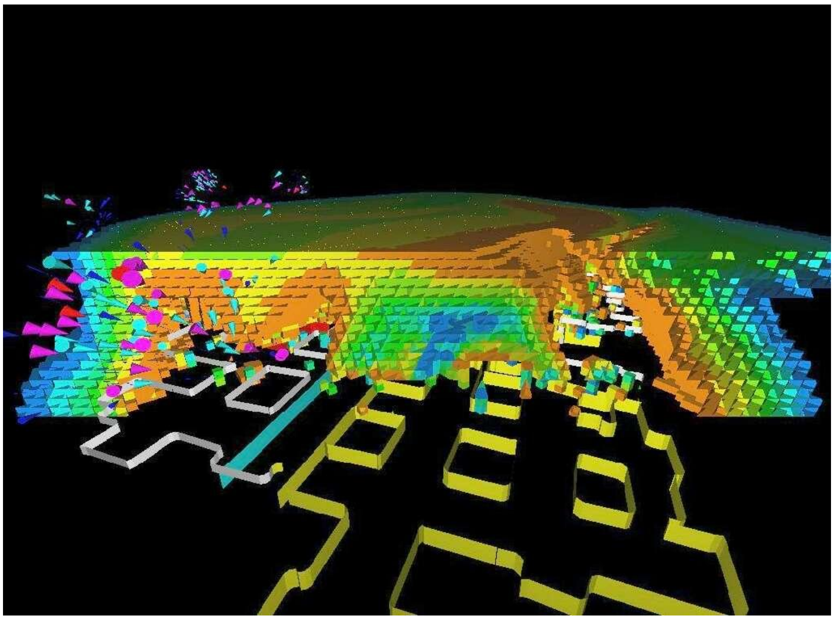

Figure 2.6. Example of merged mining data showing topography, surface workings and underground workings.

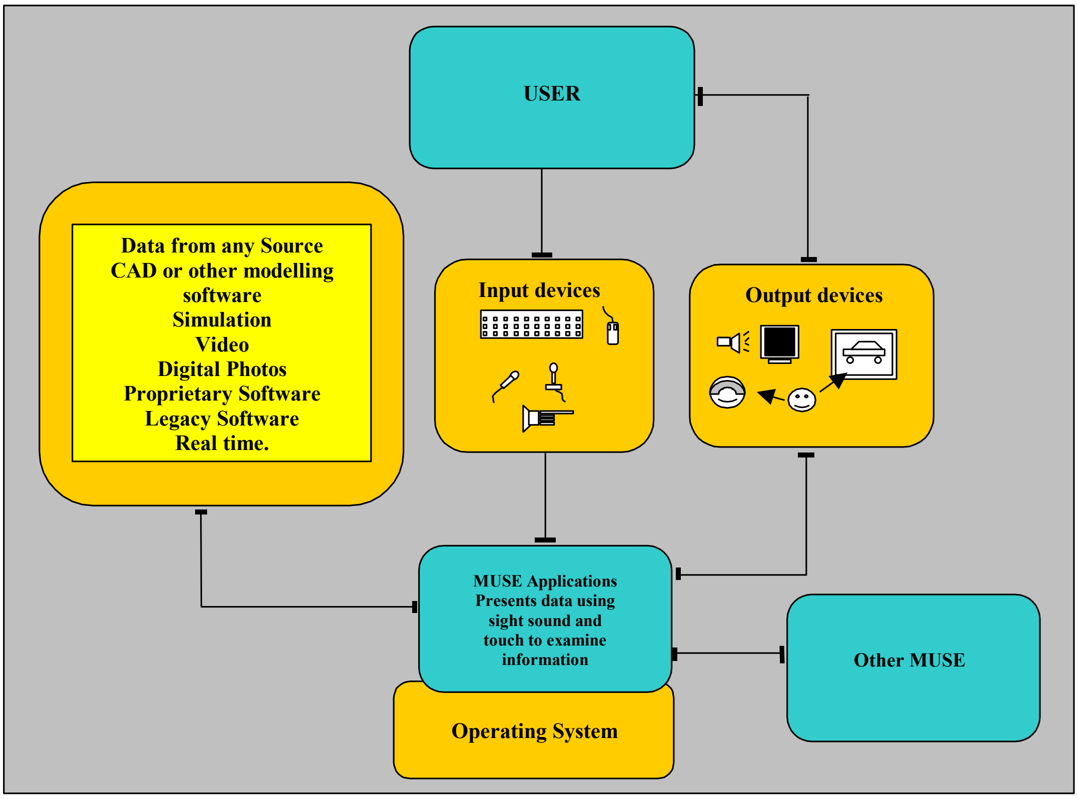

Figure 2.7. Inside the MUSE environment.

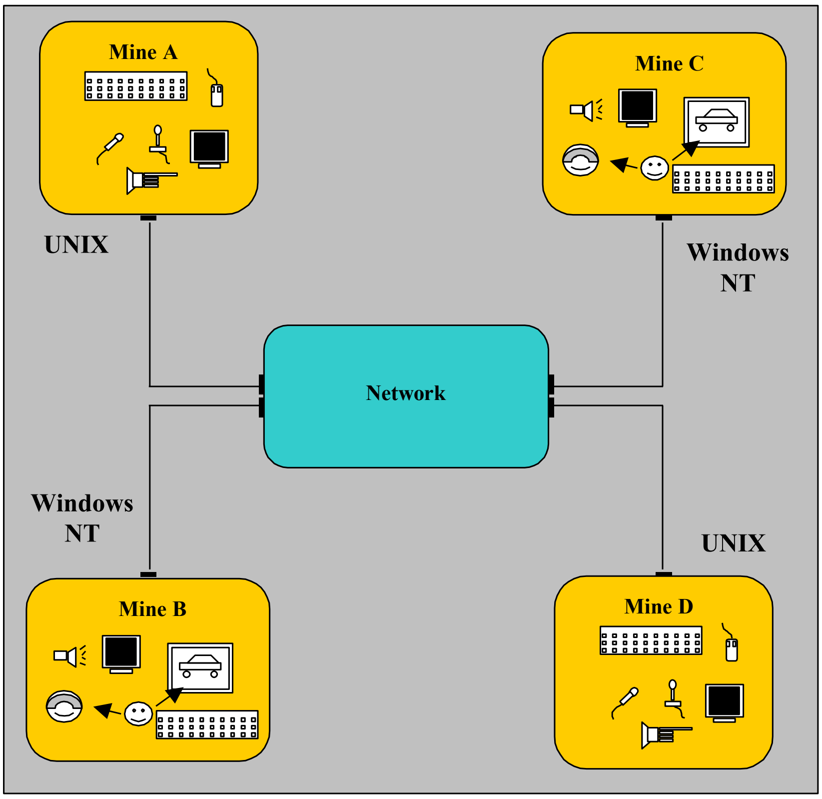

Figure 2.8. Typical Platform independent Network linking mine sites.

S.W.P. Function										
	Contributor									
Pre Start	A	B	C	D	E	F	G	H	P	Q
Start Up	◆	■	■		■		■	◆	■	
Flit Miner	■	■	■		■		■	■	■	
No stand zone (a)	◆	◆	■		■		■	■		
Cut coal	◆	◆	■	◆	■		●	■		
No stand zone (b)		◆	■	◆	■		■	■		
Straight ahead cut	◆	◆	■	◆			■	■		
Break right	◆	◆	■	◆			■	◆		
Break left	◆	◆	■		■		●			
Pillar lift	◆	◆	■		■		●			
Electrical isolation		◆	■							
Change picks	◆	◆	◆		■		◆		■	
Fill miner oil	◆	◆	■				◆		■	
Shut down	◆	◆	■				◆			
Recovery of miner		◆	■				◆		■	
Replace water sprays	◆						◆			
Change cable	◆		■				◆			
Lube miner							◆		■	
Frictional ign. mitigation			◆				◆		■	
		◆								

<u>Legend-</u>
- ◆ Written as SWP
- ■ Training /assessment
- ● 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 3.1a Matrix of S.W.P. showing Continuous Miner Operator tasks

Legend-

◆ Written as SWP

■ Training /assessment

● Part of larger SWP

Contributor

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

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 3.1b Continuous Miner Operator Tasks

Legend-

◆ Written as SWP

■ Training /assessment

● Part of larger SWP

Contributor

SWP	A	B	C	D	E	F	G	H	P	Q
Isolation	◆	◆	◆	◆	■		◆		■	■
Remove/replace cutter head barrels /seals	◆	◆		◆			◆			
Remove /replace roof bolters	◆			◆	■					
Remove/replace rib bolter	◆				■					
Remove/replace gathering head	◆	◆		◆			◆			
Support head	◆			●			◆			
Support boom	◆						◆			
Inspect head	◆									
Inspect conveyor	◆									
Repair/replace/adjust crawler tracks	◆	◆		◆			◆	◆	■	
Repair/ replace/adjust conveyor chain	◆	◆		◆			◆	◆	■	
Inspect oil levels	◆									
Inspect oil leaks	◆									
Brake test	◆			◆						
Replace radio cont. solenoid	◆								■	
Replace boom swing cylinder	◆	◆		◆			◆		■	
Replace stabilizer jack	◆			◆			◆			
Code A electrical inspection	◆	◆	◆	◆			◆	◆		
Mech. Periodic Inspection		◆	◆	◆			◆	◆		
Periodic filter change	◆								■	
Change lights							◆		■	
Replace trim chain							◆		■	

Figure 3.1c. Continuous Miner Maintenance Task

Continuous Miner Maintenance Tasks (Continued)

Legend-
◆ Written as SWP
■ Training /assessment
● Part of larger SWP

Contributor

SWP	A	B	C	D	E	F	G	H	P	Q
Replace shovel jack							◆		■	
Replace foot shaft		◆					◆	◆	■	
Replace head lift cylinder		◆		◆			◆		■	
Replace boom lift cylinder		◆		◆			◆		■	
Replace stab jack		◆					◆		■	
Replace traction planetary		◆		◆			◆		■	
Replace track idler roller		◆		◆			◆		■	
Replace cutter motor							◆		■	
Replace Hydraulic pump							◆		■	
Replace conveyor drive							◆	◆	■	
Replace gathering box				◆			◆	◆	■	

Note:
Contributor F material was considered not detailed enough.
Contributor Q was in the process of reviewing the procedures for maintenance and the material supplied was not sufficiently detailed to be assessed.

Figure 3.1c Continuous Miner Maintenance (continued).

Legend-
◆ Written as SWP
■ Training /assessment
● Part of larger SWP

Contributor

SWP	A	B	C	G	O	Q
Isolation	◆	◆	◆	◆	◆	◆
Pre start	■	■	■	◆	◆	◆
Start up	■	■	■	◆	◆	◆
Shut Down	■	■	■	◆	◆	◆
Flitting	◆	◆	■	◆	◆	◆
Drilling	■	◆	■	◆	◆	◆
Roof Bolt Installation	■	◆	■	◆	◆	◆
Rib Bolt Installation			■	◆		
Radio Transmitter Check		◆			◆	

Figure 3.1d Mobile Roof Bolter Operator Tasks

Legend-
◆ Written as SWP
■ Training /assessment
● Part of larger SWP

Contributor

SWP	A	B	C	G	O	Q
Isolation	◆	◆	◆	◆	◆	◆
Code A Electrical		◆	◆			
Weekly Service Elect.		◆	◆			
Weekly Service Mech.		◆	◆			
Monthly Service Mech.		◆	◆			
Power Oil Fill		◆				
Crawler Track Replacement		◆			■	
Trouble Shoot/Fault Find					■	
Basic Maintenance					■	

Note:
Mobile roof bolters are not used by all contributors hence a limited amount of material was gathered from the selected contributors

Figure 3.1e. Mobile Roof Bolter Maintenance Tasks

Legend-

◆ Written as SWP

■ Training /assessment

● Part of larger SWP

Contributor

SWP	I	J	K	L	M	N	R	S	T
Isolation		◆			◆				
103 Inspection					◆				
Basic Truck Operation	■	■	■		◆	■			
Double Sided Loading (shovel)	■	■	■	◆	◆	■			
Single Sided Loading (shovel)	■	■	■	◆	◆	■			
Operate on Access Road (dry)	■	■	■	◆	◆	■			
Operate on Access Road (wet)	■	■	■	◆	◆	■			
Parking on Access Road	■	■	■	◆	◆	■			
Dumping	■	■	■	◆	◆	■			
Operate at Loader	■	■	■	◆	◆	■			
Operate at ROM Bin	■	■	■	◆	◆	■			
Operate at Washery	■	■	■	◆	◆	■			
Operate at Workshop	■	■	■	◆	◆	■			
Approach Stopped Vehicle		◆	■	◆	◆	■			
Communicate (2way radio)	■	■	■	◆	◆	■			
Working under High Walls	◆			◆	◆				
Entry to Restricted Areas	◆			◆	◆				
Tipping at Dams	◆	■							

Note:
Contributor R material had not been received at the time of writing the report.
Contributors S and T are suppliers who have promised material that has not yet been received.

