STATE OF THE ART OF VIRTUAL REALITY SIMULATION TECHNOLOGY AND ITS APPLICATIONS IN 2005.

SCHOOL OF MINING ENGINEERING,

UNIVERSITY OF NEW SOUTH WALES.

RESEARCH REPORT

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DR PHILLIP STOTHARD

PROF JIM GALVIN

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SUMMARY

The School of Mining Engineering at the University of New South Wales (UNSW) has been developing immersive, interactive computer-based training simulators for a number of years with research funding provided by Coal Services (CS), the Australian Coal Association Research Program (ACARP) and the Australian Research Council (ARC). The virtual reality (VR) simulators are being developed to improve the effectiveness of training in the Australian coal mining industry with a view to enhancing health and safety. VR theatres have been established at UNSW and at the Newcastle Mines Rescue Station (NMRS).

A range of experienced and inexperienced mining personnel has already had the opportunity to train in them. A capability in immersive, interactive virtual reality training has been established and the reaction to the new technology has been positive and confirmed the benefits to be gained in going to the next stage in developing this capability.

Given the significant advances in computer technology that have occurred since this research was initiated at UNSW, it was considered wise to undertake a study of the 'State of the Art of Virtual Reality Simulation Technology and Its Application in 2005'. This should enable informed decisions to be made on technologies and techniques that could further enhance the simulators and give insight into how the existing VR capability at UNSW can be placed on a sustainable foundation.

This Research Overview summarises the findings of the study. It recommends the continued development and testing of the simulators towards a system that presents the users with hi-fidelity imagery and function that is based on 3D models, developed using real mine plans, safety data and manufacturer's drawings.

The simulators should remain modular in design, such that equipment can be updated and added easily over time. Different mine training scenarios and models based on sound educational principles should be developed with major input from experienced mining industry personnel.

The simulations that have been developed, that is, Self-Escape, Rib Stability and Sprains and Strains should also continue to be developed and refined. The study has confirmed that such simulations are a powerful visualisation and training tool for enhancing the understanding of mine safety procedures and operations in the coal mining industry.

This Scoping Study was undertaken with funding provided from the JCB Health and Safety Trust administered by Coal Services Pty Limited. The support of the Trust and trustees is gratefully acknowledged. The contributors of information are also gratefully acknowledged.

1.0 INTRODUCTION

The School of Mining Engineering at the University of New South Wales (UNSW) has been developing immersive, interactive computer-based training simulators for a number of years with research funding provided by Coal Services (CS), the Australian Coal Association Research Program (ACARP) and the Australian Research Council (ARC). The virtual reality (VR) simulators are being developed to improve the effectiveness of training in the Australian coal mining industry with a view to enhancing health and safety. VR theatres have been established at UNSW and at the Newcastle Mines Rescue Station (NMRS).

A range of experienced and inexperienced mining personnel has already had the opportunity to train in the theatres. A capability in immersive, interactive virtual reality training has been established and the reaction to the new technology has been positive and confirmed the benefits to be gained in going to the next stage in developing this capability.

Given the significant advances in computer technology that have occurred since this research was initiated at UNSW, it was considered wise to undertake a study of the 'State of the Art of Virtual Reality Simulation Technology and Its Application in 2005'. This should enable informed decisions to be made on technologies and techniques that could further enhance the simulators and give insight into how the existing VR capability at UNSW can be placed on a sustainable foundation.

The main aim of the study was to review a selection of international and domestic technologies and techniques developed by various groups. The groups are research and development based and also commercial concerns. It was expected that the collected information would provide insight into the tools and systems available for the sustainable development of the simulations deployed to the Mines Rescue Stations in NSW. Costs for the sustainable development could also be explored.

It was also expected that the study would identify similarities between systems used elsewhere in Australia and overseas, thus allowing any duplication between systems and techniques to be identified. Potential collaborators could also be identified.

The information and the technologies reviewed in this study are not exhaustive and some developers and producers declined to participate. However, the data collected and the reviewed systems are believed to cover the complete spectrum of hardware and software that are available to further develop the simulators. It is believed that developers that declined to participate in the study use systems analogous to those included in the review as many research groups used systems of similar format.

The data collected by the study is presented as a brief review of the capabilities of each site visited, a comment on the development group's size and experience, a tabulated review of the systems and techniques and an approximate dollar value of the system used. The reviewed data and systems lead to a discussion and conclusions being drawn that are the basis for the technology and development team required for the next stage of simulation development.

Overall, the study shows that simulation technology is a mature industry and has advanced considerably since the initial Feasibility Study performed for Coal Services in 2001 (Stothard et al 2001)). The technology has been successfully applied to many situations including mining and is at a level where almost any environment can be replicated and made interactive.

The costs of simulation technology remain between the $10K desktop PC based systems, through mid-ranged systems costing $100K to high-end systems costing over $15m for a complete facility. Cost generally reflects fidelity, level of immersion and interactivity and increases as the complexity of the visualisation facility increases.

In several cases, the simulations examined lack the genuine consideration of human factors. That is, how do people relate to the simulated environment? In many cases, engineers developed the technology and scenarios resulting in powerful technology, running high fidelity visualisations and high-tech user interfaces. There is now a requirement for the learning outcomes of user interaction with the simulations to be investigated in greater detail particularly in the case of the simulators to be deployed at NSW Mines Rescue Stations.

2.0 RESEARCH OBJECTIVES

Interactive training simulations have been developed at the University of New South Wales (UNSW) and deployed at the Newcastle Mines Rescue Station (NMRS) in NSW. The simulations have provided an opportunity for industry instructors and workers to experience the technology. The feedback from industry and the potential trainees has been positive. The consensus is that simulation technology and scenarios could be applied to many more mining industry-training applications.

The technology and techniques used to develop the existing training simulators are based on technology identified in a Scoping Study in 2001. It was to be expected, therefore, that in the interim there would have significant developments in computer-based training techniques – software and hardware – and that other groups around the world would developed training simulators. Hence, it was decided that a review of the existing technology and techniques was warranted before making recommendations on future technology and techniques.

To this end, another Scoping Study was proposed, with the main objectives being to,

- Make an assessment of the existing training simulators installed at UNSW and NMRS.
- Review the effectiveness of the existing technology with NMRS /Industry and identify possible improvements.
- Identify past and present providers of VR technology in Australia and overseas and, where possible, contact or visit them to assess their status.
- Contact developers of VR technology used in other industries and identify their capabilities.
- Identify simulations that are web based, cross platform and that complement the existing simulators.
- Identify/re-assess the model building techniques and technologies to identify any improvements.
- Re-assess the scale of models in relation to the required level of detail and assess the capacity of the models to run across different platforms.
- Assess the educational basis of the application of the technology to training programs.
- Identify quantitative techniques for assessing the effectiveness of simulator based training programs.
- Identify fully interactive immersive environments (such as UNSW's CAVE environment) and assess their relevance to a mining simulation.
- Analyse and critique the gathered information.

- Draw conclusions and make recommendations to Coal Services on the findings of the Scoping Study and the future direction of the project.

The information included in this report is primarily the result of site visits made to different research establishments that have developed interactive simulations and visualisations. Other information is based on papers and website information provided by developers.

The chosen sites were a representative international cross-section of interactive simulation developers. The visited sites were keen to discuss their work and experiences and make presentations.

Analysis of the simulation systems was performed through a general consideration of common parameters between sites, such as facilities, team size, equipment, publications costs and so on. In an attempt to quantify technology and maintain brevity in the report, parameters are presented in tabular form later in the report.

A general discussion and conclusions were drawn from this information. These form the basis for recommendations to Coal Services re the format and options for developing a simulation capability that is effective and sustainable.

3.0 CONTRIBUTORS AND SOURCES OF INFORMATION

This study is concerned generally with identifying the 'State of the Art of Virtual Reality (VR) Simulation Technology 2005'. The main focus of the study is on producers of simulations related to mining and primary industries.

To obtain an international perspective and obtain a benchmark against which the simulators that have been installed at UNSW and NMRS could be compared, VR researchers were approached in Australia, USA, UK and Germany. A list of contributors that responded positively and that were visited is shown in Table 1.

Table 1: Sites visited and reviewed.

Site	**Location**	**Operational Basis**
UNSW School of Mining Eng.	Sydney, NSW, Australia.	University / Industry
Continuum Resources	Perth, WA, Australia.	Commercial
CSIRO Haptics Laboratory	Sydney, NSW, Australia.	Government
CSIRO / ACCR / TAFE	Perth, WA, Australia	Government / Industry?
NIOSH, Spokane RL	Spokane, WA, USA	Government
NIOSH, Morgantown CDC.	Morgantown, WV, USA	Government
NIOSH, Pennsylvania CDC	Pennsylvania, PA, USA	Government
University of Washington	Pullman, WA, USA	University / Industry
University of Nottingham VISART	Nottingham, UK	University / Industry
University of Loughborough, Advanced VR Facility	Loughborough, UK	University / Industry
DMT, Germany	Dortmund, Germany	Government / Industry
DSK, Germany	Essen, Germany	Government /Industry
EFR-Systems Germany	Dortmund, Germany	Commercial / University
RailCorp	Petersham, NSW, Australia	Government / Commercial
Silicon Graphics	North Ryde, NSW, Australia	Commercial

Prior to visiting the sites, a review of the Web and a directory of VR developer websites uncovered in the 2001 Feasibility Study suggested that many VR researchers (>50%) that were active in 2000 had stopped development of VR. This proved misleading as such sites are old and suggest that only a few groups around the world have continued to develop VR systems successfully. In fact, in many cases, it was found that research and development had continued but under a different name. The term VR has become outdated and has a stigma attached to it resulting from media hype in the early days that promised the technology would deliver more than it practically could.

Many researchers have relabelled their systems to include descriptions such as 'Interactive Computer Generated 3D Environments', 'Interactive Visual Environment Centres', 'Reality Centres' and so on. This is something that should be considered for the simulators installed at UNSW School of Mining Engineering and NMRS.

Many active developers of VR simulations were contacted and those that were co-operative and open to discussion were visited at their facility. Several commercial developers declined to be involved in the review and others did not respond to contact via email or phone. In total, fourteen sites that are developing VR simulations were visited. This was considered a large enough group to make an assessment of the technology and techniques used for simulation and to determine the organisational structure and capabilities of such groups. The contributors ranged from industry producers through to government funded research organisations and University Faculties.

All organisations made presentations of their systems. Generally, they were all of a very high standard. Different sites provided different levels of information and preparedness and this appeared to reflect the type and level of organisation present within the group.

Broadly speaking, it was expected that University sites would be less formal than commercial or government run sites and this was born out during the site visits. Each site was loosely considered against criteria such as first impressions, presentation, team size, organisation, hardware, software, existing simulations placed into industry and educational basis of the simulations. The criteria were kept deliberately broad as it was expected that some developers would be purely interested in technology, others in techniques and others in Human Factors engineering.

Other contributors of information through review of their websites and brochures are listed in Table 2. The producers of interactive simulation technology are numerous and again this list is not exhaustive. There are many groups around the globe using similar techniques and methods. Where possible, copies of brochures are placed on the Appendix CDROM.

Table 2. Contributors of information whom were not visited.

Group	**Location**	**Operational Basis**
AIMS Solutions	Nottingham UK	Commercial
5DT	Los Angeles USA, Pretoria, RSA	Commercial
Immersive Technologies	Perth, Australia	Commercial
University of Queensland	Queensland, Australia	University/Industry

The comments, observations and data relating to specific sites are tabulated in Table 3 and discussed in more detail in subsequent sections of this report. The Table reveals that:

- Almost all the groups visited are now using P.C. based simulation technology.
- Many have migrated from Silicon Graphics (SGI) based equipment to P.C. based equipment. However, this maybe a temporary situation.
- None of the researchers have migrated from P.C. based equipment to SGI.
- Many of the systems experienced were modular based systems with open architecture and off the shelf hardware.
- Over 50% of the developers would prefer to use open source software to develop the interactive nature of the simulations.
- Very few of the developers have real machine control interfaces connected to their simulations. Notable exceptions were the high quality simulations developed by DMT for DSK, and the simulations developed by EFR-Systems and SGI for RailCorp. However, this reflects the purpose of simulations, that is, these were 'driver/operator' training simulators. The rest were procedural or visualisation simulations.
- All of the simulations were partially or completely immersive via a flat screen, Cave environment, curved screen or 3D shutter glasses or a combination of these.
- The majority of simulations had a facility for user interaction other than machine controls.

- The majority of developers had developed models in 3DSMAX and exported them into their respective viewing software. A couple of developers had used different modelling software known as Creator.
- The level of resolution in the simulations is generally high with extremely high-resolution video renders produced by Continuum Resources and DMT and high-resolution real time simulations produced by UNSW, SGI and EFR-Systems. Unfortunately, these models are memory intensive and wouldn't to run on a conventional personal computer - except for UNSW.
- The majority of developers have developed systems ranging between $500K and $1m.
- Only Uni' Loughborough, SGI and RailCorp have entered the multi million-dollar realm.
- EFR-Systems have produced predictive simulations that would be over $1m.
- The team size for many of the groups is around two to five developers with a couple of groups having more than 10 people working on a project.
- None of the systems were found to be platform independent and most were Windows based.
- Only five groups operated Unix systems.

