EMERGENCY PLANNING SIMULATIONS AND VIRTUAL REALITY TECHNIQUES IN MINE EMERGENCY MANAGEMENT

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ABSTRACT

Emergency management requires a rapid effective response in high stress conditions. Rescue actions are taken on the best available information. Preparation for emergencies involves the prior establishment of information collection, presentation, and integration systems, plans for dealing with a range of issues, training of emergency managers and mines rescue brigades, and having a capability to respond in place.

Much of the information required is based around spatial and time sequence data, the significance of which lies in its relationship to surrounding conditions. Modern monitoring is capable of supplying large amounts of information which must be assessed quickly. Virtual reality techniques have the capability to integrate multiple data sets into a single visualisation. This visualises a 3D display presentation which represents the true spatial relationship of the objects combined in the images. The virtual reality programmes can interface with models and simulations which use monitoring data, and incorporate the results in visualisations. Virtual reality techniques can be linked with computer based decision support systems, for rapid comprehension and intuitive analysis of data in an emergency.

These new computer based programmes have a number of applications for emergencies. They can be used as a tool to manage emergency operations, by presenting data, linking to other models or simulations, and decision support programmes. Another role is in training, both for management teams, and specific operations of the mines rescue brigades. A third application is in planning at specific mines, to assist in the development of mine emergency plans. Following disasters the programmes could be used to re-create the events through time.

VIRTUAL REALITY AND COMPUTER TECHNOLOGY

Computers are widely used to monitor and control dynamic processes in industry. Where process behaviour can be modelled precisely, computers can be used to simulate outcomes for a range of conditions. By combining this modelling with computer graphics it is possible to create simulators for complex equipment operations. Probably the best known of these are aircraft simulators, and although very expensive, allow safe training of pilots for high risk events. Simulators are becoming more widespread and mining companies have been supporting the development of one for training in dragline operation. Where equipment is very expensive and the results of failures in training severe, the construction of specific equipment simulators has been justified.

General purpose simulation has been developed in virtual reality environments. In a virtual world a user is immersed totally in a computer simulated world, where the appropriate view in seen in stereo glasses, no matter which way the user looks. The user appears to be in and part of a world. These effects require large and expensive facilities, and the RMIT in Melbourne is developing a large virtual reality "CAVE". A simpler variant of this is a Visionarium, where the user sits in a specially constructed theatre, at the focus of a 3m high 180o curved screen. Depth of field is created by multiple projectors and computers, and although no true stereo image is used, a powerful 3D effect is created. These facilities cost in excess of $10 million.

In general entertainment there has been rapid development of low cost simulation technologies which can be applied to computer games. As entertainment, these technologies have concentrated on effects which feel real to the participants, without attempting to accurately represent all the aspects of the game environment. By trial and error, developers have found the most computer efficient ways to create sensations and impressions in the players. Ordinary computer screens and conventional PCs are now powerful enough to create extremely realistic effects. The software for virtual reality techniques has been developed by companies such as Silicon Graphics, who use advanced graphics in their Visionariums. Versions of the software suitable for smaller workstations and PCs, are now bundled with widely available internet products and accessible to any top end PC user.

In the computer generation of virtual reality there are a number of distinct tasks. One is the visual representation of some place or thing, and this is generally understood as computer graphics. The best way to represent an object depends very much on the purpose of the exercise, and to select the most appropriate "look" of an object to achieve the desired result is an important task in itself.. The second element is the modelling of object behaviour to a set of rules that mimic natural behaviour or some other desired outcome.

GENERAL SAFETY APPLICATIONS OF VIRTUAL REALITY

Virtual reality techniques can be used to create models of the real world which have many potential applications in safety. An obvious use is the one referred to above, that is, the training in operation of equipment in simulators. Errors of trainees do not damage equipment or the people involved. One of the first groups to apply the new technology to mine safety was the AIMS research unit at the University of Nottingham (McClarnon et al 1995). The potential for virtual reality training systems was summarised by Denby et al (1998) as:

- Demonstrating correct/incorrect and standard procedures
- Advise trainees during simulations
- Test competencies and record decisions for review
- Demonstrate unusual situations
- Train staff for hazardous situations safely

A demonstrator programme for testing the competency of truck drivers to detect faults on their vehicles has been used to illustrate the potential of small PC based systems. Analysis of potential risk can also be carried out using virtual reality techniques. Applications have been developed in relation to vehicles in mines, both surface and underground. Examples include the visibility limitations of drivers of mining equipment and the potential for collisions and the running over of people, the generation of risk envelopes around moving vehicles that change with vehicle speed, and modelling of the interaction zone around mine equipment. (AIMS 1998a, 1998b).