Figure 3.1f. Rear Dump Truck Operator Tasks

S.W.P. Function	**Contributor**					
	A	B	C	G	O	Q
Isolation	◆	◆	◆	◆	◆	◆
Pre start	■	■	■	◆	◆	◆
Start up	■	■	■	◆	◆	◆
Shut Down	■	■	■	◆	◆	◆
Flitting	◆	◆	■	◆	◆	◆
Drilling	■	◆	■	◆	◆	◆
Roof Bolt Installation	■	◆	■	◆	◆	◆
Rib Bolt Installation			■	◆		
Radio Transmitter Check		◆			◆	

SWP	A	B	C	G	O	Q
Isolation	◆	◆	◆	◆	◆	◆
Code A Electrical		◆	◆			
Weekly Service Elect.		◆	◆			
Weekly Service Mech.		◆	◆			
Monthly Service Mech.		◆	◆			
Power Oil Fill		◆				
Crawler Track Replacement		◆			■	
Trouble Shoot/Fault Find					■	
Basic Maintenance					■	

Legend-

◆ Written as SWP, ■ Training /assessment, ● Part of larger SWP

Figure 3.1g. Mobile Roof Bolter Operator Tasks

Evaluation of Safe Working Procedures

Score for Each criteria – Max. = 10

Criteria	**Contributor Score**							
	A	**B**	**C**	**G**	**O**	**Q**		
Control Explanation	0				7	8		
No Stand Zones	0	7	3	3				
Cable Handling	0	5			7	8		
Warn Others	0	5	3	2		8		
Total	0	17	6	5	14	24		

Note: Contributor Q can be considered most suitable for this SWP.

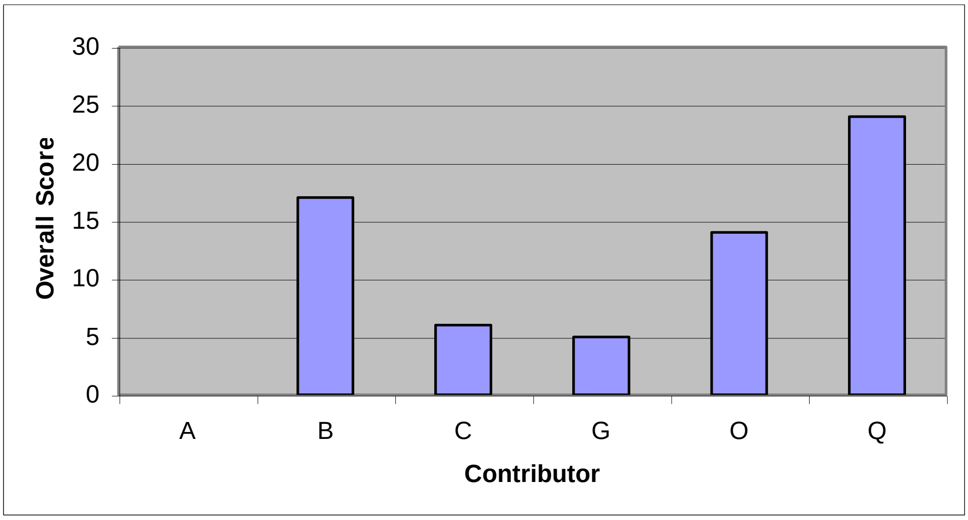

Figure 3.2a. Ranking of S.W.P. for Mobile Roof Bolter - Flitting

Score for Each criteria – Max. = 10

Criteria	Contributor Score							
	A	B	C	G	O	Q		
Positioning	2	5	7					
Roof Support	2	5	7			7		
Tools	2		5			7		
Dust Boxes	2					7		
Drill Guide	2		5			6		
Explanation of Controls	2		7			8		
No Stand Zone	7	8		7				
Protective Equipment	5	8		7				
Total	24	26	31	14		35		

Note: Contributor Q can be considered most suitable for this SWP.

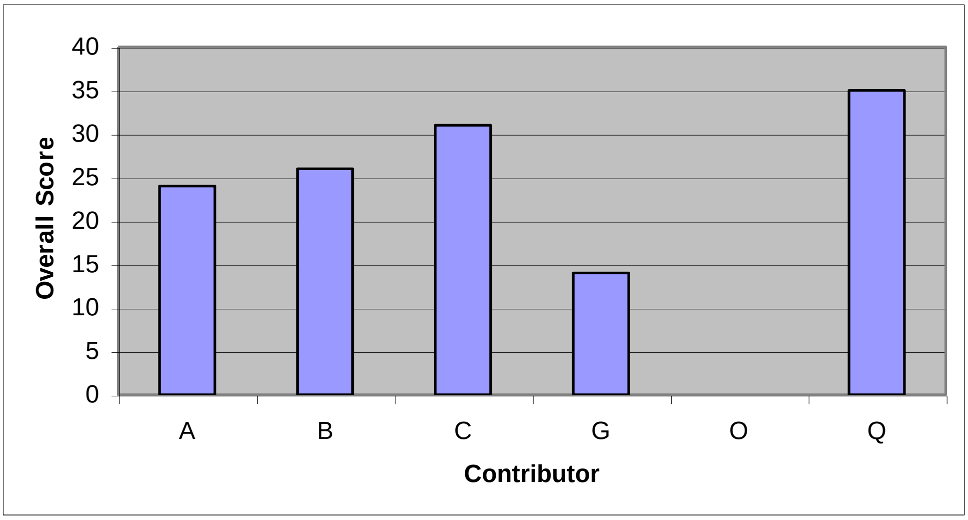

Figure 3.2b. Ranking of S.W.P. for Mobile Roof Bolter – Drilling

Score for Each criteria – Max. = 10

Criteria	Contributor Score							
		B	**C**					
Positioning		5	5					
Isolation		7	7					
Steps in Procedure		6	8					
Other SWPs Referenced			5					
Protective Equipment		5	6					
Recording		7	7					
Total		30	38					

Note: Contributor C can be considered most suitable for this SWP.

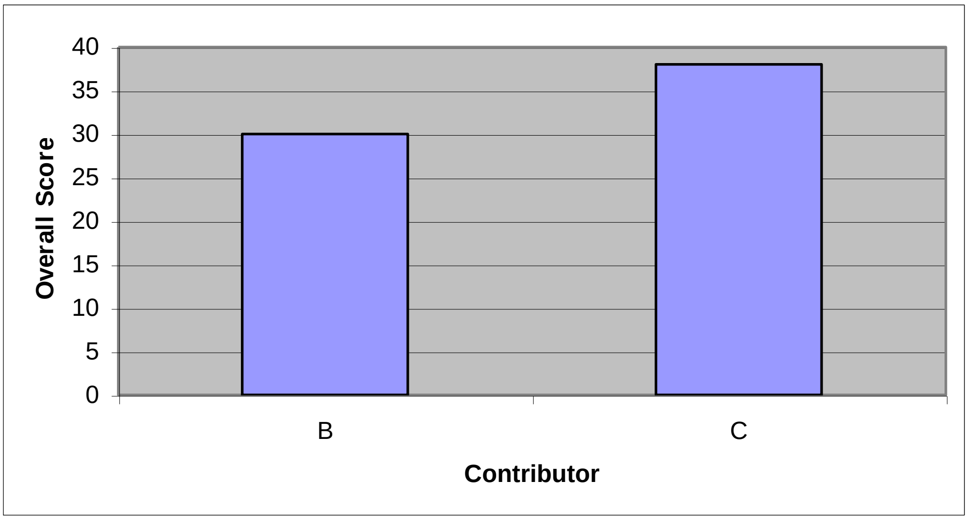

Figure 3.2c. Ranking of S.W.P. for Mobile Roof Bolter – Electrical Inspection

Score for Each criteria – Max. = 10

Criteria	Contributor Score							
		B	**C**					
Position		2						
Isolation		7	4					
Steps in Procedure		7	7					
Reference to other SWPs			7					
Tools								
Protective Equipment								
Recording		5	7					
Total		21	25					

Note: Contributor C can be considered most suitable for this SWP However contributor B material could also be useful.

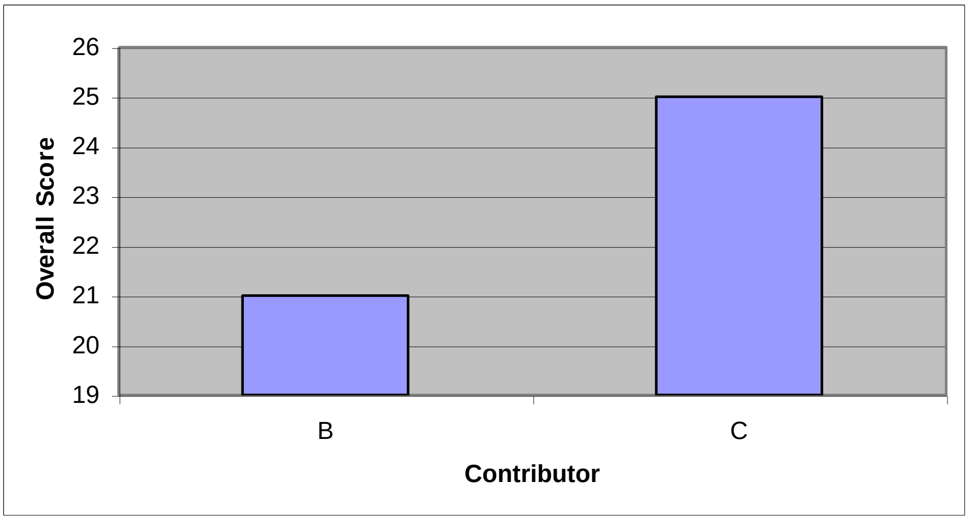

Figure 3.2d. Ranking of S.W.P. for Mobile Roof Bolter – Mechanical Service

Score for Each criteria – Max. = 10

Criteria	Contributor Score							
	I	**J**	**K**	**L**	**M**	**N**	**R**	**S**
Retard Operation	4	3	5	5	3	2		
Stopping and Parking	2	2	7	5				
One Lane Operation	3	5	5	7	4	3		
Queuing	5	4	4	4	4	3		
Separation Distance	7	6	7	4	7	3		
Speeds and Conditions	8	6	7		7	4		
Other Vehicles	6	5	5	5	5	5		
Total	35	31	40	30	30	20		

Note: Contributor K can be considered most suitable for this SWP However contributors I, J, L, M, material could also be useful.

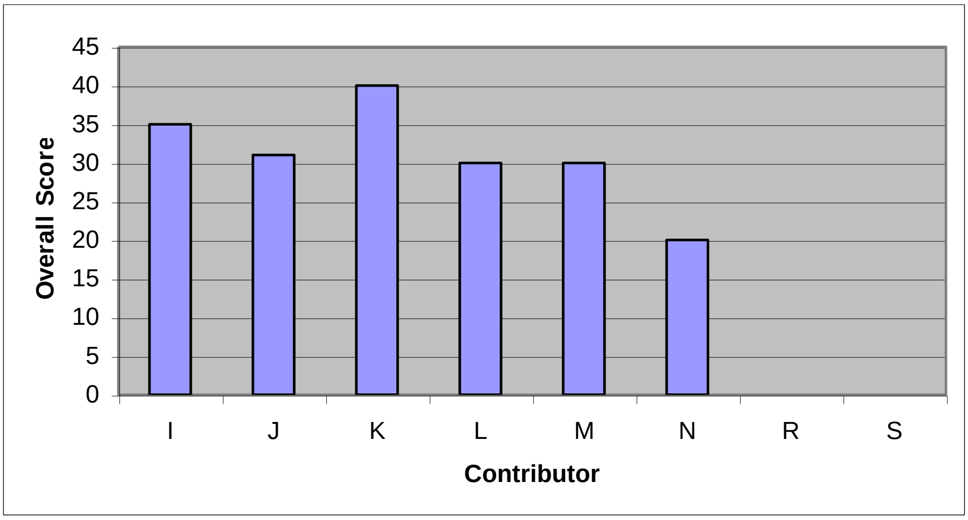

Figure 3.2e. Ranking of S.W.P. Rear Dump truck - Operate on Access Down Ramp

Score for Each criteria – Max. = 10

Criteria	Contributor Score							
	I	**J**	**K**	**L**	**M**	**N**	**R**	**S**
Queuing	4	5	3	7	2			
Communication	5	5	5	5	2			
Backing	4	3	3	8	3			
Reference Other SWPs	5	5	6	2	2			
Total	18	18	17	22	9			

Note: Contributor L can be considered most suitable for this SWP However contributors I, J, K, material could also be useful.