When Tables 1, 2 and 3 are considered together, it is clear that the majority of groups involved in simulation research are linked to Universities by one means or another. Where the group is University based linked to a commercial arm, there seems to be scope for larger budgets to be maintained and better transfer of technology to industry. Companies like EFR – Systems and SGI / RailCorp have had access to large development funding and a pool of programmers and modellers. The benefits of this are born out in their simulations and the quality and complexity of the equipment and simulations produced is extremely high.

Where budgets are 'smaller' such as DMT/DSK and NIOSH, at around $750k, the resolution of the simulations and the interactivity is still very high and impressive.

At the lowest end of the budget scale, games software has been used and the quality of these systems – for example NIOSH Spokane is very good and has proven useful in the mining industry.

Table 3 facilitates an assessment of systems suitable for enhancing the simulators deployed at NMRS and the recommendation of technology options. These options are presented in the recommendations sections of this report.

Feature	UNSW	Continuum	CSIRO Syd	CSIRO Perth / ACCR	CSIRO Brisbane	NIOSH Spokane	NIOSH M’town	NIOSH P’Brg	Uni’ W’ton	Uni’ Notts VIRART	Uni’ L’boro’	Uni’ Qld	DMT/DSK	EFR	SGI Rail
P.C. Based	√	√	√	√	√	√	√	√	√	√	√	√	√	√	X
SGI Based	X	√	√	X	N/A	X	√	√	√	X	√	?	X	√	√
Transferred from SGI to P.C.	X	√	√	N/A	N/A	X	√	√	√	X	√	X	X	√	X
Transferred from P.C. to SGI	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Modular	√	X	√	√	√	√	√	√	√	√	√	√	√	√	√
Open Architecture (Hardware)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	X
Open Source (Software)	X	√	√	X	X	√	√	√	X	√	√	X	√	X	X
Machine Control Interface	X	√	X	X	X	X	X	X	X	X	X	X	√	√	√
Driver Training	X	X	X	X	X	X	X	X	X	√	√	X	√	√	√
Procedure Training	√	X	√	X	X	√	√	√	√	√	√	√	√	√	√
Fully Immersive	√	X	√	X	X	X	√	X	√	X	√	X	X	√	√
Partially Immersive	√	X	√	√	√	√	√	X	√	X	√	√	√	√	√
User Interaction	√	√	√	X	X	√	√	√	√	√	√	√	√	√	√

Table 3. Features of various VR training simulations

Feature	UNSW	Conti nuum	CSIRO Sydney	CSIRO Perth / ACCR	CSIRO Brisbane	NIOSH Spokane	NIOSH M'town	NIOSH P'Brg	Uni' W'ton	Uni' Notts VIRART	Uni' L'boro'	Uni' Qld	DMT/DSK	EFR	SGI Rail
Models built in 3DS MAX	√	√	√	√	√	√	√	√	√	√	X	√	√	√	X
High Resolution	√	√	√	X	N/A	√	√	X	X	X	√	?	X	√	√
Visualisation	√	√	√	√	N/A	√	√	X	√	X	√	√	√	√	√
Single Screen	√	√	X	√	X	X	√	X	√	√	√	√	√	√	√
Multi Screen	X	√	X	√	X	X	√	X	√	X	√	X	X	√	√
3D Image	√	X	√	√	X	X	√	X	√	X	√	√	√	√	√
Multimedia access	√	X	X	X	X	X	X	X	X	X	√	√	√	√	√
Cost <$100K	X	√	X	X	X	√	X	X	X	X	X	X	X	X	X
Cost >$100K <$500K	√	X	X	X	X	X	X	√	X	X	X	√	X	√	√
Cost >$500K <$1m	X	X	√	√	√	X	√	X	√	X	X	X	√	√	√
Cost >$1m	X	X	X	X	X	X	X	X	X	X	√	X	X	√	√
Team Size	5	2	5	3	4	2	2	3	4	>10	5	3	4	6	>10
Own Software	X	√	√	X	X	X	X	X	X	X	X	X	X	√	√
Platform Independent	X	X	X	X	X	X	X	X	X	X	X	X	X	x	√
Windows Based	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Unix	X	X	√	X	X	X	√	X	√	X	√	X	X	X	√

Table 3. Features of various VR training simulations continued.

4.0 REVIEW OF THE UNSW MINING ENGINEERING SIMULATOR

The training simulators developed by UNSW School of Mining Engineering for the Mines Rescue Station at Argenton were developed through a tripartite research project funded by Coal Services, ACARP and UNSW. Three generic simulations were developed based on the original research proposal. These were concerned with self-escape from a longwall face, rib stability assessment and surface sprains and strains.

Much time and effort was expended on the development of a complete working mine model based on an actual NSW underground coal mine. The model was developed for the self-escape scenario and required sufficient model flexibility such that enhanced self-escape modules could be easily adapted and modified at a later stage. A cut down version of the longwall mine forms the basis for the rib stability scenario and a proposed underground sprains and strains scenario.

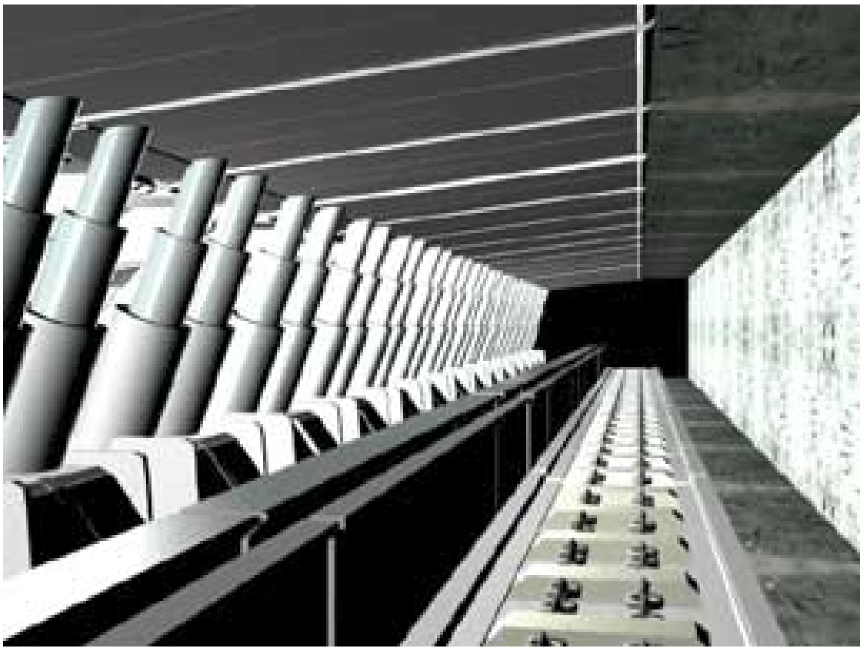

Figure 1 Example screenshot of the Longwall Simulation

The project drew on experience and input from the NSW coal mining industry and all three of the simulations delivered to the Newcastle Mines Rescue Station (NMRS) show basic function specific to each simulation's objectives. The resolution of the simulations is high and the objects and environments do appear as they would in real life. The underground mine is, however, too clean and could benefit from randomness in the simulation as occurs in a real mine - an inherent problem in many mine simulations.

The model development is performed in 3DSMAX and model viewing and interaction is performed through SAFE-VR. The system runs on a high-end personal computer (PC) fitted with a powerful graphics card and 2GB of random access memory. Images are displayed on a rear projected flat screen and interaction is through a joystick and touch-screen user interface.

Producing the model mine required the development of systematic and logical procedures to maintain the flexibility of the model and to ensure that the model objects were interchangeable from scenario to scenario and mine site to mine site. The number of individual objects required for the anticipated levels of interaction is large and using a complete mine as the basis for the self-escape scenario presented the team with some technical challenges. Despite this, some excellent real-time models have been produced that run on a single processor PC. However, the models could benefit from some reduction in polygon count and processing that should be performed regardless of this review.

The scale of interaction and size of models placed in memory and the resolution and fidelity have far surpassed what was achievable or expected on a PC in 2001. The simulation development has benefited from the application of 'off the shelf' components and software for model development and a logical process of object development. Adhering to this approach has provided a foundation for the easy update and modification of software and hardware at relatively small cost during the project. This was one of the key objectives identified in the original concept of the development of a simulator to train mine workers. It also allows for porting of the models to newer software and hardware identified and proposed in this study. That is, existing models will require 'minimal' modification to be utilised on newer hardware and software systems. The UNSW system needs to be ported to more capable computers.

The simulations deployed to Mines Rescue now require greater input from experts in particular fields in mining and education. Such experts now have the opportunity to provide a detailed specification relating to what the learning outcomes should be for a mineworker who interacts with the simulator.

Thus far, the simulations have been developed by engineers and have concentrated on developing technology and procedural developments. The emphasis of the UNSW simulators has been on the delivery of a hi-fidelity mine environment into which trainees may be immersed. This was considered essential from general industry feedback following the initial Feasibility Study produced by Stothard et al (2001).

The use of cartoons and 'stick creatures' was not considered suitable for acceptance into the industry. Indeed, with people's expectations of 3D modelling seen in big budget movies, it was considered essential to make the simulations as real as practicable. An example of the

Longwall model used in the self-escape scenario and the prototype facility at UNSW is shown in Figure 1.

The simulations that have been deployed at NMRS have been observed by industry following their commissioning. The 'Self Escape' scenario is used in every Underground Induction and Refresher Class. The scenario is currently used in automatic mode prior to trainees going into the 'physical' underground mine model for a practical exercise. At present, the module shows a longwall panel and has limited questions and decisions for users to respond to.

Candidates viewing the simulation are very impressed with the new technology and instructors comment, "That it gets and holds the trainee's attention." This is one of the key objectives of using simulation. Instructors at NMRS have also commented that, for the simulation to be maintained long-term changes and additions would be required. This is expected as part of the development process.

Some example enhancements to the self-escape suggested by the instructors at NMRS are:

- Increase the number of questions asked by the simulator as a person self escapes.
- Increase the number of obstacles or decision points.
- Develop a development panel scenario.
- Develop a range of variables e.g. smoke, gases, checking through trap door for fresh air.
- Establish an instructor variable input.

These comments show that the instructors and potential trainees are developing a positive approach to the technology and beginning to develop an ownership of the simulations. This is an encouraging development and can only lead to more and more relevant simulations being produced that are based on real industry experience.

The rib stability scenario provides a system for training that allows hazardous situations and indicators to be identified by the user. However, the indicators used in the scenario need to be assessed in more detail via testing using experienced and non-experienced industry personnel. The inclusion of some sort of remedial action rather than hazard identification may be beneficial. Group discussion of remediation may also be important.

Similarly, the sprains and strains scenario may benefit through replication of tasks that cause sprains and strains in a different software package, as described later in this report. The output from this package can be imported into the simulation and the impact of poor procedure demonstrated more effectively. At the moment, the surface sprains and strains simulation lacks realism, despite containing a human biped model. The lack of realism is due to software limitations that can likely be overcome through the use of updated and new software packages identified elsewhere in this review.

The simulations developed and deployed to Mines Rescue have provided a high-resolution, relatively low cost immersive environment based on a real NSW longwall coal mine. The scenarios have provided a foundation and opportunity for industry personnel and underground workers to visualise and experience a computer generated simulation of the working environment.

The feedback from Mines Rescue is that the simulation engages the trainees. This is a very important comment as the main objective of simulation technology is to do exactly that.

The simulations have benefited from the use of PC based technology and 'off the shelf' software described in the original Feasibility Study. They have also benefited from the use of real mine equipment and plans where the technical issues involved in producing a realistic looking mine that can be easily adapted to sites of different characteristics have been addressed.

The simulations are now at a stage where experts in the mining industry can look at the computer-generated mining environment and ask for specific detail and interaction to be placed at a specific point. Such detail should be derived from the development of a specification that considers the learning outcomes expected from the interaction of trainees with a particular area of the simulation.

Enhancements to the fidelity of the simulations and the scalability of the mine models are no longer restricted by technology. Porting of the models to higher tech systems and interactive 3D software is possible and should be undertaken.

The development of models and scenarios in an academic environment may not be sustainable in its current form using small teams. This is a limitation and a possible remedy is discussed elsewhere in the report.

5.0 CONTINUUM RESOURCES

Continuum Resources produce high-resolution computer generated visualisations. The company is an experienced 3D model builder and has produced visualisation models for industries as diverse as petroleum through to council planning departments and theme parks. Continuum builds its models on the 3DSMAX software platform and renders them to CD or DVD for viewing. Examples are shown in the attached Appendix CDROM.

Continuum is operated as a private entity. Eric Pickstone is one of the primary decision makers. At the time of the visit to Continuum there was only Eric and his colleague present in the office located at Central TAFE in Perth. Apparently, the team size in small, with Continuum using contract modellers to build and program models. The facility is modern and the impression given by Continuum is one of a relaxed concern but professional.