Equipment safety analysis using computer simulations of human interaction with equipment, has also been developed by researchers at the National Institute for Occupational Safety and Health (NIOSH). Their purpose was to develop accurate 3D computer models of mine incidents, and analyse incidents to determine equipment operation and how interaction with operators may contribute to incidents. One example developed was the operation of a roof bolter. Human motion data was incorporated with a roof bolter model using human modelling software JACK. Other studies modelled a mine hoist incident. (Ambrose 1996, 1998)

EMERGENCY MANAGEMENT

Emergency management is characterised by unexpected combinations of rare events, emotionally charged environments, inadequate information on conditions, potentially significant hazards, and time sensitive action requirements. The diverse and complex data input, and unusual combination of events make virtual reality tools an ideal technique to assist in emergencies. Virtual reality methods can provide the tools to manage an emergency, to assist planning and the development of emergency response plans, and training tools for emergency managers and mines rescue teams.

Functions of Emergency Management

Emergency management includes many different activities, but breaks down to some basic steps which are:

- Collect information on the mine
- Analyse the significance of the data
- Make decisions of appropriate action
- Instigate specific activities and tasks

In a real emergency this is an iterative process with new data continuously flowing to the command centre, but these same steps are repeated throughout the operation. The way virtual reality computer techniques might assist or interact with these processes are examined.

Information

Mine information and data can been looked at in two ways. There are "static" data sets which represent fixed systems which provide a framework in which dynamic events occur. These static data sets describe the basic structure of the mine site and include information on the position and layout of things such as:

> the mine layout, water pipes, air lines, sprinklers, stoppings, gas drainage lines, electrical power centres, boreholes, communication facilities, cribs, roof support, geological models, beltways, egress routes – to list just some.

Virtual reality techniques have the ability to present a number of objects in their correct 3D spatial relationship, and visualise them in designated ways. The data on particular features can be stored in any

database and computer system which is connected to the virtual reality system, and instructions on how to access the data and graphically represent it can be embedded in the virtual reality system. One of the features of internet based virtual reality programmes is that they can access diverse existing databases, and do not require new data structures to be set up.

Each of the mine data sets can be visualised individually in the most appropriate way for a particular purpose, and different ways of representing a feature can be built into the system as desired.

The second data type is dynamic, or data streams which are reporting changes in monitored conditions. These include information on:

> the location of men and equipment, gas analysis data, ventilation status, communication messages - to name a few.

This information contains a dimension of time, and is significant not only for the state it reports, but also for the changes that are occurring through time. The representation of changing situations cannot be done through static representations and requires simulations or models, which provide a framework to understand the processes which are occurring through time. Virtual reality visualisation has no inherent modelling capability, but can interface with models and simulations, and display the modelling results in relation to other spatial information.

Significance of data

The significance inherent in static data is in its relation with other data types. For example, a particular component of a mine electrical system is located at a point in the mine layout. In working with different aspects of the mine, it is critical to be able to quickly establish the spatial relationship of the fixed infrastructure. It is in this field that the virtual reality programmes have provided a ready tool to present the spatial relationships of all the mine infrastructure for which digital databases are maintained.

Where changes are occurring and there is time series data, the significance of data requires modelling or simulation. Some models are simple, for example the reporting of the position of a moving vehicle, where the model might estimate the anticipated time of arrival from a sequence of positions in time. Other models/simulations useful in mine emergencies can be extremely complex, for example interpreting the location and status of a fire from tube bundle gas sample analyses, where there is uncertainty in the survival of stoppings.

Decision making

After information and modelling has been presented, an emergency management team has to make decisions on what action to take. In doing this it is usual to draw on experience to guide the decision. It is possible to evaluate alternatives and use risk analysis techniques to come to a conclusion on the most appropriate action given the information at hand. There are several problems in applying normal procedures in emergencies.

- There is often inadequate information to be certain of outcomes
- Emergencies present situations beyond normal experience
- Situations can be very complex with interactions of many factors

The situation in emergencies has parallels with military campaigns, and a well proven technique through the ages has been to train participants rigorously to react in designated ways in the face of crises and uncertainty. Considerable effort has been made in the training of mine rescue brigades, but it has been less common for the potential controllers of mine emergencies to be trained.

A computer based decision support programme has been developed by the Australian Coal Industry research Laboratories (ACIRL), but the product, ECAS, has not been taken up by industry. Considerable effort was put into analysing the various scenarios facing emergency management teams, with input from the mines rescue services. The programme leads an operator through the factors involved in a particular issue, and indicates the options for action. It provides a way of checking that all relevant information available is being used. The lack of interest in the programme probably stems from the limitation in computers it can run on (Microvax and Macintosh) and the relatively unfriendly interface to the shell programme used in its construction. There is a need for a user friendly programme of this type.