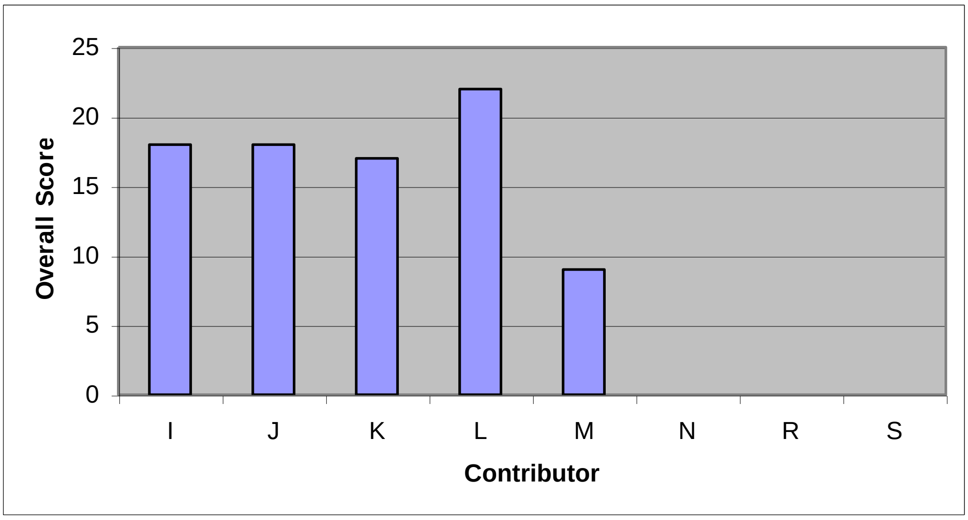

Figure 3.2f. Ranking of S.W.P. Rear Dump truck - Operate at loader

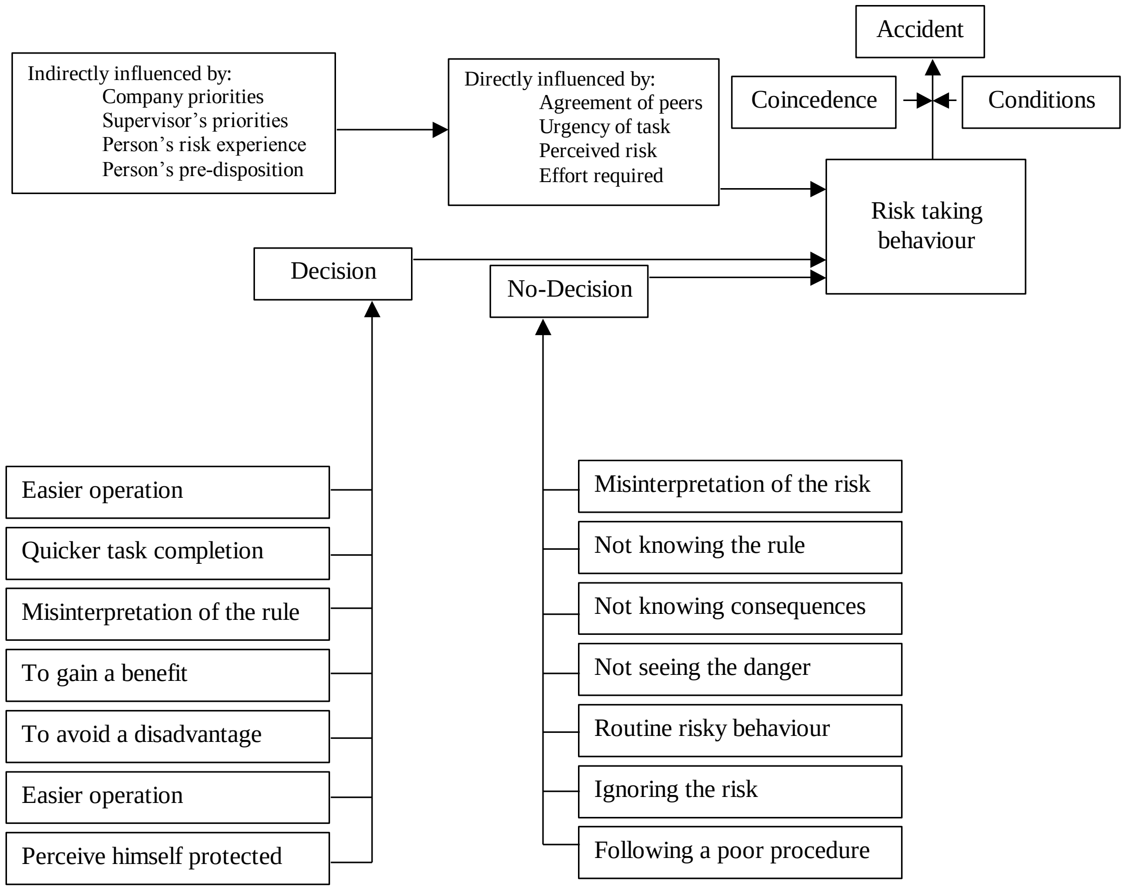

Figure 4.1 – Pitzer's Conceptual Model of Risk Taking and Accidents

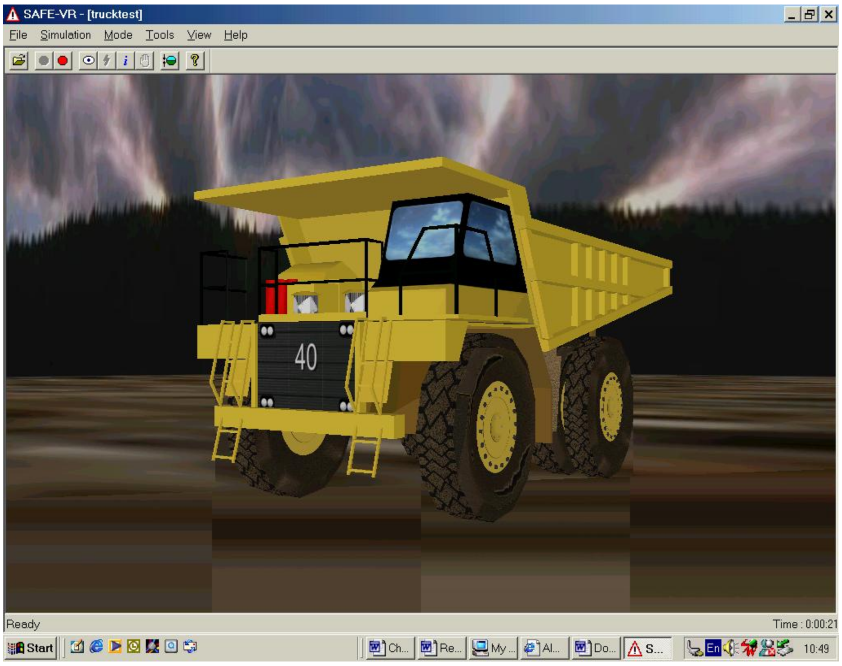

Figure 5.1. Example Screen of a *SAFE-VR* Program.

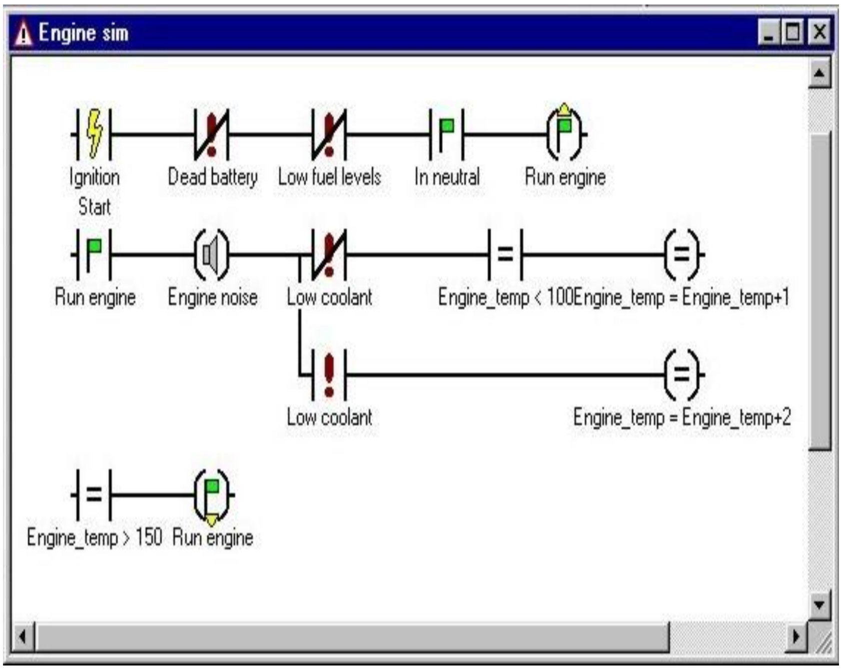

Figure 5.2. Example program layout.

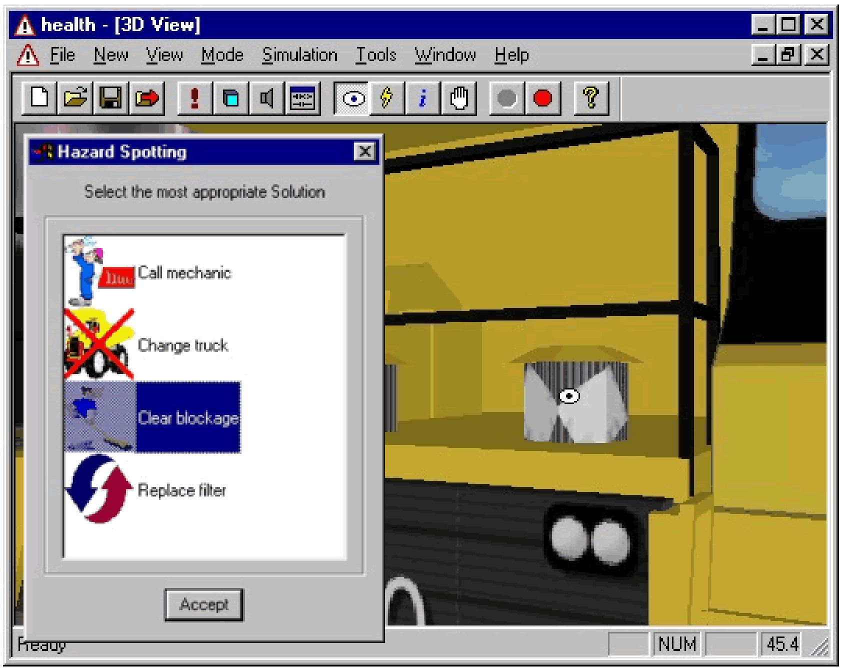

Figure 5.3. Example of Hazard Spotting.

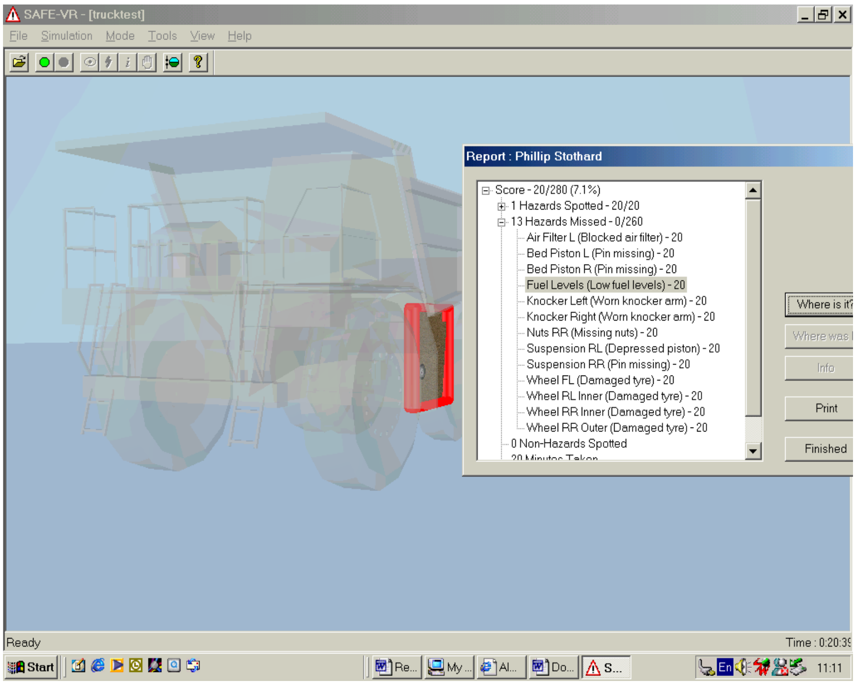

Figure 5.4. Example of a 'missed' hazard location.