The level of detail in the demonstration CDROMS is very good and realistic. However, when questioned about the transferability of these high-resolution models onto a real-time interactive simulation, the large file size and object size produced by the models was considered a problem and it was commented that some realism would be forfeited.

The cost of development of model objects was difficult to ascertain and when asked about the costs involved to develop a truck model Figure 2, the answer was two days to two weeks depending on the amount of detail and animation involved in the simulation. To be fair to both parties, a formal specification should be used to acquire an accurate quote should Continuum be used for model development.

Continuum has also developed a display engine. An estimated cost for a license for this engine is $12000. The engine still requires further development, however, Continuum has developed a 3D weather model for Channel 9 weather in Perth using the engine. This took 3 months to develop. The source code is available if a developer outside Continuum wanted to indulge in a collaborative development project. The system could be modified to a display and interactive simulation.

The personnel at Continuum were keen to collaborate and would be willing to quote for model development for the simulators being deployed by CS. Continuum has a great deal of visualisation experience and some interaction experience. A concern however is that the team is small and the engine used is still in development and does not have a drag and drop interface. Continuum would be most useful as a contract model builder for the simulations and, perhaps, as a developer of interactive software later in the project.

Figure 2. Example of high-resolution video rendered images produced by Continuum

6.0 CSIRO HAPTIC WORKBENCH

The Haptic Workbench has been developed by CSIRO and is a virtual environment that allows people to see, feel and manipulate three-dimensional virtual objects. Haptic workbenches can be networked together to allow two people at separate locations to see, feel and work in the same virtual space. In the demonstration provided by CSIRO, the Marsfield site in NSW was linked to the site in Perth, WA via their high performance CENTIE network connection. The demonstration showed that a person in Perth is able to physically interact a person (trainee) and the VR world in Marsfield and vice versa. It is a very impressive system.

The Haptic Workbench provides a 3D Image via Shutter Glasses and a monitor that reflects into a 600*300 mirror. (See Figure 3).

According to CSIRO's website (http://www.csiro.au), in a Virtual Environment (VE) the senses are co-located in a virtual space. This multi-sensory experience may involve some or all of the senses of touch, sight and hearing. The Haptic Workbench is an advanced virtual environment that emphasises touch and sight. Users are able to manipulate the 3D images that they are viewing while feeling realistic touch constraints. It supports scientific and industrial visualisation and interaction for data analysis, data sharing, real-time data acquisition and control of computational methods. The Haptic Workbench was developed in the Virtual Environments Laboratory of the Cooperative Research Centre (CRC) for Advanced Computational Systems (ACSys). The VE laboratory is a joint activity of the Australian National University (ANU) and CSIRO.

Since 1997, ANU and CSIRO have worked with a number of Australian companies to prototype hapto-visual applications for the mining and petroleum industries. CSIRO is also working with the Royal Australasian College of Surgeons and MedicVision to investigate possibilities for anatomy education and surgical skills training.

The 3D images in the Haptic Workbench can be rotated through 360 degrees in all directions. The system runs on high end PC (Dual processor 4GB RAM) or SGI based. 'Phantom'. The 'Pen' shaped mouse allows interaction with image and provides the user with force feedback that allows the user to 'feel' the 3D image.

It is a very powerful technology and the demonstration showed the extremely high bandwidth capabilities of the 'CENTIE' network connection between Sydney and Perth. The haptic system costs, around $60000 depending on the platform. The software development is extra.

The technology would be useful in the future for demonstrating hazardous procedures underground where a physical experience of the environment is required. It also finds potential application to the simulated operation ofequipment. An important factor in this system is that an instructor remote to the trainee, that is, potentially in another state, can instruct and physically guide the trainee whilst performing a procedure unfamiliar to the trainee.

The group at CSIRO is keen to collaborate and develop the system. Such interactivity would complement the existing simulators. However, it is a technology that would need to be tested against mining conditions and techniques before incorporation. CSIRO would be useful collaborative partners.

Figure 3. Example of the CSIRO Haptic Workshop Facility.

7.0 NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH. (NIOSH)

Spokane Research Laboratory

The Spokane Research Laboratory is a USA government funded research facility. It presents a very good first impression. The facility is a high quality, well-managed concern. There is the inevitable tight security present everywhere in USA nowadays, however, the facility and its personnel are accommodating and open to visitors once security issues have been addressed.

The primary contact for the Mining VR project at Spokane is Tim Orr. The Mining VR team at Spokane consist of two capable developers who are skilled in VR simulation development and are easy to communicate with. Spokane's experience of Mining VR has been gained through the development of simulations using gaming engines. The group has technical and academic experience, showed a keen interest in the UNSW VR and was keen to share experiences. The second member of the Spokane team is a young technically competent graduate. He has assisted in development of the simulation and was keen to exchange information and assist UNSW.

Whilst at Spokane, an offsite visit to meet to Washington State University was made with the Spokane group. (See comments under Washington State).

Examples of Spokane Research Laboratory's VR are available in the appendix CDROM and a screen shot is shown in Figures 4 and 5. The simulator is a desktop based system and the project's main focus is multi-user mine escape-way training using desktop virtual reality. The researchers have imported mine maps into the software for the purpose of practicing actual evacuation routes and procedures. This is very similar to the UNSW self-escape scenario.

According to Orr (2004), various scenarios for evacuation can be practiced in a three-dimensional computer simulation of the mine in a disaster situation, complete with smoke, fire, and other dangers. Depending on the trainee's job description (i.e. foreman, shift boss, beltman, etc.), certain tasks need to be performed in addition to navigating primary and/or secondary escape routes. Each scenario allows for individual or team-based training, and provides a means to educate the mineworkers in hazard recognition and hazard avoidance.

The simulation is based on the Unreal 3D game engine (www.unrealtournament.com) and the engine is used to develop both the model and its interaction. The engine has excellent graphics – however, the size of model that can be displayed or used needs to be examined carefully. The model has a similar look to the game ‘Doom’ and could certainly be made to look more like a mine with some alteration. The ‘shoot em up’ look of the simulation needs to be modified to remove the game feel. However, the game nature of the simulation software may have a negative impact on the experience gained in the simulator.

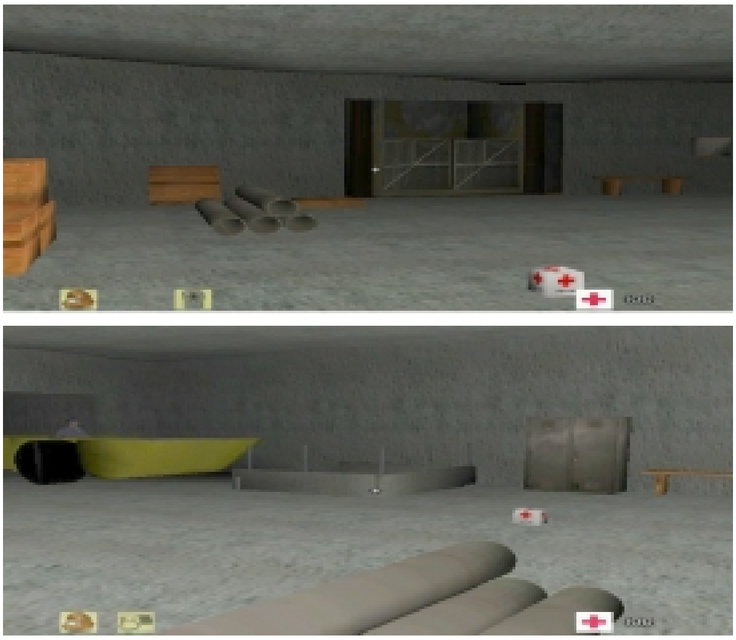

Figure 4. Example screen of the Spokane Training Simulator.

Unreal 3D also has the added advantage of inbuilt multi user networked capabilities and it is possible to interact with the simulation over the web and through a local network. Particle systems within the system appear satisfactory but could be improved. It may be possible to incorporate UNSW’s Mine 3D smoke system.

A developer license costs $500 (US). This needs to be confirmed, as does the nature of the license. Apparently licensing is related to volume of ‘game’ sold. Low volume = low cost. Unreal 3D has its own scripting platform for developing simulation interaction – similar to C++. However, there must be an assessment of the trade off between drag and drop in Safe-VR and Virtools against hand scripting by programmers.

Unreal 3D has a drag and drop interface for world building and lighting and direct import of existing models from 3DSMax is possible with some format modification an optimisation. Unreal 3D is may be useful for the development of further simulations and enhancement of current development of smaller interactive models.

The NIOSH system is dual processor PC based with high-end workstation graphics cards running on Windows XP. The simulation is a mine fire simulation that is an interactive, and network capable. It is multi user and could be operated over a Wide Area Network (WAN). At present, the function in the demonstration is limited and the mine appears to be very angular. However, it does have potential.

Figure 5. Truck hazard simulation developed at NIOSH, Spokane R.L.

The Spokane development team expressed a keen interest in collaboration and would be able to build scenarios from a specification if required. They also had a keen interest in sharing resources and experiences and were interested in the idea of developing and participating in a model and code repository that is open source for mine simulations built in 3DSMAX and Unreal 3.

The idea of an open source model repository is a good one but would have to be discussed with CS, ACARP and UNSW's UniSearch for the practicalities. There would also need to be a formal contact with NIOSH people to discuss the options. This is a good opportunity for technical links and international collaboration and should be seriously considered.

The $500 US cost of a developer license is considerably cheaper than Continuum's engine and is certainly attractive. The licensing issues need to be examined.

The overall budget used for simulation development was not disclosed but it was below the $100k mark.

CDC - Morgantown Research Laboratory

Morgantown is a 'State of the Art' research facility located adjacent to the University of West Virginia. The facilities are modern and high tech in many areas of research. The VR research facility is run and operated by two main researchers. The team provides VR for the research facility when requested. The system used is a four-walled immersive VR environment. The basis of the four-walled environment is shown in Figure 6. The immersive image is projected on the two sidewalls, the front wall and the floor. The image is made 3D through the use of shutter glasses.

As part of the group's safety research, the team have developed a scaffolding and high bay simulation to assess construction workers reaction to working at heights indoors, on outdoor scaffolding and on a roof. The system provides an excellent feeling of height perspective and is high resolution. The system was used for scientific study of human balance in construction workers in real and virtual environments (Simeonov 2002).

Motion capture was performed via a motion plate device that monitored strains in three degrees of freedom and also via a motion capture 'Opto Track' (Northern Digital) device interfaced to the simulation.

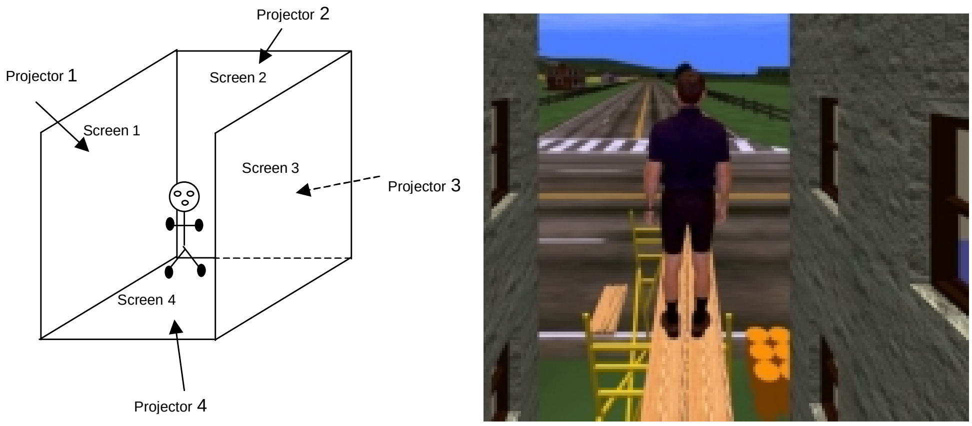

Figure 6. Shows the basis of the four-walled immersive environment.

The original system at Morgantown was based on Silicon Graphics hardware (SGI) and software. The original SGI system cost in excess of $750000 (US), the system has since been replaced by high-end multi processor, networked PCs that apparently run the system easily. The reason for the change was the annual maintenance cost of the SGI system. The figure mentioned was approximately $45000 (US) per year.

The group are also developing visualisations for vehicle development looking at blind spots on backhoes and other industrial machinery.

The researchers at Morgantown made comments on the Human Interaction with their simulations and they presented users with a how do you feel questionnaire after the simulation. The results of the questionnaire were not readily available but the response was believed to be positive.

The team had also used laser scanners to produce a digital human showing the actions of a safety harness under tension when a worker had fallen from a scaffold. Morgantown had used a different type of software called Virtual Jack for assessing ergonomics. Virtual Jack is discussed later. Morgantown has written several papers on Jack.

The team at Morganton were good communicators and professional and were interested in collaboration and development of simulations for mining. Their experience would be extremely useful for a collaborative project looking at human factors.