Mine rescue activities/tasks

In the immediate response to a mine emergency and mine recovery, mines rescue activities involve four main tasks:

- Ventilation control and re-establishment
- Ground support or excavation
- Rescue and medical services
- Fire fighting

To undertake any of these tasks, specific information, equipment and operating procedures are required. Mines rescue brigades have developed standard ways of carrying out these tasks through experience and simulated trials in mines. This body of knowledge could be included in computer assisted support programmes and simulators for training. The task oriented programmes would be modules in an overall management package.

Once a decision is made that a mines rescue brigade will enter a mine to, for example, extinguish a fire, the fire fighting module could be activated. It would be designed to include all the relevant static data sets, and link to relevant models and simulations, which could assist the brigade in their work. A virtual reality based programme could display the location in the mine of relevant features eg. the mine layout, the fire's position if known, fire fighting equipment, and mine infrastructure such as water lines. The results of modelling could be incorporated and relevant modelling includes gas analyses trends (various ratios) for fire intensity and gas analysis trends for ventilation conditions. Each module would be customised with the input of all the involved parties.

CSIRO and Mines Rescue VR Emergency Management

CSIRO Exploration and Mining in conjunction with the mines rescue services propose to develop virtual reality based emergency management programmes. The aim is to produce computer tools which can assist in the actual management of emergencies.

The development has started with the simplest task, which with virtual reality, is the integration of existing data sets. These are visualised together in combinations that have a logical connection. If all types of data are simultaneously displayed it can result in a meaningless jumble, so data which relate to specific features or activities are combined in carefully designed ways. Although everything can theoretically be displayed at once, the grouping of data is a way to manage the large amount of information which has to be handled.

In developing the system, real mine data is used as it is recorded in current mine databases. In consultation with mines rescue groups and mine management, the relevant data is selected and the preferred visualisation style determined. Links to the databases and graphics instructions for each characteristic are then embedded in the programme.

The capability of the programme will be expanded to cover all useful data, and the incorporation of links to a range of ventilation, rescue procedure, self escape and other modelling and simulation routines. There is no limit to the activities which could be included in modules, and apart from those covering mine rescue activities, other general service functions such as managing the press, relations, organising accommodation and food and the like could be added. The programme and modules could also be linked to decision support software such as an upgraded ECAS, and work in parallel, supplying the details required by the decision support programme.

The MERITS Programme

NIOSH at the Pittsburgh Research Laboratory is developing a computer programme to simulate a major mine emergency. The Mine Emergency Response Interactive Training Simulation (MERITS) will help meet a variety of needs. It will evaluate the knowledge and skill of personnel in leadership positions, train individuals, and test a company's formal response plan which will guide the simulated response.

The primary target audience for MERITS is command centre personnel. The interface will provide information typically available to those decision-makers and require input from them. A map of an actual or computer generated mine will be incorporated to add realism. An emergency will be randomly selected within specified conditions, and the underground situation will unfold through the simulation programme. The progress of the underground simulation will be reported to the command centre. Surface concerns, such as personnel scheduling, media interactions, and traffic problems, will also be included. MERITS will be a tool for command centre personnel to practice their skills at managing a major underground mine emergency via a personal computer and the Internet. Because of the focus of past related work, initial programming will address response to fires at underground coal mines.

MERITS will be an interactive multimedia computer simulation, delivered via the internet, of an underground mine that is undergoing some type of emergency. It will simulate both underground and surface activities at the mine site, and provide a means to inform users (command centre trainees) of those events and allow them to attempt to resolve the emergency. The users' decisions, in turn, will affect the progress of the simulated emergency.

Some underground activities that MERITS will simulate include the spread of the fire and smoke

under the influence of the mine's ventilation system, the actions of the miners attempting to escape the mine and the rescue teams attempting to find the miners, and unexpected events such as roof falls. The underground simulation will be based primarily on many Pittsburgh Research Laboratory research studies concerning mine ventilation simulation, self contained self rescuer (SCSR) training and field audits, oxygen cost studies, miner demographics, and analyses of miners' behaviours during past emergencies. It will build upon a previous, graphics-based computer model developed by Pittsburgh Research Laboratory researchers that used computer simulation to assess miners' abilities to escape an underground mine fire. That survivability model considered many factors involved in an escape, including mine design, location of the fire, spread of smoke, SCSR availability, travelling speeds, oxygen consumption, and time.

Surface events will include interactions with the media, medical services, labour, government officials, and unofficial visitors (for example, victims' families), weather (such as flooding that interferes with the flow of supplies to the mine), and traffic problems.

The Host PC will perform the simulation of the underground and surface activities. The host will pass (through a local area network or Internet connection) relevant information concerning those activities to the Local PC, which will communicate with the trainees.