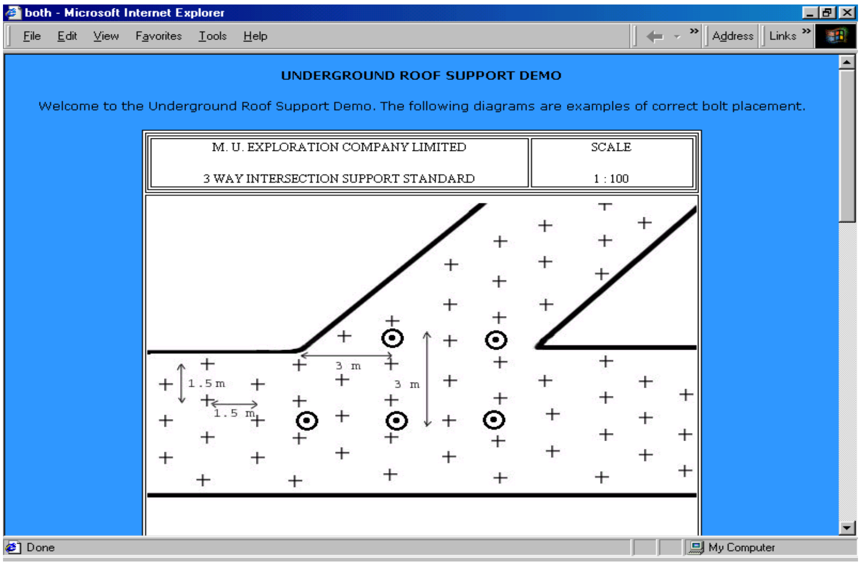

Figure 5.5. Correct rock bolt placement information.

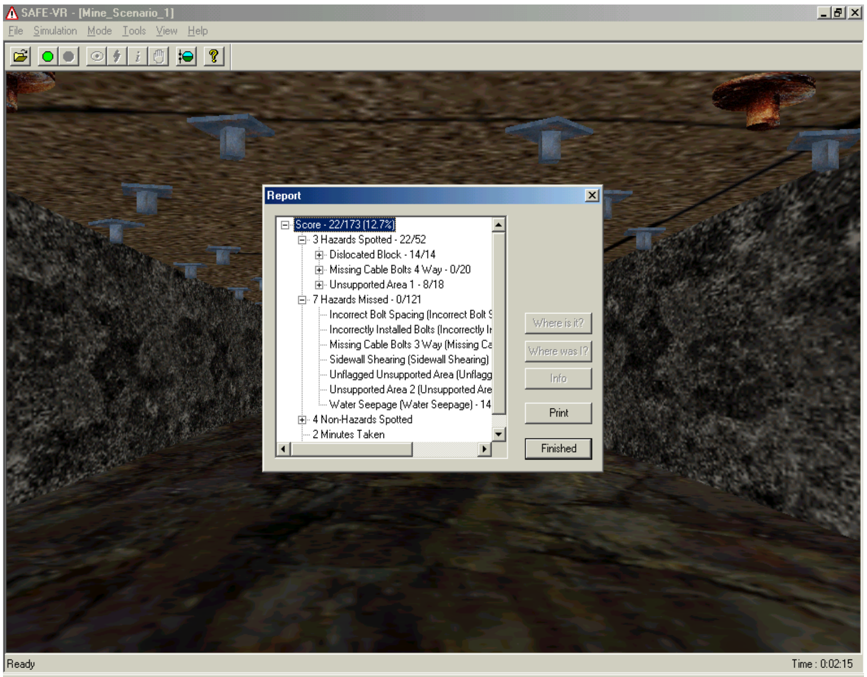

Figure 5.6. Hazard report.

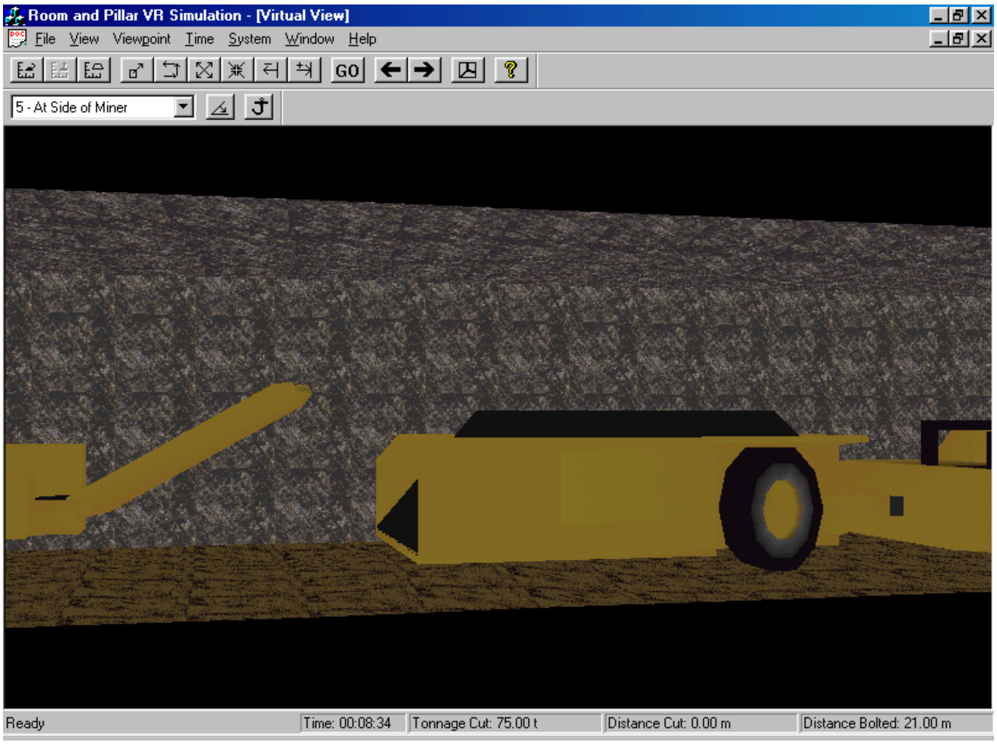

Figure 5.7 Room and pillar simulation

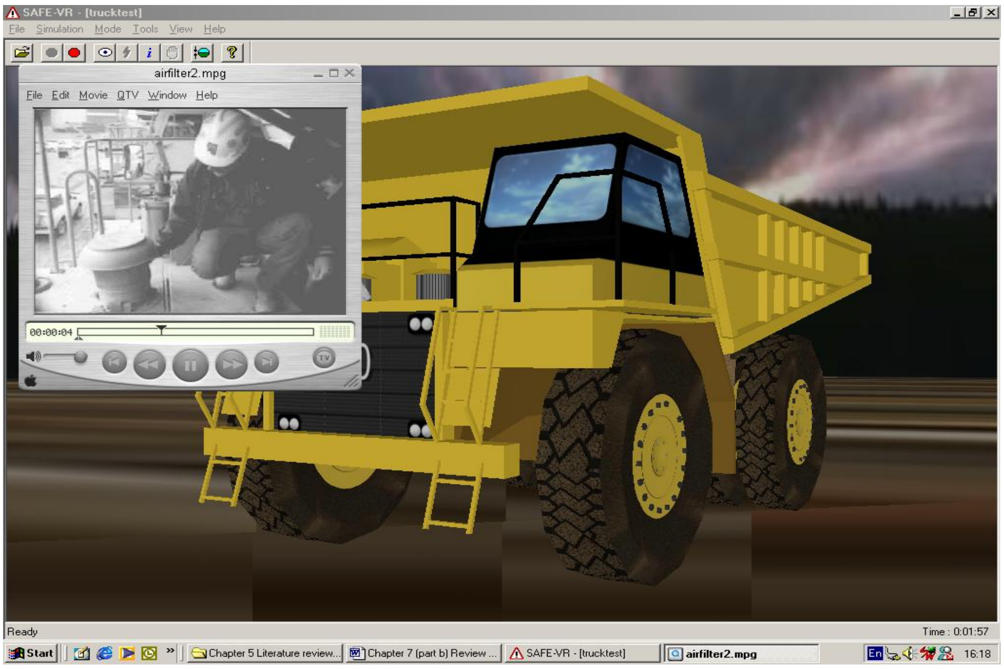

Figure 5.8. Spotting a mechanical hazard with a digital video of the problem.

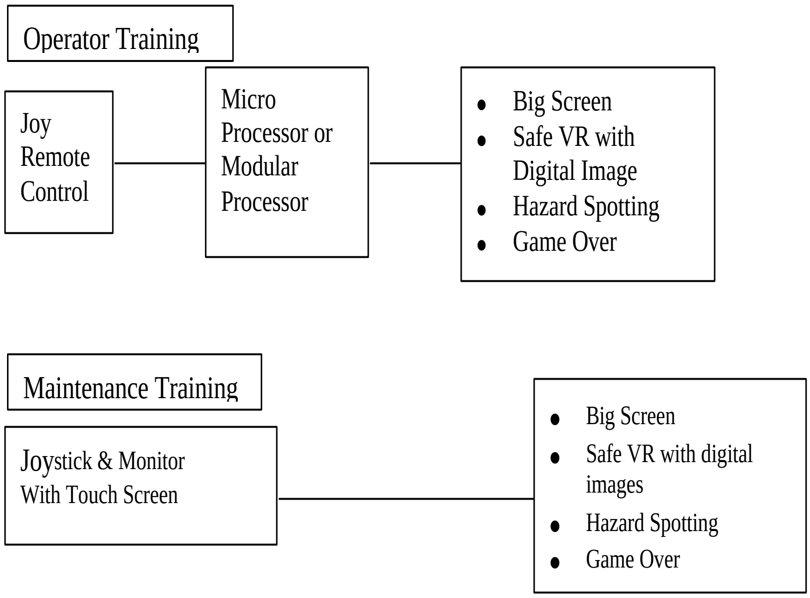

Figure 5.9. Sketch of the proposed Safe-VR simulator.

Figure 5.10. Continuum Resources Crusher Simulation.

Figure 5.11. Continuum Resources Submarine Rescue Simulation

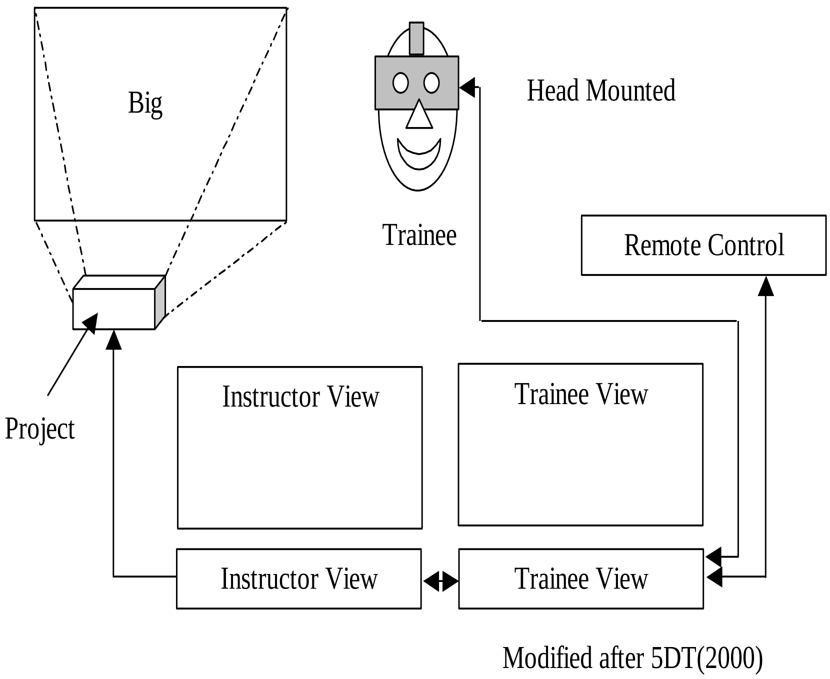

Figure 5.12a. Layout of Fifth Dimension Technologies Simulator.

Figure 5.12b. Headset in Fifth Dimension Technologies Simulator.