The demonstrations at Morgantown were mainly visualisations and did not have the type of interaction that would be required for interactive training of mineworkers. However, other factors that require assessment could be assessed with this system. For example, ‘vertigo’ in a restricted vision escape scenario. The necessary interaction could be programmed into the simulations with some time investment.

Pennsylvania Research Laboratory (Bruceton Research Centre)

The research facility at Bruceton incorporates the US Bureau of Mines. It is a quality research facility based around mining and associated activities. At Bruceton, there has been considerable research performed into the safety of mine workers and an example of their work is the publication by Ambrose (2004). The study monitored and modelled variables in the work environment such as operator anthropometry, work posture, choice of risky work behaviour, and machine appendage velocity. To study these variables, a computer simulation package known as ‘Jack’ was used.

JACK is a software package developed at the Centre for Human Modelling and Simulation at the University of Pennsylvania, and is available from Unigraphics Inc. Jack provides a 3D interactive environment for controlling articulated figures.

The software features a detailed human model and includes realistic behavioural controls, anthropometric scaling, task animation and evaluation systems, view analysis, automatic reach and grasp, collision detection and avoidance, and many other useful tools for a wide range of applications.

The cost of Jack is around $50000 (AU) with particular add-on modules starting at around $13000 to $40000 (AU) depending on the application. Information on Jack is available in the Appendix CDROM and at http://www.ugs.com/products/efactory/jack/ .

The study performed at NIOSH was based on the actions performed by operators of a roof bolter. A human model was built into Jack and to capture and validate the model a 'real' model of a roof bolter was built and motion capture recorded for various operators. From this, parameters such as stress and strain on the digital human were calculated and unsafe actions such as hand on the drill steel bit and hand on the boom arm of the roof bolter were identified.

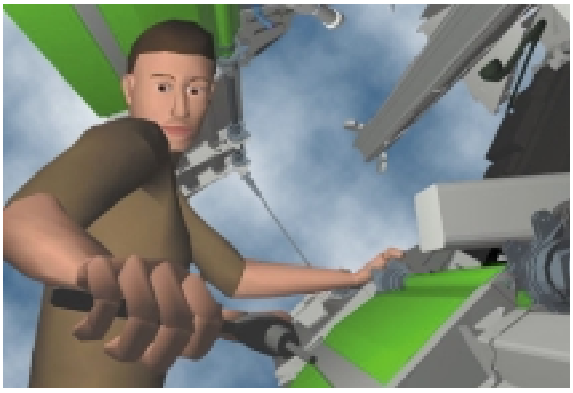

Figure 7. Shows a simulation built using JACK

In short, Jack has the power to mimic human interaction with a machine or environment and show the consequences of unsafe acts. The impacts of these unsafe acts can be demonstrated on the digital human – 'Jack'. This tool would be very useful for the assessment and demonstration of sprain and strain injuries and the potential injuries that can result from sprains and strains. Jack is shown in Figure 7.

The Bruceton Research Centre research group has also developed a Mine Emergency Response Interactive Training Simulation. The system is known as MERITS and provides trainees with an opportunity to gain command centre experience during a simulated underground coalmine emergency. The computer-based training system allows trainees to practice information gathering, situation assessment, decision-making, and coordination skills without physical risk to personnel.

Individuals representing mine emergency response personnel, various state safety officials, and private mine management from four states have participated in MERITS training. MERITS is different to other simulators in that it is a desktop based system that runs in real time as would a real emergency. The system does not have the 3D simulated mine environment that is present with other simulators.

The software relies on the group interaction of team members to ensure a safe escape from the mine. Time delays in the program give the feeling of time and if missed by the group or a particular individual, the computer logs this and if appropriate offers prompts to the team. The simulation is essentially a pen and paper or whiteboard exercise where the team make decisions based on the information given at the time. The system does not use procedural training to provide a means of rescue or evacuation.

Researchers at Bruceton that have worked on this simulation do not believe that people will follow set procedures to escape. They believe that people will primarily rely on local information that is available to them at the time of the emergency. Also, they believe that the day-to-day hierarchy of authority and leadership does not always prevail. That is, leaders under a normal situation are not necessarily the leaders under emergency conditions.

Bruceton also question whether 3D simulation is actually training or an environment experience? This is a good question and warrants further investigation.

Overall, the MERITS system is powerful as a command-room training tool but it is limited in its present for form with regard to its suitability for training underground workers in hazard recognition and safe working procedures.

The Bruceton Research group are interested in collaboration and would be useful people in the development of sprains and strains scenarios and the impacts of these situations. However, JACK should be appraised against other similar programs prior to purchasing a license due to the large cost.

8.0 WASHINGTON STATE UNIVERSITY VRCIM

Washington State has a Virtual Reality (VR) facility contained in the School of Mechanical Engineering. The facility is known as VRCIM (www.vrcim.wsu.edu). The group consists of two researcher staff and a couple of PhD. students. The facility is modern and presents well and the researchers are enthusiastic about their work.

The facility was set up through a joint engineering faculty and industry grant. The collaborators were Kenworth, CAT and a car manufacturer. The original system was built on Silicon Graphics (SGI) equipment and the demonstration showed how vehicle parts can be assembled in a virtual world. The system consists of a three-walled immersive visualisation theatre, a ‘data glove’ containing strain gauges for grip measurement and a pair of shutter glasses. The group also has a flat screen 3D visualisation facility.

The main areas of research are ergonomics for truck cab design, human representation in VR and machine operation assessments. Example screenshots are shown in Figure 8.

The demonstrations showed that vehicle parts could be assembled in VR as they would in the real world thus allowing manufacturing techniques to be developed. The parts used in the simulation are derived from real CAD engineering drawings.

The physical attributes of an object in the virtual world can also be applied - such as gravity, mass and hardness. The graphics in the simulations are reasonable and adequate for the development process that is underway. For a real application such as mining, the fidelity may have to be increased.

According to the group, the original SGI system was expensive to set up at $1m (US) and the continuing maintenance of the system was in excess of $15000 (US) per year. The group has now moved to a PC based system that controls a single 3D screen. This system also uses 3D glasses for stereo.

The PC based demonstrations shown during the visit were ‘standard’ 3D visualisations shown at several other sites. The models did not contain any user interaction and were not really training packages. The demonstrations were good visualisations and would need work to be at the level of interaction required in the simulators deployed at Mines Rescue.

The group showed interest in collaboration and would have some useful experience in developing object interaction for assembly and maintenance of mining equipment. This system would be a useful addition to the future simulators

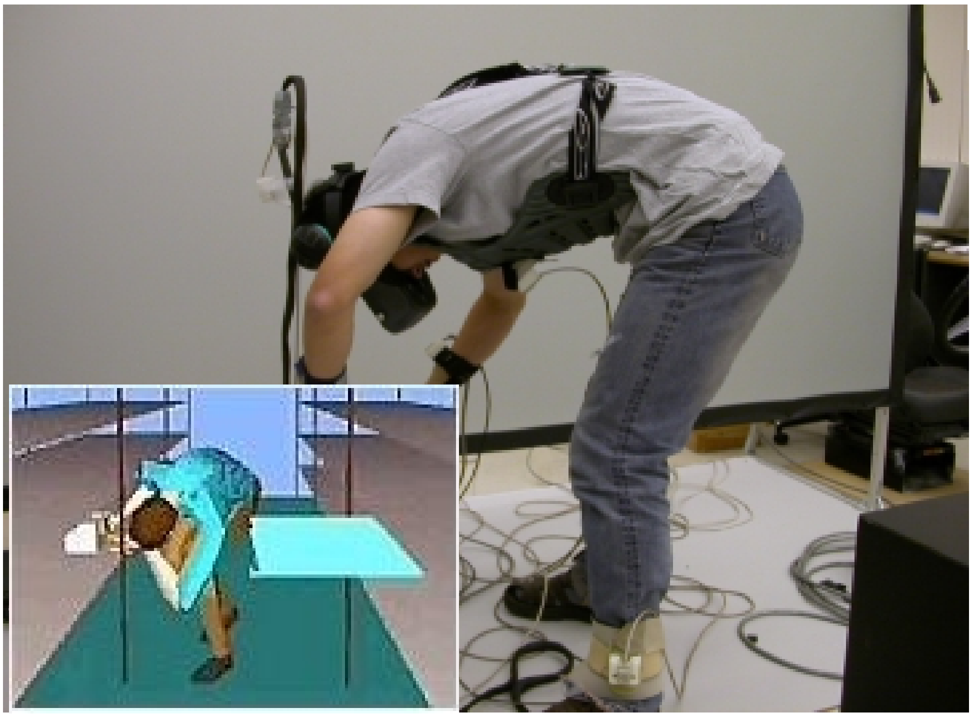

Figure 8. Virtual Human Representation (After VRCIM, Washington State University)

9.0 UNIVERSITY OF NOTTINGHAM VIRART

The Virtual Reality Applications Research Team (VIRART) is based in the School of Mechanical, Materials and Manufacturing Engineering at the University of Nottingham. Dr Richard Eastgate heads the group. VIRART is a multidisciplinary, independent, research and development group with expertise in ergonomics, manufacturing engineering, computer systems, psychology, operations management and computer aided design. VIRART carries out substantial research into design and evaluation of Virtual Environments (VEs) and Virtual Reality (VR) technologies in conjunction with the Institute of Occupational Ergonomics (IOE).

The group concentrate on the development of virtual reality simulations and also on the interaction between users and the virtual worlds. The group has performed several studies on the interaction of people with disorders with virtual environments and also development of virtual environments. VIRART has studied and published several papers on their practical experiences of building VR systems in for example, Tromp et al (2004), Wilson J.R. (2002). The group have also examined the application of Virtual Environments to support learning of Social Interaction Skills (Cobb et al 2002). D'Cruz et al (2002) has described the general process of moving from user requirements to functional and user interface specification. VIRART have many more experiences along similar lines and the experience would benefit the development of the simulators from and educational and human factors perspective.

The VR demonstrations shown at VIRART were PhD student developed simulations and were developed to compliment a specific area of research, for example, equipment assembly. Virtools was used to develop the simulations. (http://www.virtools.com/) Virtools is a drag and drop VR development package that would be useful for simulation development at UNSW.

The VIRART group consists of approximately sixteen research people. The group is drawn from different disciplines and they are an interesting group to talk to. They are a group that has considered VR technology from a different perspective to the 'normal' technology angle and they are primarily interested in the Human Factors aspect. The diversity of VIRART research is shown in Figure 9.

The group would be interested in collaboration but probably not as sub-contractors. They would be useful collaborators for investigating the transfer of training in the development of the simulators deployed at Mines Rescue.

A joint research project with VIRART looking at human factors associated with the transfer of training to mine workers would provide some useful results.

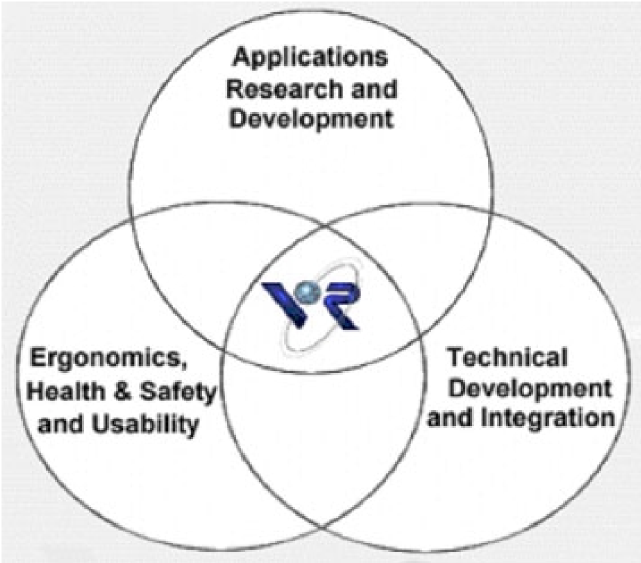

Figure 9. The overlap of disciplines at VIRART

10.0 UNIVERSITY OF LOUGHBOROUGH AVRRC.

The Advanced Virtual Reality Research Centre (AVVRC) facility at Loughborough University is a modern 'State of the Art' research facility. It presents a professional image and accommodates a complete spectrum of VR simulation technology and display techniques. It is very advanced and well funded.

The AVRRC states its missions as being, "To develop effective multi-sensory, interactive human-computer interfaces, through research and academic enquiry. This work encompasses immersive and pervasive computing environments. Underpinning our research is a deep knowledge of the complex human factors issues that pervade all modern human-computer interfaces. "

The AVRRC is sponsored by a group of industrial partners including British Telecom and is equipped with the latest 'State of the Art' Visualisation Dome as shown in Figure 10 and 11.

According to the AVRRC's website (www.avrrc.lboro.ac.uk), the VisionDome® is a fully immersive, multi-user, single projection Virtual Reality environment. The system was developed for interactive space development. When users are placed inside the VisionDome they are drawn into a fully immersive 180-degree hemispheric screen. The screen is tilted and is positioned so that it fills the users' field-of-view creating a high sense of immersion. Users experience environmental sound and images that take on depth via the unique optical system. Users do not have to wear head mounted displays, stereo glasses, or other restrictive devices to experience the VisionDome. The VisionDome is ideal for multi-user, multi-sensory display for simulation, training.