At times, problems may arise that prevent the trainees from addressing all other issues until they resolve the immediate situation. For example, the unexpected arrival of a distraught family member at the command centre (depicted via digital video) may interrupt the trainees from addressing other problems until the family member can be calmed down and moved to an appropriate facility away from the command centre. If required resources (food, medical supplies, etc.) are exhausted or delayed during the simulation, or other unanticipated developments occur, it will be the responsibility of the trainees to address these issues while still attending to other ongoing activities. These "interruptions" will provide a sense of realism by exposing trainees to the stresses that can be involved in an actual emergency.

The MERITS simulation will operate on a set of "rules" which define its possible behaviours. The rules will cover classes of information necessary to create a realistic simulation. These classes of information will include (but not be limited to):

- Human factors - physiology, psychology, level of training, etc.
- Physical factors - mine location, ventilation systems, etc.
- Internal and external resources - fire fighting equipment, rescue team availability, roof control materials, food, transportation, etc.
- Political considerations - relations with federal, state and local authorities, media impact, relations with victims' families, etc.
- Economics - costs associated with rescue efforts, etc.

Although MERITS will be able to generate a random emergency, a scripting feature will allow trainers to develop specific simulation exercises. The trainer can update these exercises periodically to provide new and varied training experiences. This feature will also permit controlled experiments where the trainer knows in advance the type of emergency scenario that will be generated.

Delivery of MERITS

MERITS will run on two computers simultaneously - the host PC and the local PC. These two computers will communicate by a local area network (LAN) or Internet connection. The host PC will perform the simulation of the underground and surface activities. The host PC will pass relevant information concerning those activities to the local PC, which will communicate with the trainees.

The exact requirements for the hardware and software may change as the project develops. However, the hardware needed to run the simulation will be restricted to what will be available to most individuals, schools, training centres, and companies by the time the simulation is ready for distribution.

Project Status

The development of the exercise content for MERITS is being conducted in three phases:

- A Mine Rescue Training Exercise. (underway)
- The MeritsOne Development Version. (underway)
- The MERITS Version for Distribution.

During phase 1, a training exercise for mine rescue team members will be created. This exercise will be used by the MERITS development team to test software for later use in MERITS. It will also be a stand-alone training product that will be available via this web page. An emergency scenario has been chosen. The scenario has been authenticated through its use in mock drills with mine rescue teams in the state of Pennsylvania. Development of

an exercise that will be appropriate for Internet delivery is underway.

During Phase 2 (MeritsOne) the initial version of MERITS will include a limited set of features and will address a simple emergency situation. Starting with this simple version (MeritsOne) will allow project team members to practice putting together the components of a mine emergency and test the simulation without the complexity that is planned for later versions. MeritsOne is being based on a generic mine and a typical emergency situation. Resources available to the command centre will be provided on a screen menu. Because of past work completed in this area, it will be based on a small underground coal mine. Everything outside of the command centre will be simulated. (underground areas, gates to mine property, phone lines, etc.) Input to the simulation will be in the format of command centre requests and/or decisions. Multiple trainees may work together as the command centre team to determine the input. Such teams could be composed of company, state, federal, and labour representatives. MeritsOne will also be used to test user interfaces and the technical details of Internet delivery. An emergency scenario has been selected. Key decision points related to such an event have been outlined. A mine map has been chosen and is being converted into a format appropriate for future programming needs. A resource list has been developed.

Phase 3 (MERITS) will be built on the framework developed for MeritsOne, but will be more complex and adaptable. Some of the features that will be included are:

- Users will be able to tailor MERITS by inputting mine maps, available resources and portions of an Emergency Response Plan for testing.
- The level of instructional cues to be given to users can be selected.
- Some command centre personnel, such as government officials, will be simulated.
- Emergency scenarios will be more complex. For example, miners may be trapped underground, media presence will increase, or problems with power supplies may occur.

AN INTEGRATED EMERGENCY RESPONSE PROGRAMME

Three groups applying virtual reality techniques to mining have been working on areas of emergency support. The AIMS group at Nottingham have developed simulation of mining processes, and looked at safety in relation to moving vehicles. They have provided training packages for mines rescue and are interested in the re-creation of mine incidents. Joint work is being done by the AIMS group and CSIR in South Africa. CSIRO in Australia has concentrated on developing a mine emergency management tool for use in emergencies, and recognised its application for planning and training. The NIOSH group are working on a comprehensive training programme. All the research groups are in an early stage of development in emergency programmes, and the different focus each group has developed to the issue, has been recognised through visits and technical exchanges.

Cooperation between the various countries will continue to increase, and the research teams at CSIRO and NIOSH have proposed a formal collaboration. It is anticipated that in pooling efforts, a comprehensive mine emergency tool will be achieved quicker than otherwise possible, and each country will benefit by accessing the strengths of the partners. The final product will address all the objectives of the parties and provide an emergency management tool for use by mines, a planning tool to develop emergency plans, and a training tool for mines rescue , mine staff and emergency management teams.

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