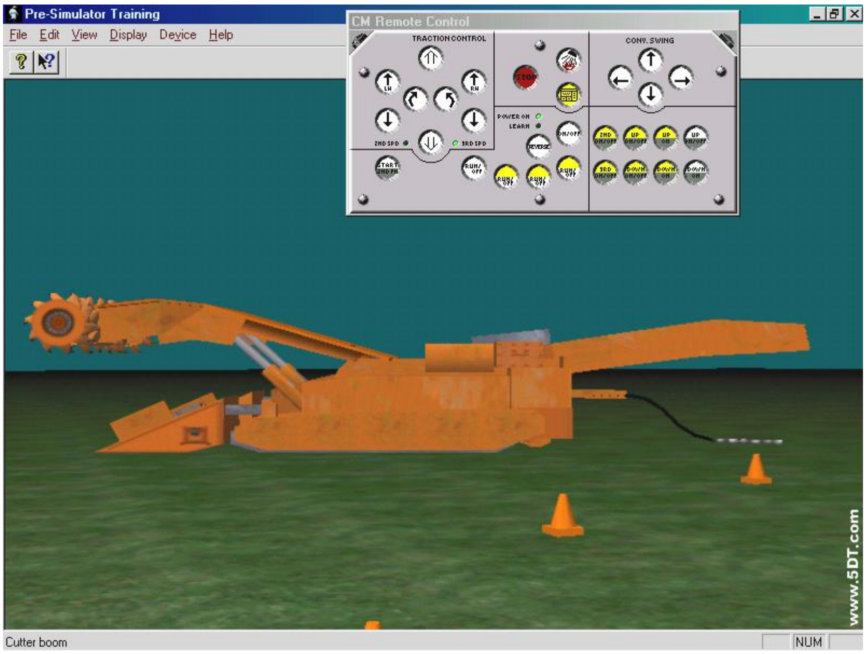

Figure 5.12c. Trainee View in Fifth Dimension Technologies

DOAB component	Reaction Time	Impulsivity	Risk-taking	Tracking	Attention
OPERATING SYSTEM					
Cont. Min. – operation	**Medium**	**medium**	**very high**	**high**	**very high**
Cont. Min. – maintenance	**medium**	**medium**	**very high**	**low**	**very high**
Cont. Min. – supervision	**high**	**high**	**very high**	**low**	**very high**
Roof Bolter	**high**	**high**	**very high**	**medium**	**very high**
Off-Road Truck	**very high**	**high**	**high**	**very high**	**very high**

Table 6.1 – Applicability of DOAB components to mining operating systems

Note

Figure 7 No figures relate to Chapter 7

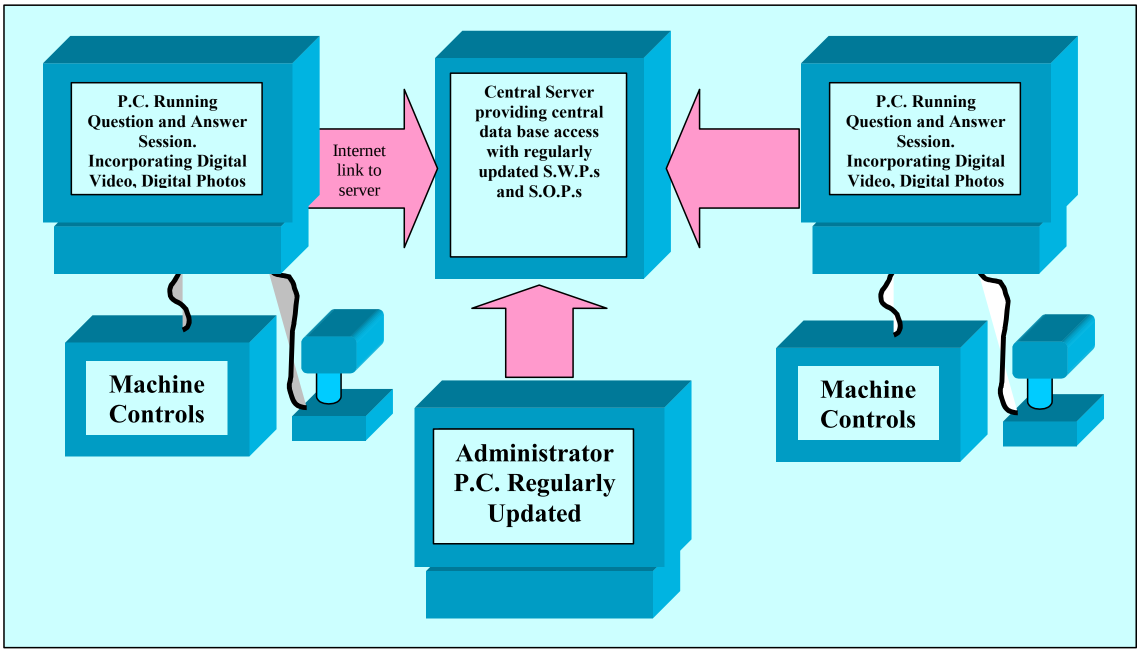

Figure 8.1. Option 1. Basic simulator using networked PCs

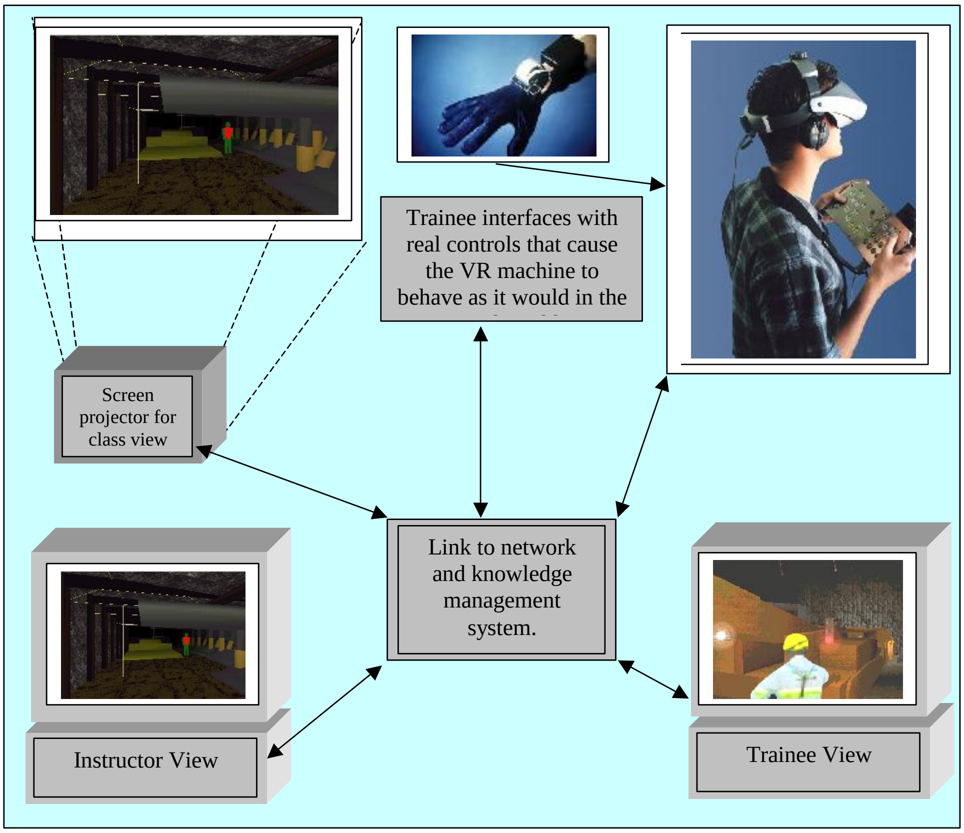

Figure 8.2. Option 2. Training simulator incorporating immersive technology.

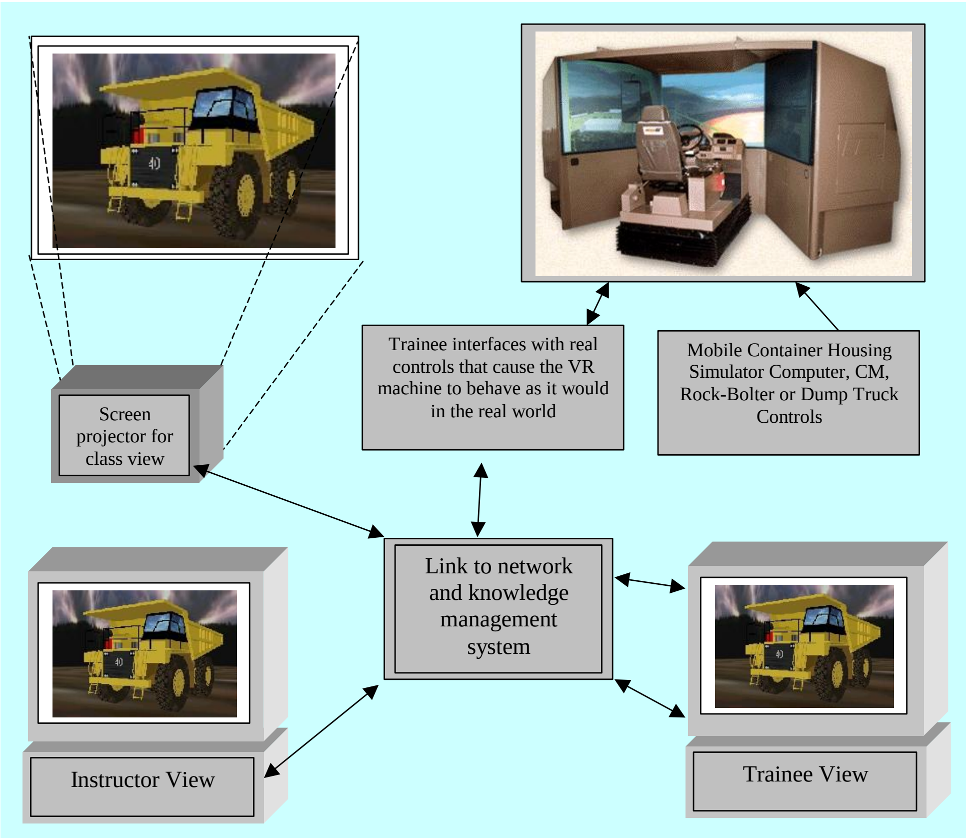

Figure 8.3. Option 3. Mobile-Container Based Simulator System

Appendix 2

Personality Testing

Personality Testing

Personality Tests

A person may not take risks when being observed or in a training scenario but may behave in a different way when at the work place.

Equipment designed to test how a person behaves under stress should include translate the virtual world to real-life The system should be able to tell if someone is:

- prone to make errors, slips, lapses, mistakes
- prone to make inappropriate decisions
- lacks fundamental knowledge
- is a slow learner
- lack skills
- lacks experience
- lacks (hand-eye) coordination
- shows machismo or bravado.

The System should be able to

- be compared to written or verbal tests eg Cripple Ck
- be supplemented with alternative scenarios
- e suitable for both experienced and inexperienced trainees
- possess various skill levels, as in games, to increase experience before actually being tested in the work place.
- Provide for differing education and literacy levels
- Allow for the fact that Risk Takers are from all educational backgrounds.

Simulator training may:

- benefit inhibited personality-types
- not necessarily identify risk takers but may make errors due to failure to ask questions particularly in a class situation – this individualised medium overcomes this issue
- determine if a trainee is only concerned with his own well being or those of others
- determine knowledge of S16 of the OHS Act and duty of care to not only himself but others
- ensure that with constant change in format and approach, the trainee cannot "learn" the test
- should use continually changing scenarios
- assess fitness for duty
- be used to test for drugs and alcohol
- reveal the presence of emotional issues
- fatigue
- assess the individual's perception of risk and the acceptance of risk
- whether rules are overlooked in favour of own perceptions
- ascertain whether workers will take risks in a VR setting, that is, take the easy way as they mostly will do in real life

However, other factors should also be taken into consideration such as;

- Individual is aware that he/she is being tested and thus accurate behavioural responses may be difficult
- Hawthorne studies showed that people while being studied can behave differently to when they are not being observed.
- "People's (risk-taking) behaviour is difficult to predict, to monitor and to change."

Appendix 3

MineWISE Interactive Training

Australian Mining Consultants (AMC), through collaboration with joint venture partners, has produced a set of multimedia based training courses. AMC is a Registered Training Organization, providing Nationally Registered Training. They are based in Melbourne and have a long history of providing training and educational courses to industry and universities.