The Vision Dome at AVVRC is impressive technology and the approximate cost of the visualisation dome is around $560000.

The AVVRC also have other visualisation techniques including an immersive wall. The immersive wall is an immersive multi-user, Virtual Reality environment for interactive space development. The emphasis is on wireless user interaction on a three-dimensional image. The Immersive wall is analogous to the system installed at mines rescue except for the 3D component. The immersive wall is further enhanced by an environmental sound system. Wireless handheld devices have been integrated to enable users to interact with information displayed on the screen. It is possible to turn the immersive wall into a mini CAVE system.

The AVRRC have other facilities including high performance computing facilities, virtual reality labs and video conferencing links. A comprehensive description of these facilities is available at http://www.avrrc.lboro.ac.uk. However, many are outside the area of interest for mining.

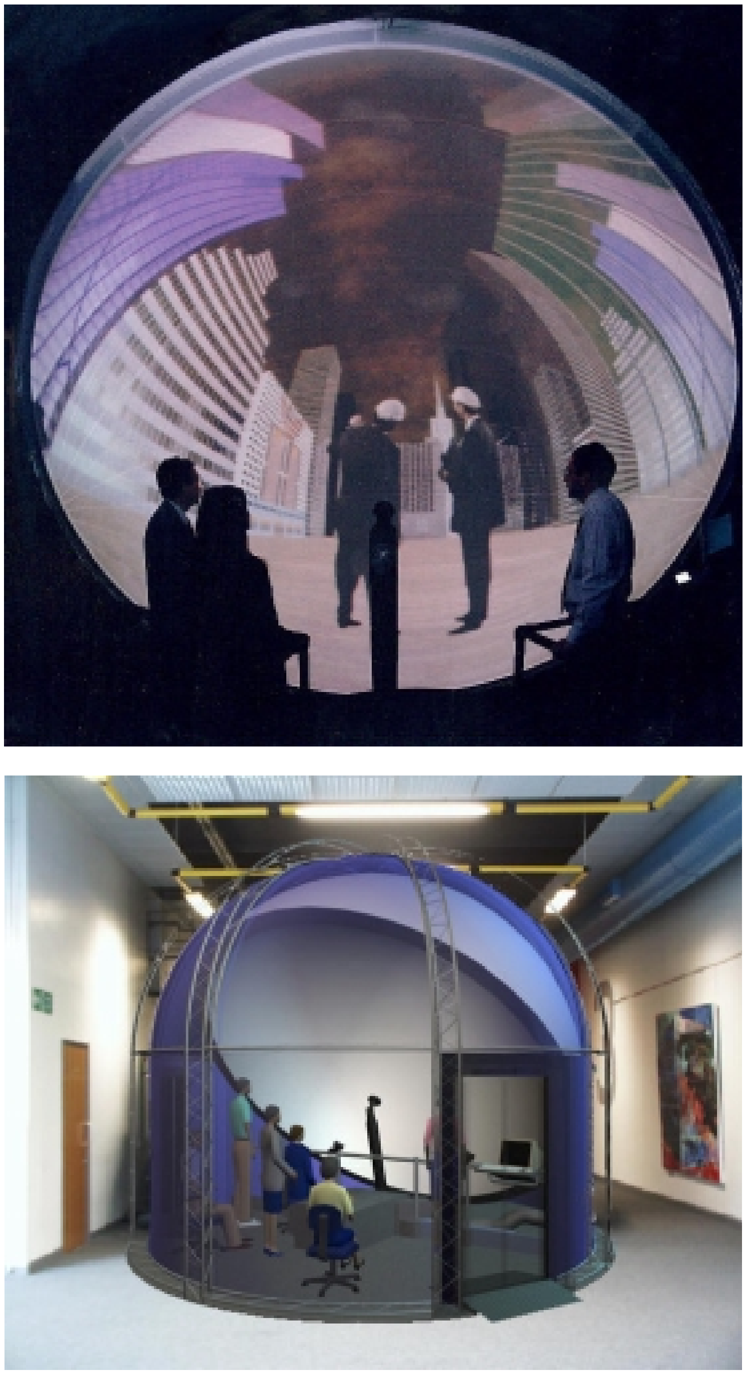

Figure 10. Shows an example of Loughborough Universities Visualisation Dome.

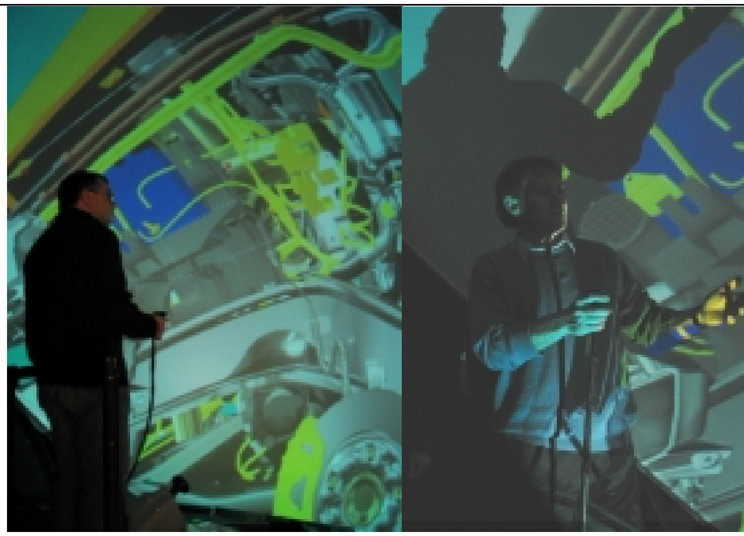

Figure11. A view inside the Visualisation Dome at Loughborough University AVRRC.

The project team at Loughborough is a group of approximately 6 researchers made up of fulltime staff and PhD's. The team is lead by Prof Roy Kawalsky who has developed simulations for the military and aviation. The group at Loughborough originally used Silicon Graphics (SGI) equipment and have found this equipment to be very powerful. However, the group has now moved over to PC based systems due to the cost of maintenance associated with Silicon Graphics (SGI) machines.

The modelling software used at Loughborough is MultiGen Paradigm's model creation software known as Creator. The software is analogous to 3DSMAX; however, Creator has improved optimisation of models for real time VR something that the simulators at UNSW and Mines Rescue would benefit from.

The cost of a commercial license for Creator is $22000 + $4400p.a. maintenance. Loughborough run their simulations in SGI's OpenGL Performer. Open GL performer. OpenGL performer is approximately $1460. Detailed information on Creator and OpenGL Performer is contained in the Appendix CDROM

The group at Loughborough Uni' were interested in collaboration and interested in porting some of the longwall mine simulation to their visualisation dome. They also mentioned that it is possible to view the dome in action with the Longwall model via their video conferencing facility.

The group at Loughborough has a lot of experience and is interested in researching VR technology and the associated human factors. They would be an extremely useful technical and academic collaborator.

11.0 DEUTSCHE MONTAN TECHNOLOGIE GMBH

DMT are a government and industry based mining research and consulting group. The group presents as a very organised and professional organisation. Dr Martin Schmidt has led the development of the DMT/DSK Mining Virtual Reality training system.

The sites visited while at DMT were Deutsche Stein Kole (DSK)'s training facility in Essen, DMT's research facility and EFR-Systems in Dortmund.

The DSK site is an underground Training Mine situated in an old tailings dump. Mine trainees developed the mine over many years. The mine is shown in Figure 12. At the Training Mine the trainees are shown the practical application of their virtual reality training program. For example, training for drill and blast was initiated by a demonstration of a real machine as shown in Figure 12.

The process required to operate the machine has been replicated in VR via a 3D model of the machinery that is interfaced to real machine controls. The software now used to develop the models is EON. EON is a very powerful 3D modelling software package that provides access and interaction with models over the Internet. (http://www.eonreality.com). Figure 13 shows. The aim of the simulation is to provide experience in the positioning and operation of a drill machine. Various machine movements are effected through the use of real machine controls. Force feedback provides the user with an indication of incorrect machine operation. The system is desktop based with the option to show the user screen on the large screen in the VR room. Machine controls are interfaced using USB ports.

The existing 3D models are high resolution and sufficient to convey the operation of the equipment. There is a drilling jumbo model and associated drill and blast equipment. DMT also have a longwall visualisation model.

The VR research group consists of Dr. Martin Schmidt and an Engineer plus contract modellers, approximately four people in total. The simulations developed for DSK have been used to train real mine workers with some tangible results. According to Schmidt and Rossmann (2004), mine workers have increased their average development rate in roadway development after undertaking training in the VR simulators. Schmidt and Rossman also discuss the benefits of access to real-time maintenance procedure database that is accessible underground. This system uses handheld PC's that are intrinsically safe.

DMT site where the research facility is based was also visited. The facility is a similar set up to CSIRO with specialists in different fields (not just mining) working on projects. DMT has shed many people in recent years due to the contraction of the German coal mining industry operators.

EFR - Systems (http://www.cosimir.com) was the third site visited. EFR-System produce Cosimir. Cosimir is a system for the development and presentation of realistic virtual worlds. The system provides a tool for the presentation of 3D applications in an immersive stereoscopic manner. The system can be integrated to head mounted displays, stereoscopic screens and even a CAVE™ configuration depending on the application. 3D simulators have been developed with Cosimir for the training of forest and construction machine operators , Figure 14.

Figure 12. The underground training mine for a drill and blast operation at DSK.

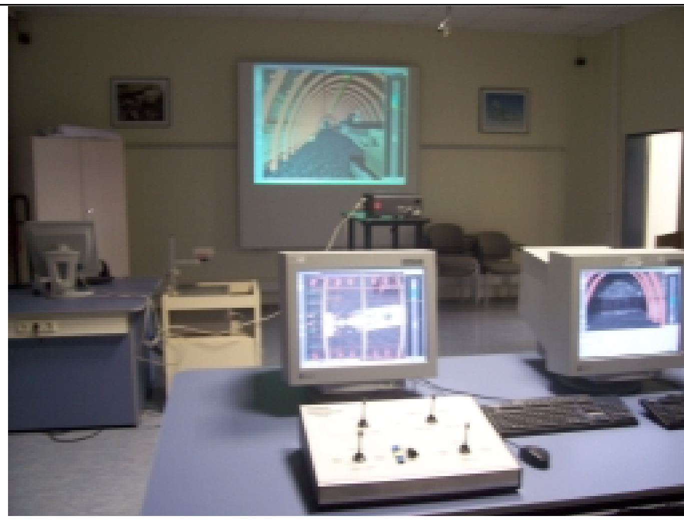

Figure 13. Real machine controls interfaced to the simulation.

Trainings sessions for forestry workers were developed in cooperation with the Neheim Forestry School. Students begin by learning how to control the complete harvester and aggregate and proceed gradually to be confronted with more and more difficult challenges. Initially, the trainees are familiarized with the operator controls. The focus is the efficient handling of the machines.

Once these have been mastered, the training proceeds with an interactive introduction to the capabilities of the on-board computer system and instruction on the management of product lines and contracts. The exercises are selected in such a way that they place the focus on core practical aspects of the training. In contrast to real machines exercises can be repeated as often as required and knowledge and skills developed. Some exercises contain a competitive component so that students can measure their own progress directly in terms of time and points. This approach may be useful for Mines Rescue personnel training.

Cosimir is a tool for the development of a wide spectrum of Virtual Reality applications, ranging from 3D visualisations through to the interactive 3D simulation of complex systems. The system is modular and can be tailored to any application. An example of the Cave environment is shown in Figure 15.

Figure 14. Tree Harvester simulator developed in Cosimir. (After EFR-Systems).

The presentation by EFR-Systems and Martin Schmidt and his colleagues places this group of researchers in a good position with regard to collaboration. They have experience of deploying simulations to the coal mining industry and developing applications that compliment real mine applications. The conditions and environments are very close to those in NSW coalmines and collaborative development of simulations with DMT would be extremely beneficial to the project.

The Cosimir software costs $100K for a development license. Each stereoscopic screen of the EFR-System costs $165K. That is, around $1.2m for an Immersive Cave environment. This system is very high quality. EFR systems could also bring some excellent experience to the project. Cosimir and EON should be assessed in more detail from a systems analyst aspect to assess their true potential.

Figure 15. EFR-Systems Cosimir ‘driven’ Immersive Cave Environment.

12.0 RAILCORP

The facility at RailCorp's Petersham Reality Training Centre is a multi million-dollar facility containing 'State of the Art' visualisation and driver training facilities. The facility is Federal Government funded. There are several Silicon Graphics (SGI) 'Reality Training' rooms with at Petersham. An example of the RailCorp simulator's resolution and facility is shown in the Figure 16.