The first mineWISE module is *Ground Conditions Awareness,* and other modules in development include *Mine Ventilation* and *Mine Backfill*. These modules are on CD-ROMS, and can be used on PCs that have a CD-ROM drive. AMC expect that using mineWISE interactive training, in combination with traditional training methods, will result in better knowledge retention, thus improving safety and efficiency in the workplace.

Figure 5.17 Information on correct fan location

The mineWISE demo shows some of the ground conditions awareness, barricades, scaling, and ventilation courses. The modules are not simulations, but presentations of basic information (see Fig. 5.17), with graphics and interactive components. The ground conditions awareness module also had a voice over to explain the points on the slide. Interactive exercises include answering questions, locating geological features, a 3D exploration of an intersection, and appropriate scaling locations. Throughout the modules, where new terms are introduced, a mouse click on a highlighted word offers a definition. Simplistic approaches are used for technical subjects, for example, rock stress is explained using an analogy with a simple water flowing animation.

Complete modules will have exams at the completion of the training session. Trainees can use these modules at any pace by using the “Next” buttons at the bottom of the screen. Past slides can be recalled and the entire slide can be replayed by clicking on these buttons with a mouse.

This is not a simulation, but it is more interactive than classroom training, thus making inattention impossible. This demo already has multimedia, such as a voice over, animations, and interactive exercises, and this shows further interactivity is possible. Depending on the content of a module, this could be used for training new employees and for conveying information to existing personnel. This system is useful conveying information, and should be considered by the Joint Coal Board for background training prior to a simulation.

CSIRO

Virtual 3D maps of an entire mine can now be created using Internet technology, according to a group of CSIRO scientists and journalists. CSIRO is the major Government based research organization in Australia. They assist the general Australian public with information and referral on scientific issues, and help make Australian businesses more effective through arrangements such as collaborative research, contract research, commercial licensing arrangements, and consulting and technical services.

Virtual 3D maps may be achieved through languages such as VRML, HTML, and Java. CSIRO scientists have developed a technology that uses unrelated data collected during the life of the mine to create a 3D map. The computer system has a simple interface, allowing inexperienced computer users to learn how to use the entire system in under an hour.

The user can work with data from anywhere in the world with an Internet connection. 3D visualisation is more effective than dials or numbers, hence providing fast and effective communication about the mine. This could be used, for example, to assess an emergency situation better and faster by emergency staff. Ultimately, this technology is a means of communication and, in the future, will be able to transfer other 3D content, such as weather and environmental information.

According to the CSIRO website, the 3D visualisation and geological modelling research program is supported by ACARP, BHP Coal and Shell Coal. Sharing of complex 3D data sets between mining operations, through Internet technologies, is expected to improve decisions, therefore improving mine safety.

The objective of this research is to produce a 3D data integration and data communication technique, using the Internet, and a low-cost interactive interface. Data to be transferred will be time-based and location data, and access to external data repositories will be possible. The visualisation group at Coal Mine Engineering,, is focussed on using a combination of VRML and Java with a standard web browser for this Internet based interactive environment.

This technology offers advantages over other visualisation technologies, such as the integration of 2D and 3D data, text, images, sound and video into a single virtual environment, and the availability of VRML and web browsers. Java also allows the control and interaction of the VRML world, whilst in the web browser environment. This group also reveal that previously only costly powerful workstations could view these 3D complex interactive models, whereas sufficiently configured computers can now also view these models. Current VRML projects by the visualisation group are Goonyella Punch Longwall, TrapGully Opencut Coal Mine, Appin Underground Coal Mine, Longwall Powered Supports, Global Scale Data, and the Queensland Centre for Advanced Technologies (QCAT).

This technology is a means of communicating 3D content, and as the Joint Coal Board Simulator is envisaged to be web-based, this technology is relevant and should be considered.

Mine Safety and Health Administration MHSA

The Mine Safety and Health Administration (MSHA), a US Government organization) web page (see Fig. 5.18), provides a wealth of safety information for all members of the mining industry, from the general public, to miners, and also to those involved with technical aspects of mining.

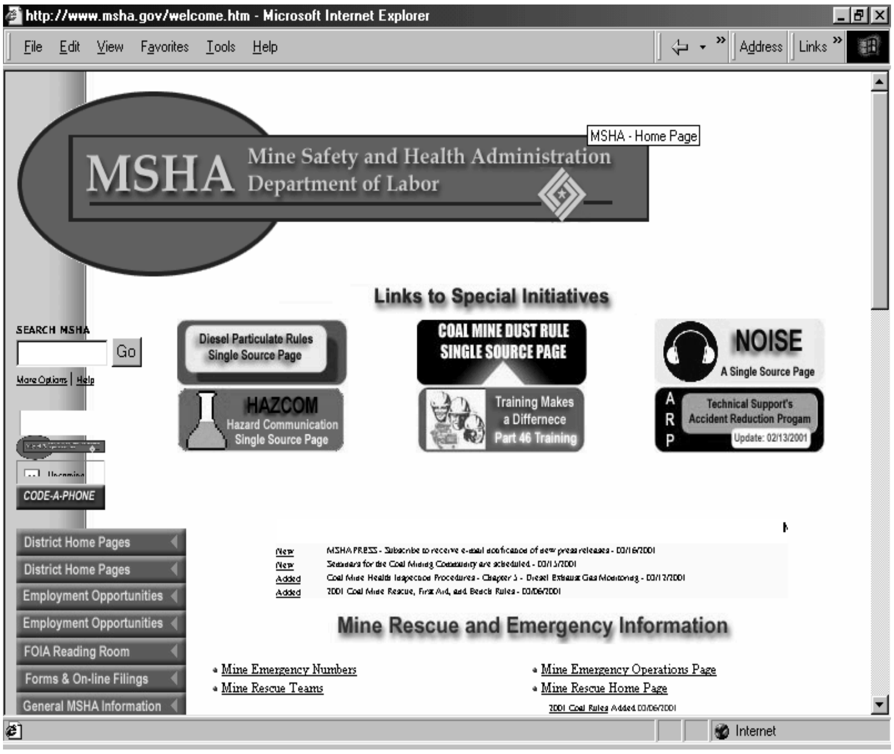

Figure 5.18 MHSA Web Site

Information and services included in this site are:

- Mine accident stories;
- Mine accident reduction initiatives;
- Fact sheets;
- Accident/fatality rates;
- Useful links;
- Survey data;
- Anonymous reporting of safety infringements, ideas, etc.;
- Technical reports;
- A Guide To Miners' Rights and Responsibilities Under the Federal Mine Safety and Health Act of 1977;
- Links to mines rescue contest home pages;
- Press releases;
- Training modules; and a
- Bulletin board of safety suggestions.

For example, when this site was accessed, an electrical awareness training program was available for download. The training program made use of multimedia, in this case, a PowerPoint presentation and a video. The quality of information provided in the presentation was simple, brief, and informative, designed for the regular mine worker.

This site is reasonably easy to navigate, with a contents column, shortcuts throughout the home page, and a search facility. It does, however, leave room for design improvement, and for more information and safety programs. This is a good start for co-ordinating safety related information for easy accessibility for everyone.

This integration of multimedia and other information could be used as a basis for training. The internet allows easy access for anyone, and allows a complex web of linked pages to be shown. Ultimately, a portal web site could be designed with links to VR worlds (preferably interactive with assessments), training information, links to further training organizations, mining regulations that relate to training and safety, and the latest news with regard to training systems and safety. This portal site should integrate all future internet based mining safety and training systems.

Performance Associates

Performance Associates specialises in mine and metallurgical plant start-up, training, operations, and maintenance services. Performance Associates have designed computer-based, Windows-based, multimedia process-plant training systems. These systems contain the same information as in hard-copy manuals, and, after some initial training, Performance Trainer is suitable for training new employees, and for refresher training.

Features of the Performance Trainer include interactive animations of metallurgical processes, video clips of actual processes, spoken narration, testing, text modifications by a supervisor, and hyperlinking to glossary terms, operation principles, and video clips. These simulations involve changing variables, such as a valve, and the simulation shows the user what effect this action has on a system (see Fig. 5.19 for an example of a Sump Level Control Simulation). The training system claims greater retention by the trainee, because of the multimedia medium.

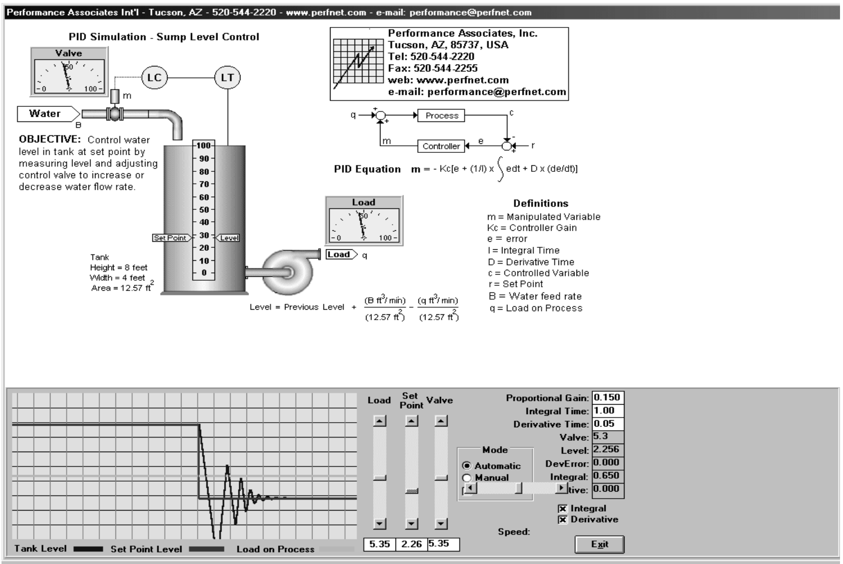

Figure 5.19. Sump Level Control (Performance Associates)

Sega and GT Interactive

Much of the literature on simulation technology acknowledges that technological advances, and their reduction in price, are a result of improvements in the digital interactive entertainment industry. Technological advances for gaming have been fast, due to the size of the industry and the profits involved.

Sega, for example, are a major company in this industry. Sega offers consoles as well as games. Dreamcast Consoles offer 3D graphics, 3D audio capabilities and 128-bit processing. They also include a 56K modem for internet gaming. Peripherals are available to enhance the gaming experience. These include the Jump Pack, which allow the user to feel collisions, explosions and crashes, the Fishing Controller, and a Dreamcast Broadband Adapter for faster online gaming with high speed Internet Service Providers. Sega offers gaming that seemingly become closer to reality with the release of each new gaming system.

Another company that provides much of the worlds entertainment software is GT Interactive They develop and provide computer and video games for a variety of consoles, such as Playstation, Nintendo, Sega, Macintosh computers and PCs. The sophistication of these programs improves every year, making the games more realistic.

SymSystems

Symsystems manufactures and refurbishes training devices for civil and military aircraft They sell both the hardware and the simulation software. SymSystems Mission Simulator System (MSS) software allows simulator development of different aircraft models and avionic systems, therefore being reusable.

The real-time simulation environment offers realistic dynamic aircraft simulation with out of the window visual scenes. They also offer realistic threat environment simulation and mission scenario development. These systems have real world digital terrain databases and reconfigurable cockpit displays. Importantly, these simulators, MSSs or others, can be linked through networking.

SymSystems also offers the Aural Cueing System (ACS), which is a software and hardware system that controls the digitally stored sounds associated with simulators. It is PC based and, according to SymSystems, is a low cost system.

\The software controls the selection, volume, pitch, priority, and repetition of the stored sounds. The commands for the control of sounds come from and Ethernet or serial interface. The ACS PC consists of a Pentium class CPU with keyboard, mouse, video card, Monitor, Ethernet card, and two Open Sound System (OSS) compliant sound cards. The Mixer option adds a SymSystems mixer card, one intercom station jack and volume control box, and two headsets to the system. The ACS includes a library of generic aircraft sounds.

One of the simulators SymSystems offers is the Generic Table Top Trainer (TTT). This is customisable and uses commercial off-the-shelf components. These TTT devices consist of the one or more monitors, for the window scene and for controls, and primary flight controls, stick and throttle. TTT systems are based on a combination of PCs and/or SGI machines and use the MSS software.

This is a PC based system that is networked to other PCs, and this is perhaps an appropriate hardware configuration for the Joint Coal Board Simulator.

University of Queensland (CMTE)

The Cooperative Research Centre for Mining Technology and Engineering (CMTE) is based at the University of Queensland and performs research into several mining disciplines. One of CMTE's current research areas is the development of a Virtual Reality (VR) dragline simulator.