The equipment and simulators at RailCorp are developed by SGI. The simulations have been under development for around five years and present high quality railway infrastructure simulations. The simulations cover driver instruction where the driver interacts with the locomotive controls as he or she would in a real situation and station and day-to-day operations. Various railway operations procedures are included in the simulations and the trainee receives instruction on the procedures prior to undertaking the training on the simulation. That is, the simulation tests the trainee's understanding of a situation and what procedures should be followed in a certain situation. The variables in the simulation are set by instructors on a daily basis.

The simulations are not interactive in the way that the simulators at Mines Rescue are, that is, the simulator does not ask the trainee specific questions about a scenario. In the case of accident or incident simulation, the simulation is used as a high quality visualisation of a scenario. After the group visualisation there is then a group discussion of the situation and how the scenario could be dealt with in the real world. Questions about the choices made and what would be better choices and outcomes are dealt with through group discussion. This may be useful for underground mining situations - especially self-escape and rib stability.

The human factors associated with the simulations introduced at RailCorp have also been studied. The results of this study are yet to be published and should be available later in the year. Some of the human factors considered and discussed at the visit were that the simulations were found to be – in some instances – too graphic. As a result, the simulations are 'faded out' as a graphic point relating to an incident is made. This is because some drivers and station staff have experienced such incidents in real life and can find the graphic realism of the simulations produced 'too real' and reminders can be traumatic.

The demographics of the workforce at RailCorp is analogous to the NSW Coal industry where many of the workers are in they're mid-forties or older and sometimes reluctant to embrace new technology. Getting them to assess and identify risk on tasks that they perform on a daily basis and which they have performed for sometime was met with some scepticism. However, the workforce has adapted to the technology and now see it as a positive experience and embrace the technology as an excellent alternative to 'chalk and talk' lectures.

Figure16. Example of RailCorp's Locomotive Training Simulator

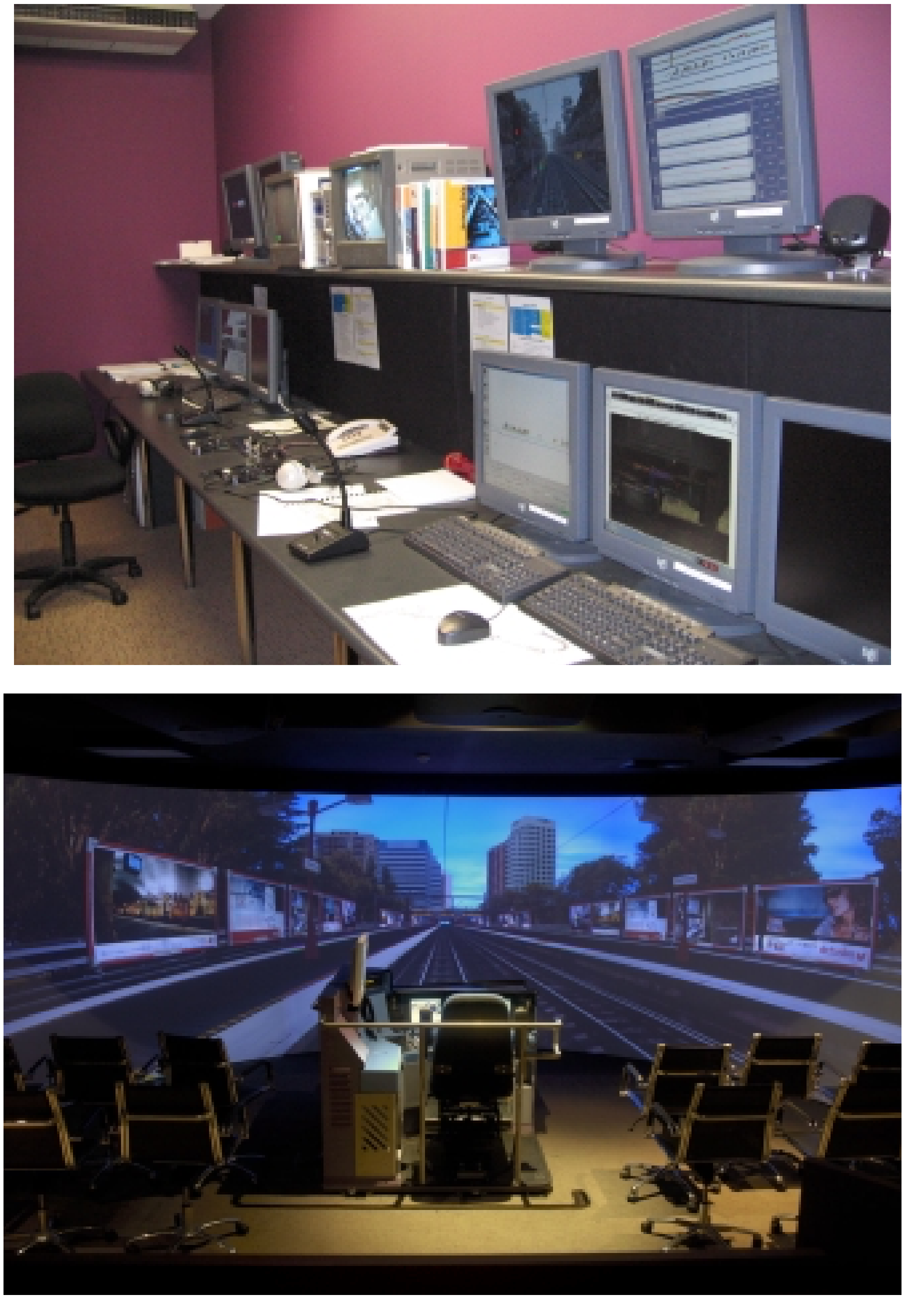

Figure 17: RailCorp's simulator control room

The system used at RailCorp runs on SGI hardware and software and a fulltime SGI computer technician is required to maintain and run the system. Several instructors run the simulations 'classes'.

The simulations are run on a mixture of flat 2-D screens viewed from inside a functional railway locomotive cab and a large curved screen simulation again interfaced to locomotive machine controls (Figure 16 and 17). The cost of the complete facility was in excess of $15m dollars including building and rooms. The cost of hardware to produce a curved screen interactive simulation running on SGI's '4 pipe' prism is around $150K per machine plus simulation development. The system needs four digital projectors to run the simulation at a cost of approximately $50 each ($200k). The curved screen is an extra cost and depends on the screens specification (can be up to $100K). The manufacturer's equipment controls are also an extra

The total cost for the 'State of the Art' system used at RailCorp would be approximately $500K per system. Systems at Petersham use rear screen projection and curved screens are not really suitable as transportable facilities.

The experiences gained from training railway workers would be extremely useful in developing simulations for the coal mining industry.

13.0 SILICON GRAPHICS

Silicon Graphics is a world-renowned, computer-system developer that has specialized in developing scientific and engineering visualisation machines for industry. The architecture of SGI machines is very different from personal computers (PCs) and as such they are generally more reliable and able to manipulate much larger data sets such as large polygon counts inherent in 3D real-time visualisation.

The simulations being developed by Coal Services, ACARP and UNSW for deployment into the Mines Rescue Stations are being continually developed at the limits of PC technology and while the systems are coping, as more and more complex scenarios are developed and objects are made to look more and more photo-realistic, the limits of PCs will be realised.

Figure 18. Shows the Prism system and the immersive VR facility that can be developed.

In the original scoping study, SGI machines were placed out of the reach of the project due to budget constraints and the manner in which it was intended to develop the simulations. However, since 2001 and in particular in the past few months, there have been significant changes in the way that SGI machines are offered. Many of the tools used to develop simulations did not easily port to SGI equipment and the operating system and architecture was closed in general. Also, the machines were extremely expensive when compared to PCs.

The direction that SGI has now taken is to use the Open Source operating system Linux on their systems. Linux benefits from there being no or very little licensing issues. There is access to a wide community of developers and many of the systems used for interactive simulation development and deployment are being transferred to the Linux operating system.

SGI have also reduced the cost of their machines and the associated maintenance costs that many researchers visited in this review considered prohibitive. An example of the current SGI equipment known as the SGI Prism family is shown in Figure 18 and has a specification that would relieve many of the memory limitations that the current and future simulations will experience if deployment continues on PCs – moving to multi processor PCs and networked PC graphics is an option by may also be a short term option. The differences in SGI and PC machines are highlighted in the SGI white paper, "Choosing a Visualisation System for Your Organisation." A copy of this document is located in the Appendix CDROM.

Table 4. Shows the system feature and benefits of the SGI Prism system.

Feature	**Benefit**
World-leading Architecture with NUMAflex	
Modular and Scalable	Seamlessly and independently scale system resources (CPU, I/O, memory, storage, graphics) to meet customer visualization needs
Global Shared Memory	Eliminate time consuming data preparation by interactively visualizing vast data sets using a single, system-wide, shared memory
High Bandwidth, Low Latency	Increase productivity by achieving maximum performance on all your data with SGI world-leading 6.4GB/second interconnect technology
Open and Industry standards components	Leverage innovation with industry and open standards components - Intel® Itanium® 2 processors, ATI® FireGL™ graphics, and Linux®
Scalable Graphics Compositor with dynamic load balancing	Increase performance and image quality by combining the power of multiple GPUs
Complete Visualization Ecosystem	
Visual Area Networking	Transparently access and share data and resources from cross-platform clients connected across modern networks for efficient collaboration
Reality Centre® Facilities	Achieve accelerated team insight with the ultimate in immersive environments
QuickTransit dynamic translator	Run existing IRIX® applications*
Comprehensive Development Environment	Exploit the power of true scalable visualization with a host of OpenGL® visualization tools and APIs, including OpenGL Performer™, OpenGL Multipipe™ and OpenGL Volumizer™

The Prism is still considerably more expensive than a standard PC however, the system is modular and can be added to and improved as the need arises. The basic system that starts at $42K would run the current simulations. For an immersive 3D environment, computer costs would be around $100k to 150k depending on specification.

An example of the specification of the Prism is shown in Table 4 below and the SGI product brochure in the Appendix CDROM.

One of the important features of the SGI Prism system is the Visual Area Networking (VAN). This allows PCs and laptops, to interact and display massive models over a standard network connection. Processing is performed on the Prism and updated on the PC. The interaction is with the 3D environment is two-way.

Silicon Graphics offer more expensive solutions for visualisation however, there systems are robust and higher quality. They are also now easily updateable albeit at increased cost. The move from PC Windows based systems to SGI/Linux should not be dismissed as an option and it should be seriously considered as a future means for continued development of the simulators.

SGI machines are considered in the options section that follows.

14.0 OTHER CONTRIBUTORS

University of Queensland

The Institute of Sustainable Minerals Industry, Advanced Computer Graphics and Virtual Reality Research Group at the University of Queensland has developed several VR applications for the minerals industry and Minerals Council.

The group that includes Dr. Mehmet Kizil has produced applications for data visualisation education and training, environmental monitoring, accident reconstructions and risk analysis.

The systems are based around Safe-VR and VRML software and run on desktop PCs and Laptops. The training programs include mining operation visualisations, mine ventilation training, roof bar down and environmental monitoring applications.

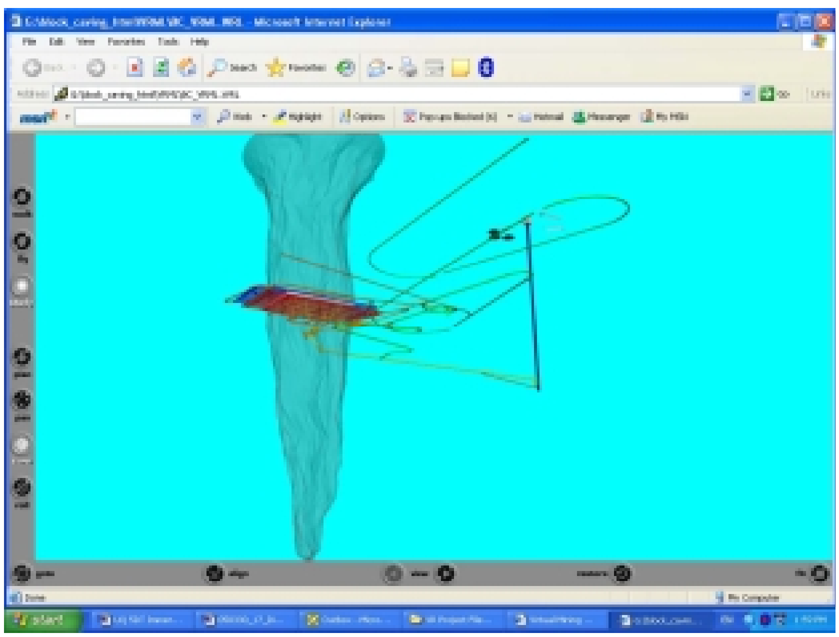

Figure 19. UQ. Block caving model based on VRML

The resolution of the simulations is good (Figure 19) and the models also describe mining methods and a set of rock mechanics laboratory experiments. The models are for teaching students about mine conditions and indicators. For example, the ventilation simulation demonstrates airflow as ventilation doors are opened and closed.

The UQ simulators are well designed and developed. However, the interactive VR simulations only appear to consider certain aspects of a mine with predetermined outcomes that a student can achieve through interaction with the simulation. The models are built in Safe-VR and are similar to the UNSW simulations in their format. However, the aim of the simulations and audience is different to those being developed at UNSW.

Aims Solutions

Aims Solutions were the developers of Safe-VR. This was the software used in the original development of the simulations. Contact with AIMS Solutions revealed that Safe-VR is no longer under development.

Since 2001, AIMS has moved outside the University of Nottingham Framework and was unwilling to participate in the study. They also did not respond to a query regarding collaborative development.

5DT (Fifth Dimension Technologies)

5DT is a high technology company specializing in Virtual Reality (VR). 5DT develops, produces and distributes VR hardware, software and systems. Their main focus is VR Training Simulators and VR Peripherals.

Their products include VR Hardware, Animation Software, Development Software, Systems and Application Software.

Most products and systems may be customized to suit the specific requirements of a user. 5DT also develops Turnkey VR Systems and Solutions for clients.

5DT produce a Continuous miner simulator priced at $95000, A Haul Truck Simulator, Wheeled Loader Training Simulator, and Dragline Training Simulator. The costs of these are not listed.

Contact with 5DT was not responded to and attempts to order a demo CDROM failed.

5DT were contacted in the original study, since then they seem to have expanded into the simulation markets outside mining including the sale of peripherals and equipment.

Immersive Technologies

Immersive Technologies have produced a variety of mine equipment simulators for driver and operators. Products range from Draglines to Haul trucks and Immersive are likely the leaders in the field of equipment training simulators for driver training.

Immersive Technologies offers transportable and semi-transportable base simulators. Both configurations are ready to provide training for an extensive range of machine types by fitting different modular Conversion Kits.

Immersive were contacted as part of this review, however, they declined to participate.

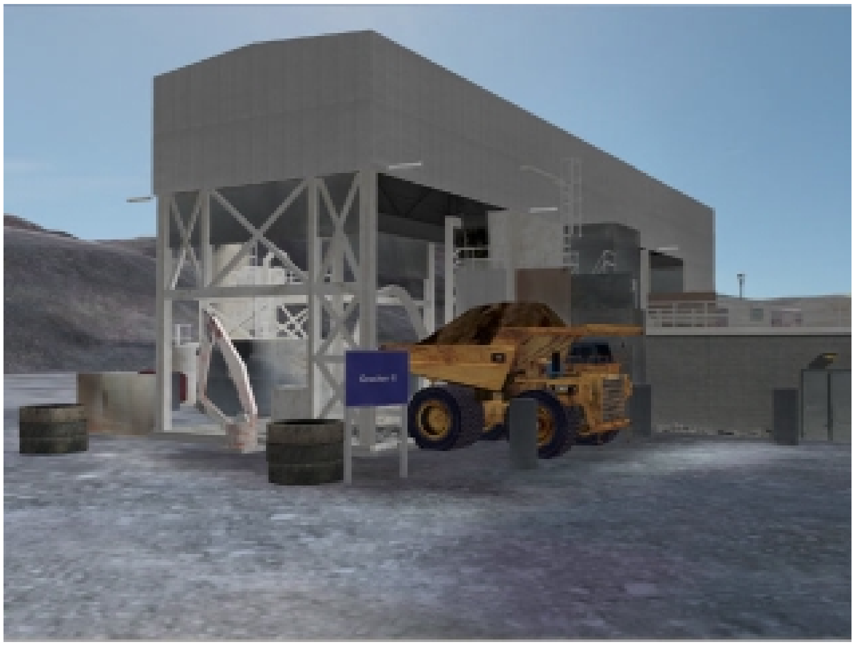

Figure 20. Immersive Technologies Haul Truck Training Simulator

The Immersive website claims that

"An operator trained in a Virtual Environment is more confident navigating and working in the actual training or work area once training is complete, ensuring maximum productivity and safety from the moment they move into a real machine.

Your Virtual Environment is a digital replica of your actual training/work area. The learning and retention rate of your operators will be enhanced as they travel through their own environment, in real time. Advance your productivity and safety without risking injury to operators or compromising real machines.

Operators trained in a Virtual Environment are more confident and assured of their ability once they step into an actual machine. An Immersive Technologies representative will visit your site in order to identify your requirements and collect the data needed to create your Virtual Environment."

This is one of those bold statements that need to be quantified through a formal study of the transfer of training and skills gained in simulators through to the workplace.

15.0 SOFTWARE DEVELOPMENTS

Since the original scoping study of 2001, there have been significant advances in software suitable for the development of VR simulations. Model and interactive content development software is very advanced. The more popular systems offer drag and drop interfaces and require little of no command line programming.

This section discusses some of the Software systems available for the continued design and development of the simulations. Detailed information on the software is included in the Appendix CDROM. All of the software listed below should be evaluated in a formal manner prior to purchase.

EON Software

EON is produced by Eon Reality Inc. (http://www.eonreality.com)

The software offers a drag and drop interface and many useful features as described by the EON brochure in the appendix. The information below is taken from the brochure.

Key features

EON Visual Effects ,creates ultra-high quality and flexible shading by taking advantage of the latest Cg shader technology available on the latest generation of graphics cards programmable GPUs. Advanced materials include phong-shading,

bumpmapping, darkmapping, cubical environment maps, HDR image-based lighting, leather, wood, fabric, NPR (non-photorealistic) hatch shading, and, furthermore, complete custom materials can be created using the generic CgMaterial node by writing your own Cg-programs.

EON CAD, support for more than 120 3D/2D file formats including native

support for CATIA, UG, Pro-E, STEP, Microstation, Alias and Maya.

EON Physics, support for kinematics, mechanisms, new collision algorithm, gravity, friction and dynamics.

EON Human, library of humans with motion and native import for Real

People format.

EON SDK, Software Development Kit with support for new visual node sets,

many more samples and improved user documentation.

The cost of a license for EON Software is $4794.94 for an Academic license $9589.88 for a commercial license. Additional modules are required depending on the application so this price can probably be doubled to $19000.

Virtools Software Suite

Virtools is a drag and drop simulation software development package analogous to EON. The following information is taken from the Virtools brochure. A copy of the brochure is available in the Appendix CDROM and at www.virtools.com .

Virtools™ Dev includes these key components:

A Graphical User Interface to develop sophisticated applications by visually assembling objects and behaviours. A Behaviour Engine to run interactive applications. A Render Engine to render graphics in real-time. The Virtools Scripting Language to create low-level specific functions without any C++ line and the SDK to create custom behaviours.

The Virtools software is a powerful system with many features that would benefit the development of mining VR applications.

The cost of Virtools is $16000 for the development environment and various add on modules to provide the correct levels of interaction with the simulations would be approximately $10000 each.

Total cost would be around $26000.

The benefits and function of EON compared to Virtools should be investigated further through a formal comparison using the existing mine models and equipment models.

MultiGen Paradigm Creator

MultiGen Paradigm has developed the Creator product series that provide a 'what you see is what you get' interface for 3D developers.

Creator has a drag and drop environment and the smallest detail can be controlled. The system allows level of detail in simulations to be set for efficient rendering of images in real time. The software has an open flight option that provides a 'fly through' of the 3D world prior to export. Creator allows extremely high fidelity models to be produced and efficiently exported to a viewer. Ita also contains Terrain modelling capabilities.

The cost of Creator is $20000 + 4000 p.a. maintenance. Creator should also be formally evaluated against EON, Virtools and 3DSMAX.

The specification for Creator is included in the Appendix CDROM and at www.multigen.com

Open GL performer

Open GL Performer is developed by Silicon Graphics and the description below is based on their information. Further information is available at www.sgi.com .

OpenGL Performer is a powerful and comprehensive programming interface for developers creating real-time visual simulation and other performance-oriented 3D graphics applications. It simplifies development of complex applications used for visual simulation, manufacturing, simulation-based design, virtual reality, scientific visualization, interactive entertainment, broadcast video, architectural walk-through, and computer-aided design.

OpenGL Performer provides the advanced features and innovative techniques that enable developers to make optimal use of system capabilities and sophisticated 3D graphics features. It provides the capability to scale easily to multiple processors and multiple graphics pipelines, deploy to a wide range of systems and price points, and be ready-made for the graphics systems of the future.

OpenGL Performer is built atop the industry standard OpenGL graphics library and, includes both ANSI C and C++ bindings. It forms the foundation of a powerful suite of tools and features for creating applications on all Silicon Graphics systems and 32-bit Intel based systems with Microsoft® Windows® 2000 or Windows® XP.

OpenGL Performer is an integral part of the Silicon Graphics Prism™ visualization systems and visual workstation simulation solutions from SGI. Performer is the flexible, intuitive, toolkit-based solution for developers who want to optimise performance on SGI systems.

The cost of Open GL Performer is $1470. Open GL Performer would be a powerful viewer due to its 'standard' multi pipe graphics capabilities.

Unreal 3

Unreal Engine 3 is a complete game development framework targeted at today's mainstream PC's, Microsoft's Xbox game console, and Sony's PlayStation 2.

Its production-proven tools and feature-rich code base enable a game development team to begin authoring all aspects of a product from day one: including art, models, levels, gameplay code, user interface, and new features.

The system is available on a low cost licensing fee of around $500 US. The general rule is low volume low cost. The engine contains a drag and drop interface for model building and a scripting editor interaction. However, the engines ability to handle massive mine models and complex interaction rather than ‘shoot ‘em up would need to be formally analysed. Also, it looks too much like a video game that may present the wrong impression to users?

Examples of Unreal 3 development procedures and licensing can be found at www.unrealtournament.com/general/university.php

The above are examples of model development software used at each of the sites visited and by other VR developers. These software systems should be evaluated and added to the library of software currently being used. The packages should be used to replace Safe-VR and provide more powerful tools for developing the simulations.

16.0 DISCUSSION

The aim of this study was to identify and research advances in Virtual Reality Technology and Techniques since 2001 and make an assessment of the "State of the Art' of VR Technology that would be useful for the continued development of simulators to train mine workers.

This report summarises the systems at the various VR research groups visited as part of a look-see tour. The study tour revealed that the technology is extremely well developed and that almost any environment can now be simulated to a high level of detail and interaction.

Several groups around the globe are developing simulations that relate to mining and heavy engineering. These range from commercial concerns that are developing 'modular' driver training simulators that compliment the operation of 'multi-million dollar' mining machines to other groups that are developing simulations for the display of exploration data. The cost of these simulators is small when compared to the overall cost of a complete fleet of trucks, railway infrastructure or oil exploration. These systems range from \$100K's s to \$1m's to implement.

At the other end of the spectrum, some groups have focussed on education and training of mining students and have used desktop based systems based on proprietary software and games based visualisation engines to produce some useful VR training packages. These are generally much lower cost than a system that mimics the operation of a piece of mining equipment. The costs of these simulations fall generally below the \$100k mark. The results achieved by these researchers are impressive considering the low budgets. The levels of interaction required and the handling of decision points in the simulations make this a challenging area of simulation development and an area for further research.

The middle ground is where the majority of groups fall and where the simulators developed by Coal Services, ACARP and UNSW fall. That is, between \$100K and \$1m. This section is where the costs generally reflect the level of immersion, interaction, realism and the type of technology used. The systems range from single processor PCs producing an immersive environment on a large flat single screen through to multi-screen cave environments running clusters of computers or Silicon Graphics (SGI) machines. System complexity increases with the number of screens used and the use of 3D imagery as does cost.

The two main platforms used for the development of VR applications are the IBM personal computer platform containing high-powered graphic cards, large amounts of memory and running Windows and Windows based programs for the development and display of VR worlds, and the Silicon Graphics (SGI) based systems running on UNIX. Recently however, SGI have begun to utilise Linux. This is an important break through for the future of simulation and its importance on computer simulation should not be underestimated.

In the recent past, and indeed this report shows that there has been a migration of developers from SGI based systems over to PC based systems. However, this trend may be about to reverse due to SGI adopting Linux. Linux is an Open Source license free operating system based on UNIX. The system benefits from collaboration of developers and programmers around the world.

Most of the systems reviewed and experienced during this study were of high quality and high fidelity. They have been developed to perform studies ranging from miner emergency escape training through to the assessment of repetitive tasks on mining machines that may cause injury over prolonged periods. Researchers at some sites have considered the human factors associated with VR training and the importance of this should also not be underestimated.

A comment made by researchers at several of the sites visited was that there is a stigma attached to the term Virtual Reality because the technology had not delivered all the promises made by the hype and the term can impede funding or people's acceptance of the technology because it is seen as a game. The suggestion was made that the description/name of the technology should be changed to something along the lines of "Interactive 3D Training Environments" or "Computer Generated 3D Environments". This is a comment that should be considered for the existing facilities at UNSW and Mines Rescue.

Travelling to different sites that develop simulations was useful from the point of view of determining the facility's operational principles and gaining a picture of the organisations that encompass the research groups. The groups in many cases were small teams of generally two to five people who were funded from within a larger organisation or research entity. That is, a University, Government Research establishment or University 'spin off' company. The organisation of commercial developers (except Continuum resource) was difficult to ascertain due to their reluctance to participate.