The system that CMTE is currently designing will provide dragline operators with real-time feedback about the terrain a machine is working in. CMTE claim that this will enable digging to continue even when visibility is poor. The system will utilize a VR interface, presently being tested, to project an image of the mine environment into operators' eyes, while still enabling them to see as normal.

CMTE suggest that operators often have to deal with glare, dust or fog that reduces visibility to almost zero. One of the aims of the system being designed by CMTE is to allow dragline operators to 'see' the environment they're digging, regardless of actual visibility. Mine planning is another aspect, in that the system will be able to display the difference between the actual environment and what is planned, so operators will have information on exactly where they should be digging and dumping to meet the mine plan.

CMTE report that the research team is trialing a commercial VR system that looks like an ordinary pair of sunglasses. The method gives the illusion of seeing a screen about three metres in front of the glasses. The image of the mine environment is projected onto the screen, and appears transparent on top of what operators normally see.

The research to develop this visualisation technology has been running in parallel with another CMTE project to develop a 3D radar scanning mechanism. Comment that the 3D radar would be mounted onto a dragline and would scan the environment to provide the data that will be visualised into images for the operator. Radar was chosen as the main scanning mechanism over lasers and other range sensors because of its ability to work well in environments with poor visibility. A prototype radar is under construction.

So far, CMTE have trailed the visualisation software and VR technology using data from an existing radar system that involved a radar mounted on a pan-tilt head that the researchers moved up and down and across to enable the radar to scan the environment. CMTE comment that the system provided extremely accurate information but was very slow because of the manual method of movement requires to get a complete picture of the terrain.

However, the system was promising because it showed that it was possible to visualize the environment using radar images even though the speed was not 'real time'. The 3D radar being developed would however be capable of scanning extremely quickly using an innovative spinning mirror that 'reflects' the radar. CMTE believe this will enable extremely fast data collection and thus, real-time imaging.

The CMTE team is currently working towards integrating GPS and compass data into the system that will be mounted on the dragline with the radar to provide information on where the dragline is pointing when radar images are collected. This information could eventually enable mines to update their databases in real time. As an operator aid, the technology is going to have applications in other forms of heavy equipment, beyond just draglines.

In conclusion, the CMTE dragline simulator is slightly out of the field of interest applicable to the Joint Coal Board simulator. However, the system does offer some ideas of delivery of information in the form of the idea of using a set of glasses that have an image displayed on them for the operator to see. This may be useful as an alternative to a training simulator where the trainee is fully immersed in VR. To evaluate this the method has to be investigated in more detail. Whether this is a direction of the JCB simulators has to be considered against the project as a whole.

WebConSim

WebConSim [1]present a technical paper that is difficult to understand unless the reader is fully literate on computer technology. Schafrik, a graduate research engineer, and Karmis, are from the Department of Mining and Minerals Engineering of Virginia Tech, Blacksburg, VA and Agioutantis is from the Department of Mineral Resources Engineering, Technical University of Crete, Greece. Schafrik *et al.* (2001) presents a different type of simulator; a new web-based user-friendly simulation tool for the Windows environment.

Output from this simulation includes production data, equipment utilization indices, and time driven event chains which can be used for virtual reality presentations. This simulation can easily be modified by engineers or management, and will allow optimum mining sequences for mine geometries and equipment layout to be formed, assisting mine operators plan these sequences.

Little work, has been done in the past 10 years to modernize applications that simulate the space and time development between mining equipment.

This application is designed so that the user can use any computer and client, that is, they may have Microsoft Windows, Palm Pilots, Unix or Apple web browsers. This is

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1 Schafrik et al (2001)

possible because the actual simulator resides on the server. This simulator consists of three modules: front-end, database, and simulator module.

The front-end module involves communication between the client and the server with http requests, using Active Server Pages (ASP), which is compatible with all popular web browsers made in the past 5 years. As all ASP processing occurs on the server, any software upgrade only occurs on the server, and not on the clients computer. The server requires Microsoft Windows 9X or NT, Microsoft ActiveX Data Objects (ADO) version 3.5 or later; Microsoft Internet Information Services version 3 or later with Active Server Pages option installed; (Personal Web Server in Microsoft Windows 9X) and the server must be powerful enough to manage all expected simultaneous connections.

Changes to the simulator, like the addition of equipment, can be made without the source code or recompiling the simulator, because the simulator itself is not an executable application. The simulator is an ActiveX Dynamic Link Library (DLL) that is executed from an application.

The output from the system include traditional reports, that include cut numbers, times and distances, and time driven event chains. These chains can be imported into animation packages, and with a VR viewer, can be used for spotting bottlenecks not apparent from printed reports, and for miner training. The website has a maintenance area for inputs into the simulator database, and an action area for entering sequence and travel paths and to run the simulation. Inputs are minimised using wizards when multiple steps are required.

The database supplies information to the simulation engine using ADO for the connection. The database is Microsoft Access 2000, and the user can override the development platform with a Microsoft Server, and Oracle database, or any ODBC database. The data in the database is divided into the following major parts:

- Layouts
- Cut Sequences
- Way Points
- Travel Paths
- Teams

The layouts are the physical dimensions of the area to be mined, while the cut sequences are the movement of the miners and roof bolters. Way points, however are not stored in to the database, but generated in each simulation run.

Teams are the mining crews and mining equipment, and this is the most complicated section of the database.

Previously simulators had been restricted to set numbers of equipment, but this simulation allows any equipment to be easily added. Former simulators also did not allow for collision detection between equipment that share routes, instead WebConSim does not allow equipment like shuttle cars to use the same path at the same time, making the simulation time more realistic. In the past, to overcome these limitations engineers had to do develop their own spreadsheets and/or work by hand in order to do time and machine analysis.

WebConSim allows multiple pieces of equipment to operate at the same time and each object decides on the optimum procedure to follow the plan which is set by the user. The simulation logic is based on equipment parameters, like tramming and breakdown rates. These parameters are calculated from statistical information available for each piece of equipment. Finally, the report collector monitors every piece of equipment at all times in the simulation, and produces the report requested by the user. This is the most memory intensive aspect of the system.

Importantly WebConSim results differ less than 10% than existing continuous miner simulators. This is a result of taking more information into account, like not allowing shuttle cars to pass each other on the same route.

Ultimately, this Internet or intranet based simulator, is built for the majority of scenarios, found in continuous miners operations. WebConSim is based on a database, and the results from this simulator are similar to existing simulators.

WebConSim is not a graphical simulator, making it inappropriate for the Joint Coal Board Simulator. However, it is possible the logic may be incorporated into the final simulator. This logic is more realistic and could be used in simulators with random scenarios. For example, in an underground coal simulator the user would see LHDs and continuous miners. The frequency and the locations of these machines could be determined by the logic shown in this simulation. The trainee needs to understand the unpredictability of the traffic underground, however, the traffic must also appear at realistic frequencies, and using the logic of WebConSim, is could be possible to create a VR environment very close to the ‘real thing’.

Wesson International

Wesson International provides simulator solutions for the professional air traffic control (ATC) industry, as well as other software solutions. These solutions range from desktop based systems to supercomputer units. That is, Wesson International simulators range from a single PC system, interfaced with a keyboard and mouse, and a couple of monitors, to a network of PCs, interfaced with a 360° screen and realistic controls.

They claim high quality virtual ATC environments with high-resolution, real-time graphics, 3D visualization capabilities, sound, and voice recognition technology.

Systems they provide are:

- TOWER/Pro Series 100 –desktop training
- TOWER/Pro Series 200 –classroom system
- TOWER/Pro Series 300 –theatre simulation
- TRACON Pro
- RAPCON/Pro –military radar simulation
- ENROUTE/Pro –enroute radar simulation
- PAR/Pro –precision approach radar simulator

The series 300 is a full VR cab simulator with a 360 degree view of the airfield, simulating an ATC tower. It offers hundreds of computer-generated aircraft and ground vehicles, and a wide variety of weather conditions.

Some of the features are voice recognition, for the trainees to learn precise phraseology, and easy scenario generation, where aircraft can be selected, flight plans composed, 3D models and airports generated, targets changed during the simulation, and weather conditions, equipment failures and emergency situations generated. Scenarios can be played back, and evaluated, and during the scenario performance monitoring records any violations.

The series 200 has the same features as the 300, except it uses free standing, rear projection displays, and requires no installation construction . The series 100, however, uses computer monitors and requires Microsoft Windows NT. To compensate for the smaller out-of-window view, scrolling provides the full 360 degree view from the simulator tower. Series 200 and 300 are also based on PCs and Microsoft Windows programs and platform, making TOWER/Pro easier and thus less expensive to repair and upgrade. This also gives a simple point-and-click interface for the students and instructors.

The TRACON/Pro is also a PC-based simulator and has trained controllers for the past nine years Routine and emergency scenarios can be generated, and with voice recognition and response, and realistic controls and communication subsystems, allow training to be conducted. With specialized keyboards and displays, TRACON/Pro can be integrated with the TOWER/Pro simulator for complete ATC training system.

These realistic scenarios prepare students more quickly and safely than on the job training, and according to Wesson International, independent studies have shown that TOWER/Pro-based training reduces training time by more than 25% over traditional methods.

The quality of simulation as shown by Wesson International should ideally be achieved in the Joint Coal Board Simulator.

UNSW Chemical Plant Simulation

The University of New South Wales School of Computer Science and Engineering[2] has produced a virtual reality (VR) chemical plant. This school is located on the UNSW Kensington campus, and has a strong research program in artificial intelligence, computer systems and software engineering.

Recently, the school received almost $2 million in external research grants in addition to $700 000 in internal grants and $750 000 from the Australian Research Council. Research at the school is undertaken by academics, research graduates and final year undergraduates.

The School has attracted academics from the UNESCO Centre for Membrane Science and Technology in the School of Chemical Engineering and Industrial Chemistry at the University of New South Wales (UNSW), and from the UNSW School of Computer Science and Engineering. The aim of this simulation is to enhance the education of chemical engineering and industrial chemistry students.

If the interaction in a simulated 3D environment is fast enough, users will feel immersed in VR and advances in technology have made this computing speed possible, even in PCs. VR chemical plants have been tested by the School of Chemical Engineering.

Industrial Chemistry and, proficiency with this software depends very little on a person's personal profile, that is, their gender, cultural background, and stage of education, and their computing experience. Through a test where participants looked at the attributes that aid object recognition, it was determined that shape, colour, texture, shading, location of an object in its surroundings, size, and level of detail are all very important.

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2 Li *et al.* (1999)

Virtual Reality Modelling Language (VRML), the ISO standard for virtual worlds, was used to build the VR chemical plants. VRML was chosen because there is a great deal of information on VRML, and a wide availability of browsers, authoring tools and models for VRML.

This model as consists of distillation columns, where the user can choose to see one in greater detail by clicking on one of the columns. This model also offers hyperlinks to photographs and text providing further information about the chemical plant equipment. Sounds, animation and models of plant behaviour have not yet been included in this model.

Major technical issues with VR models are associated with their large file. This system intended to be used at home, as well as on campus, and downloading a large file from the Internet, on an ordinary modem, takes a long time. Also, models take a long time to render even on high powered PCs. To reduce the file size, prototypes (basically a template) and compression are used for this VR chemical plant. To increase the rendering speed, the scene is simplified by omitting features that are redundant in their recognition. Additionally, the Level Of Detail (LOD) node technique, provided by VRML, allows a highly detailed object to be replaced by one that is of lesser detail when the viewer is far away.

There was a positive reaction and good performance from the VR tests on the chemical engineering students, proving that this tool justifies further development for chemical engineering education.

This system is an illustrative simulator rather than an interactive simulator, making it not suitable for the Joint Coal Board simulator. However, it offers good suggestions, like hyperlinking information to objects in a VR world, and methods of reducing file size to enhance navigational speed, which increase realism, that could be incorporated into a final simulator design.

This is a simulation built by undergraduates from the School of Computer Science and Engineering, of the University of New South Wales (Kensington campus) under the guidance of Tim Lambert. It is designed to assist chemical engineering or industrial chemistry students in their understanding of the operations of chemical plants. This has great potential as an educational tool, because it shows the system in 3D and has informative links for each part of the system. A mouse click on parts of the chemical plant, like the reflux drum, shows further information about that part of the system (figure 5.20).

This program relies on a relatively fast PC. Importantly, it needs VRML software, like Cosmo player, and an Internet browser, like Netscape and Internet Explorer for this simulation to operate. All this software is available on the Internet free of charge.

The controls in navigation of the chemical plant depend on the VRML software, however, the two software's tested, Cosmo and Blaxxun Interactive, both provided self-explanatory navigational tools using a mouse.