From the study, it appears that the small non-commercial groups that are dispersed around Universities research organisations have difficulty in maintaining funding to further develop their systems and, indeed, in many cases the simulations that are developed are not developed with a saleable commercial product in mind. This is a factor that should be considered in the sustainability of the current simulators. That is, further simulation development may have to be moved to a more commercial footing.

The simulations that were experienced were all developed to either visualise an environment or transfer some idea or concept to the user. In many cases, there was an assumption that the training delivered to the user was a positive experience. This raises the question of transfer of training using simulation. The simulations have been developed by engineers to show – in most cases - a high-resolution representation of an environment. The simulations are of extremely high quality. However, at many of the sites, the educational value and quantitative assessment of the users interaction and the knowledge and experience gained were unclear. It is relatively easy to quantitatively monitor a trainee progress in a simulation.

To add value to the experience gained in the simulation, adult educational experts should be consulted as to the method that tasks are presented and assessed in the simulations. A formal study of the transfer of training in the simulated environments in mine workers in NSW (and a control group) should be performed over the largest available population. The simulators at Newcastle Mines Rescue Station have access to such a population and a great deal of value could be added to the simulators if such a study was performed. Groups like VIRART at Nottingham University have considered these aspects and would be a useful collaborative partner.

The development and production of models in the simulation is also a mature process. The use of manufacturers drawings, real procedures and mine plans provide material that can be incorporated into models. However, it appears that only UNSW has built a model based on a complete underground mine with the aim of developing a generic mine that can have mine specific data attached to objects in the simulation. Other developers have built sections of mines and based their models on real training mines. DMT and NIOSH had the most relevant mining model and DMT's VR model of drill and blast operations is in a form that maybe directly transferable to the UNSW coal mining industry. DMT would be extremely useful collaborators in the further development of the simulations.

There are many modelling tools available now that speed up the development of simulation models and objects and the most common appears to be 3DSMAX. 'Creator' is also used for model development. Similarly, there are many tools for visualisation and interaction of the 3D models. The main tools used are EON, OpenGL Performer and Virtools. The specification of these systems is located in the Appendix CDROM. These systems are relatively inexpensive especially when considering what they actually provide.

The question of sustainability at some institutions is an important factor; many teams are small in number and are located in organisations where they are very small when compared to the entire organisation. When it comes to funding projects they are insufficient in 'weight' to move development along and this results in systems suffering from the lack of money and personnel to develop them to their true potential. This is where larger commercial organisations have the edge. They have the resources and people to dedicate to a project and deliver a product in a shorter time frame. Again this indicates that a commercial aspect to the development of the simulations should be considered.

The next stage of development of the simulations should be through closer collaboration of consolidation of researchers. Potentially, all the researchers and developers visited in this study could provide resources and experience in the development of the simulations for the coal mining industry in NSW. Groups such as NIOSH and DMT have a great deal of mining experience to offer and VIRART have experience in transfer of training and development of VR interfaces. AVRRC has much experience of technology and also human factors in VR. RailCorp have an experience that is very close to the mining psyche and would be very useful collaborators.

At the present, there is no real standard or repository for mine models and equipment. There is also no standard for the development of models. Similar types of software packages are used from centre to centre for development; however researchers are in some cases developing similar systems in parallel. The mining simulations should be brought together as a collaborative development.

The use of commercial model builders – e.g. Continuum Resources– programmers and contract mining experts would also lead to the more rapid development of scenarios. The current set up at UNSW, DMT and NIOSH is satisfactory to prove the initial concept and develop small models, however, it may be too inefficient to use on a larger basis and where complex scenarios need to be developed quickly.

The next stage of development and deployment of simulators should where possible encompass the experiences and systems of the researchers included in this review, particularly DMT and NIOSH. However, the logistics and practicalities of this type of collaboration should be carefully considered. Division and delegation of the tasks may be difficult to manage but is not unsurmountable. A development model would have to be introduced that suited all parties. This should be formally scoped out and the issues identified.

The centralisation of the production of models for the simulations and standardisation of the interactive software used in the simulations would mean that the development of simulation technology suitable for the mining industry remains feasible and sustainable. The input from several 'independent' sources would also be beneficial from the point of view of sharing experiences. The key would be standardisation of the software and systems across the industry.

Since 2001, UNSW School of Mining Engineering has become an experienced developer of VR simulations and the systems it has produced are technically robust. The original scoping study of 2001 identified technology that has since been superseded. Nevertheless, the system provides a good platform on which to continue development. The existing hardware and software can and should continue to be used. However, the recommendation is that the existing technology be upgraded and models ported to a newer sustainable system that contains more flexibility.

Overall, the 'State of the Art of VR Technology in 2005' is extremely advanced when compared to 2001. Many of the obstacles have been removed and the reliability of equipment and quality of mine models is high.

Recommendations for the systems and options that should be used in the future development systems are presented in the following sections.

All of the groups have experience to offer the future development of the simulators at UNSW and Mines Rescue. In the first instance, serious consideration should be given to developing formal links between DMT, NIOSH and VIRART due to their mining simulation experience.

17.0 TECHNOLOGY SELECTION AND SUSTAINABILITY

This 2005 Scoping Study has identified technologies, techniques and research groups involved in immersive, interactive simulation research and development. The study shows that the technology to manipulate the memory intensive models inherent in 'whole mine' simulations is readily available and mature.

The system installed at UNSW and at NMRS is placed towards the lower end of the cost scale with the aim being to keep the system modular, easy to maintain and readily updateable. This is a key factor to its success; however, the system has reached the limits of what is achievable with the current technology.

A system is required that will allow the simulators to be sustainable and evolve over time. The study has identified three sub-elements that need to be considered, namely:

- Computing Platform
- Visualisation Platform
- Development and Maintenance Capability.

Computing Platform

A significant development has occurred since January 2005. That is, Silicon Graphics machines that were out of the reach of the initial project have released more realistically priced machines that run Linux - a 'user friendly' license free operating system.

There have also been considerable advances in personal computers (PCs). Nevertheless, there are memory and processor limitations in PCs that are not so pronounced in SGI machines. Many PCs can be networked together to provide a larger processing power. However, there is latency between networked PCs that is much less pronounced in SGI equipment due to their different architecture.

All of the existing models, equipment and infrastructure installed at the Newcastle Mines Rescue Station can remain in use. The models that are run on the current system can be migrated to the SGI system. Model development can remain on the existing equipment and software. The interactive component would have to be migrated to a new viewer as the current system (Safe-VR) is no longer in development and the limits of its capabilities have been reached.

Another advantage of the SGI Prism based system is that it has a facility known as 'VAN' or Visual Area Networking. This facility allows the simulations to be run from the main SGI machine at the Mines Rescue Station and interaction can be achieved through PCs and laptop systems in real time. All rendering is performed on the main machine and an interactive 'video image' is displayed on the PC or laptop. The system can run at reasonable speeds over a standard 100mbs network connection and much faster over a broadband connection. This may be an option for more mobile simulations.

There may be a significant cost advantage, in any case, in moving to a SGI prism based system. This is because one Windows license is required for each PC. Hence, the cost of running multiple PCs could quickly match or exceed the cost of running a SGI Prism.

Table 2 summarises the cost associated with a SGI based platform for developing and running simulations.

Table 2: Estimated computing hardware and software license costs.

High end PC's for model development.	$15 000	Graphics Workstations
3D Modelling Licenses	$48 000	3DS Max or Creator
Interactive Viewer Licenses.	$30 000	EON Studio, Virtools or Open GL Performer
Sprain and Strain Software	$62 000	JACK
SGI Hardware	$300 000	Two SGI Prism Computers
	$455 000	

Visualisation Platform

The study had identified two visualisation platforms which are best suited to present day simulations. These options comprise technology that can handle the large models required for high-fidelity mining simulations.

Option 1

The current format at UNSW and NMRS is a flat screen with interaction via a touch screen, Figure 1. This technology format is not fully immersive 3D. However, with some replacement and upgrade of equipment, it could be made fully immersive and incorporate the use of 3D shutter glasses or similar technology. This would, in particular, improve the realism of the Rib Stability scenarios.

This option essentially makes use of the existing projection screen facility. However, it will utilise a different projection and computer hardware to give a more immersive experience.

The estimated cost of technology and software to upgrade the existing facility so that it can cope with increasing model sizes, whilst remaining modular, easily upgradeable and able to display 'Flat Screen Immersive 3D', is **$100 000**

Option 2

The second option is to build a new simulation facility at the NMRS that uses a curved screen similar to that used at NSW RailCorp, Figure 2. The use of a curved screen gives a sense of immersion and utilises peripheral vision during the simulation.

The cost breakdown of this system is shown in Table 3.

Table 3: Estimated curved screen theatre costs - Option 2.

Data Projectors (4)	$200 000	DLP Type
Curved Screen	$100 000	Includes installation
Total	**$300 000**	Note: Figure excludes room construction costs

Development and Maintenance Capability

The research undertaken to date at UNSW has developed and demonstrated a virtual reality training capability for the mining industry. In order to sustain and grow this capability so that new scenarios and more realistic interactions can be developed, the development team must be founded on a more commercial basis. It is envisaged that UNSW would contract a Project Manager who would provide expert day-to-day leadership and direction to the VR research and staff. The development of the fundamental simulation capabilities would continue to be undertaken at UNSW by postgraduate students supported with project funding, as has been the case to date. However, it is proposed that model development be fast tracked by much closer collaboration with other institutions, private and public, which have complementary VR capabilities and simulation libraries. It is proposed that the development of some models would be sub-contracted to other organisations.

The structure and commercialisation of future research requires further thought and advice once the direction of this research is better known. However, it is envisaged that the future development and maintenance of Immersive Visual Environment Training Simulations (IVETS) will require a minimum of $400 000/annum to support contract and sub-contract staff. The breakdown of this is shown in Table 4.

Total Costs

1 - Flat Screen Over 2 Years

SGI Software & Hardware	$455 000
Projectors	$100 000
Personnel	$660 000
	$1 215 000
Cost per year over 2 years	**$ 607 500**
(Cost per year over 3 years	**$ 505 000)**

2 - Curved Screen over 2 years

SGI Software & Hardware	$455 000
Screen and Projectors	$300 000
Personnel	$660 000
	$1 415 000
Cost per year over 2 years	**$ 707 500**
(Cost per year over 3 years	**$ 571 666)**

18.0 CONCLUSIONS

This study has investigated and presented examples of Virtual Reality (VR) technology and techniques that are being developed around the globe. The main objective of the study was to identify the State of the Art of VR Technology in 2005 that could be utilised in the further development of the training simulators developed by UNSW School of Mining Engineering for Coal Services and ACARP

The study shows that the technology has progressed considerably since the original study of 2001 and the technology and techniques have advanced considerably. The industry is now very mature.

The dollar costs involved in simulation development and deployment have only slightly reduced. In real terms though, there has been a significant reduction in cost when the flexibility and range of tools available for VR is considered against the cost in 2001.

VR systems range from desktop PC systems through to complete immersive visualisation facilities that deliver simulations of railway infrastructure. There is a system and format for almost any application that can be thought of in both training and visualisation.

The development of VR simulations is in the hands of many groups in many industries. In the case of mining research and development of VR is in the hands of several smaller research bodies that are inadvertently competing with each other.

The continued success of VR training simulator development in the different groups requires that the research groups visited and mentioned in this study to collaborate and share resources. The development process also needs to be placed on a more commercial footing from within the existing tripartite structure that exists between Coal Services, ACARP and UNSW. This will considerably speed up the deployment of simulations based on techniques developed in the existing project.

The simulators developed by Coal Services, ACARP and UNSW have benefited from the steady development of techniques that allow a generic mine to be developed and displayed in real time on PC hardware, however, the model development is such that they are running close to the limits of PC technology. For the continued success of the models and to allow more and more detail and function to be placed in the simulations and for them to run efficiently, the systems should be upgraded to include the specifications listed in this report.

The use of PCs to develop simulations has prevailed over the last few years due to the availability of Windows based development tools and the improvements in PC graphics hardware. However, the original proponents of computer graphics - Silicon Graphics (SGI) -

have very recently made a shift to the Linux based operating system and reduced the cost of there latest equipment and maintenance costs significantly. SGI machines provide a more powerful platform for the large data sets that are required for photo realistic, whole mine models used by the existing and future simulators.

The development of large-scale photo realistic mine models for training and visualisation purposes requires a development team that is commercially based. The team should consist of fulltime and contract personnel dedicated to the project full time. A model of the team that will facilitate the sustainability of the project is presented in the report.

Finally, The ‘State of the Art in 2005’ of Virtual Reality (VR) technology and techniques suitable for the continued development of a Training Simulator for mine workers in the NSW Coal Industry is extremely high. The simulators developed by UNSW have the opportunity to remain at the leading edge through further funding to upgrade technology and collaboration to improve educational input.

19.0 REFERENCES

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20.0 APPENDIX

The Appendix for this report is contained in the attached CDROM