The chemical plant is graphically simplistic at a distance. However, when approaching certain objects the detail increases in order for the world to appear more realistic. This reduces the need for details of all features to be downloaded at once, thus reducing rendering speed and making the simulation run more smoothly. For example, valve and drum bolts do not appear until the user is near enough for them to be seen.

Using the mouse to click on parts of the chemical plant provide further information for the user about that piece of equipment. For example, a click on the distillation column gives a written explanation to its function and purpose on the lower part of the web browser screen, and a real life picture of a distillation column. The virtual chemical plant is a basic representation of the system, and real images are necessary for the user to understand how they appear in real life.

Unlike navigation around other simulation worlds, the user cannot navigate through solid objects/equipment, making this world more realistic. The navigation is relatively simple, and the speed and response to the mouse clicks are quite fast.

This software, however, lacks some interactivity. Sometimes the valves can be turned, but this does not affect the operation of the chemical plant. It is expected future versions of this software will be more interactive testing student understanding of the chemical plant.

Hyperlinks to information on parts of the chemical plant are a concept that could be used by the Joint Coal Board simulator. This shows simulation is possible and fast enough over the Internet if the file size is small enough, achieved by using minimal graphical detail. This simulator does not have tasks for the user to perform; it is a purely illustrative simulator. However, it appears to have potential as an educational aid, and further work will make it interactive.

Figure 5.20. Increasing resolution as user approaches drum.

Executive Summary

BACKGROUND

The Joint Coal Board (JCB) is concerned about the number of accidents and fatalities associated with the operation and maintenance of equipment in the New South Wales coal industry. In the last decade, equipment has become more sophisticated and the manner in which work is organised and performed in the industry has changed significantly. Therefore, through its Health and Safety Trust, the JCB commissioned a consortium comprising Mine Site Technologies and the School of Mining Engineering at the University of New South Wales to research the introduction of equipment training simulators into the industry. The research is planned to be undertaken in four stages.

This report presents the outcomes of the first two stages. It recommends the development and testing of an interactive, immersive, virtual reality prototype simulator providing true to life imagery. The simulator will be modular in design such that various items of equipment can be plugged in as required. It is proposed that the evaluation of the prototype simulator be based on a continuous miner and a roof bolter, with the option to add a dump truck. This is because a high accident rate is associated with these items of equipment. Most of the research undertaken on the project to date has focused on these machines.

The research has confirmed that JCB Simulators have a huge potential to improve:

- Mine Safety
- Productivity
- Business Performance

RESEARCH APPROACH

A need was identified at the start of the project to:

- Encapsulate knowledge from multiple mine sites by using information age technology to capture and learn from experiences of others, and to
- Provide timely and effective training, re-training and up-skilling in order to keep competencies relevant and current.

Numerous procedures apply to the operation and maintenance of sophisticated equipment. A simulator offers the potential to not only train and assess the competency of mine personnel in these procedures but also to evaluate the effectiveness of the procedures themselves. In order to do this effectively, the simulator must be designed around the procedures and be simple and inexpensive to update as procedures are modified and added.

Therefore, the research is being staged in the following manner:

Stage 1. A Scoping Study concerned with:

- Identifying suitable or easily adaptable Knowledge Management Systems (KMS)
- Identifying optimum Best Practice Safety Management Plans (SMP) for each of the three items of equipment
- Establishing the feasibility of identifying and acquiring optimum Safe Working Procedures (SWP) for each piece of equipment for input into simulation model
- Evaluating the feasibility of an industry wide KMS.
- Assessing how to maintaining e-minesafe up-to-date
- Investigating how to develop an on-line community of trainees and trainers.

Stage 2. A Scoping Study concerned with determining the:

- Function
- Technical specifications, and
- Cost of a prototype JCB Simulator

Stage 3. Prototype manufacture and fields trials

Stage 4. Full product commercialisation

BENEFITS OFFERED BY VIRTUAL REALITY SIMULATION

The research has established that virtual reality simulation offers benefits relating to:

- Flexibility in time, place, rate and privacy of learning
- Developing understanding and retention of learning
- Staff induction
- Customised ‘on the job’ training in a safe environment
- Refresher training
- Fault-finding
- Equipment assembly and maintenance training
- Visualisation of the hidden
- Visualisation of the future
- The literacy level of the trainee
- Evaluation of consequences of an action
- Communicating complex data
- Identification of risk takers
- Tracking of learning progression and understanding
- Competency assessment
- Consistency of training and assessment
- Accident investigation and reconstruction

REALISING THE BENEFITS OF VR SIMULATION

For simulators to be effective, their development must be based on a ‘training needs analysis’ rather than just on the blind or spot application of technology. The research has established that in order to achieve the potential benefits of VR simulation for operator and maintenance training in the coal industry, the simulator needs to have the following characteristics:

- Interactive
- Immersive
- Realistic to actual environment, not just stick creatures

- Built on best practice SMP and SWP.
- Allow trainees to make decisions and to experience the consequences of these decisions
- Embedded hazard spotting
- Identification of attitudes and reactions to risk taking
- Simply and quick to keep up-to-date
- Affordability relative to the small size of the market

Nevertheless, it must be appreciated that the difference between a person knowing how a task should be done versus how they actually undertake the task will remain. The attitudes and aptitudes of a person will still determine how they apply the knowledge and skill imparted by simulated training. The IMPS will still apply:

IMPetuous – act without thinking of consequences

IMPatience – knows better but cannot wait

IMPunity – cannot happen to me

IMProvise – contravene SWP

The research has identified that there is potential for VR simulators to assist in identifying persons prone to these IMPS.

TECHNOLOGY OPTIONS

The research has considered the design and application of a number of simulators and technologies. The technology and framework for a JCB Simulator certainly exists. However, it is fragmented and there is no one combination of technologies in the market place that satisfies the requirements of a JCB Simulator. Simulators have generally been purpose designed for operator training on one specific piece of equipment. The developers of the technology have not realised the true potential of VR simulators with respect to mine safety.

Four leading technologies have emerged and been researched in detailed. They are

1. The AIMS Safe-VR, University of Nottingham. This offers the following features:

- Interactive
- Modular construction
- Graphical programming
- Hazard spotting embedded in the software
- Environment can be textured to a degree
- Links to video clips
- AIMS is experienced and has a track record for producing VR simulations
- Can be effectively linked to a web based database
- Cost effective

2. Continuum Resources offering:
    - Platform independent architecture for the Knowledge Management System.
    - Interactive
    - Immersive
    - Modular construction
    - Graphical programming
    - High quality computer based images

3. Fifth Dimension Technologies offering:
    - Continuous miner operator simulation
    - Interactive
    - Immersive
    - Real machine controls
    - Field experience - already trained 400 miners in operations in South Africa

4. Immersive Technologies offering:
    - Dump truck simulator
    - Interactive
    - Immersive

- Real machine controls
- Field experience – already trained drivers in operations

These four main players offer high quality simulators. However, the accompanying table shows none of the four systems satisfy all of the requirements of the JCB Health and Safety Trust with respect to the integration of knowledge and skills to achieve safe human responses. The JCB *e-minesafe* Simulator needs to incorporate a combination of the positive attributes of the four main technology options.

Feature	Nottingham VR	5DT	Continuum	Immersive	e-minesafe
VR Software	✓	✓	✓	✓	✓
Modular	✓	x	✓	x	✓
Open Architecture	✓	x	✓	x	✓
SWP Platform	x	x	x	x	✓
Machine Interface	x	✓	x	✓	✓
Immersive Environment	x	✓	✓	✓	✓
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	✓

TECHNOLOGY SELECTION

The preferred solution is to build and field test a **MODULAR BASED SIMULATOR** prototype that provides the framework for safety and training simulation across a range of mining equipment. In the first instance, the simulator would be based on delivering interactive training for the operation of continuous miners and the operation and maintenance of roof bolters, including rib bolting. There is an option to 'plug in' a dump truck.

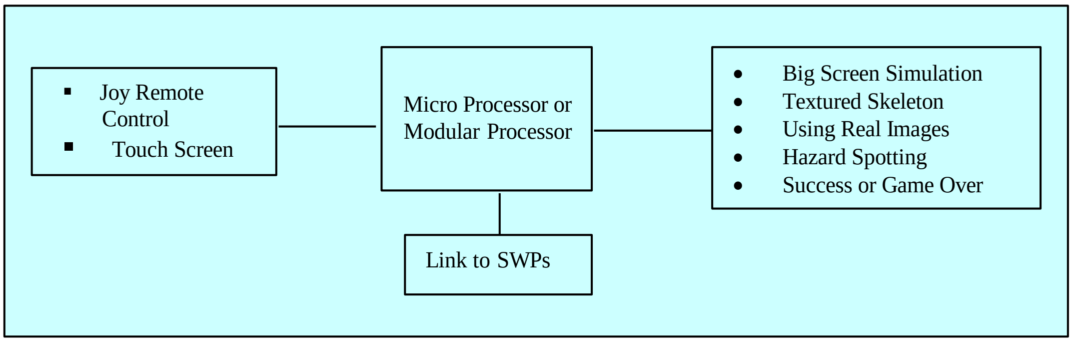
The design should be of open architecture using flexible software to allow for site specific and machine specific changes. The software must allow for splicing and pasting of video images and video footage so that the simulator is context sensitive and realistic. Instead of VR 'stick creatures', the simulations must be represented by textures inputted from digital and/or CAD images of the mining machines and surroundings.

Virtual reality training must 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 is a real life experience for the trainee. The trainee can receive immediate feedback on the consequences of poor decision making and inept skill, albeit that they do not result in real life penalties.

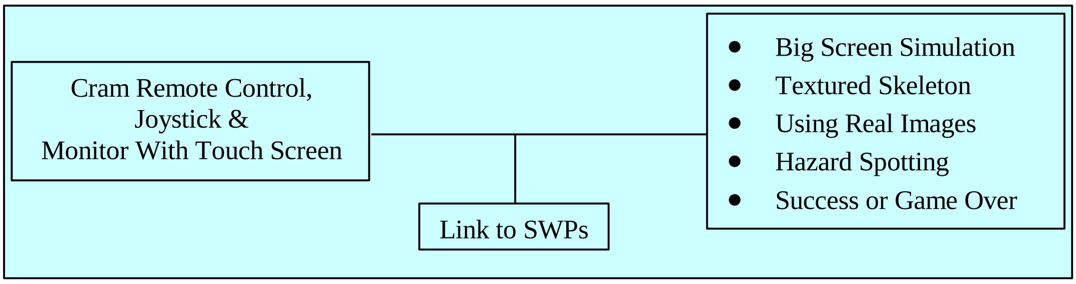
A key issue identified in the research is the issue of motion sickness when using simulators. The quality of the circuitry comprising the simulator has a significant influence on whether motion sickness occurs. If a person is stationary, motion sickness can develop quickly if the imagery is not refreshed at a high frequency. If the trainee is mobile whilst immersed, motion sickness is less likely to occur. These issues lead to the recommendation that the JCB Simulator should be based on technology that is not solely desktop based. Freedom of movement whilst using a real life control will enhance the quality of the outcome.

The recommended architecture for operator training and for maintenance training is as follows:

Operator Training



Maintenance Training



Three options that will achieve these desired outcomes are:

Option 1. Desktop P.C. based interactive simulator with real machine controls.

Option 2. Site based, immersive, interactive simulator with real machine controls.

Option 3. Mobile immersive, interactive simulator with real machine controls.

RECOMMENDED TECHNOLOGY

The four main technologies identified all have attributes that can be incorporated into the JCB Simulator. A hybrid simulator is required. The recommended layout of this hybrid system as it applies to the operation of a continuous miner is shown in shown in Option 2. The reasons for selecting Option 2 as the most appropriate layout are that it meets all the identified criteria (see matrix table) and provides the benefits of:

- being site based, making it easily accessible to trainees,
- reflecting reality in the VR simulation,
- propagating site ‘ownership,
- being easier to maintain and keep up to date than a mobile version.

RECOMMENDATION TO JCB HEALTH AND SAFETY TRUST

The project team recommends that the JCB Health and Safety Trust commissions Mine Site Technologies (MST) and the University of New South Wales (UNSW) to design, develop and commission a prototype VR Simulator suitable for safety training of an operator of a continuous miner and operators and maintenance personnel of roof bolters.

The project cost will be $1,540,000 with both UNSW and MST providing considerable in-kind support. In-kind support from UNSW will be in the form of access to the considerable intellectual resources that reside within disciplines in the university, especially in regards to information technology. MST will provide support in the form of their experience in developing and commercialising technological innovation. The proven capabilities of both organisations will be brought to the project.