# Technology aimed at improving mine safety

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**Abstract**

A range of technologies currently being developed at the University of Queensland in the Division of Mining and Minerals Process Engineering and its related mining research Centres is described. These technologies seek to improve mine safety by: (i) reducing mining hazards, (ii) reducing physical and mental stress whilst operating equipment and, (iii) improving operator training.

In the first category a novel drilling technology is outlined that improves the effectiveness of gas drainage from coal seams. Another technology in this category is reported which improves our understanding of spontaneous coal combustion. In the second category a new sensor and alarm system is detailed which alerts truck drivers when they lose concentration. Two other technologies in this category are presented. One monitors the quality of haul roads and reports to management when the road deteriorates to a point where it needs repair, that is, when the stress to the driver and the truck exceeds a pre-defined limit. The other is an alarm function that alerts a driver when other vehicles and humans are in close proximity to a haul truck – this should help prevent future accidents where trucks unknowingly run over other vehicles. In the third category a new technology is described that uses a virtual reality system for operator training.

## 1 Technologies to reduce mining hazards

### *1.1 Improved gas drainage from coal seams*

The majority of coals seams mined in Australia today can be characterised as gassy and relatively impermeable. The quantity of these gases contained in the seams must be reduced to safe levels before underground mining of the coal can take place. The low seam permeability makes this gas reduction operation difficult. In general the most, and often the only, effective way is to drain the seams by drilling holes in regular patterns in the coal. The gas flows into and along these holes and from there into pipes which convey it safely to the surface.

Today in Australia some 300 km of these inseam holes are drilled each year from underground workings across coal blocks that are to be mined. These holes are made using directional drilling techniques at a cost of about $100,000/km, or a total annual drilling cost of about $30 million. The instantaneous drilling speed achieved by these drills is a respectable 2 m/min, but the delays involved in drill set up, drill pipe installation and removal, surveying and steering, reduces the effective drilling rate to about 80 m/shift; equivalent to less than 0.2 m/min. Obviously the drilling cost is related to the effective drilling rate. In other words if the effective rate was increased the cost would fall.

A new drilling approach that has the promise to displace much of this underground drilling is the surface-to-inseam method. The technology that has been most widely applied to date is medium-radius drilling (MRD) which starts with an inclined hole at the surface. This hole is deviated into the plane of the coal seam and then drilled for a long distance, typically 1 km, in the seam. The hole is steered to intercept a vertical well (Figure 1). A pump is installed in this well to lower the water table, thereby reducing the pressure in the seam and allowing the gas to flow. To date only about 10 MRD holes, equivalent to only about 3% of the annual length of holes drilled, have been developed for mine drainage.

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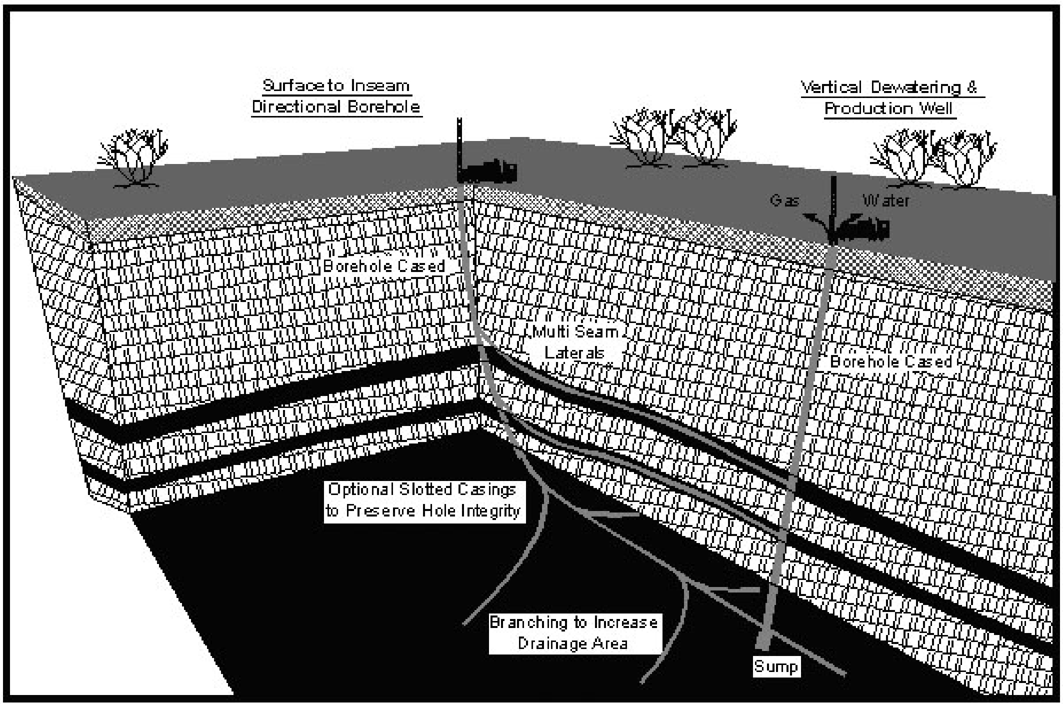


Figure 1 Schematic of medium radius drilling (MRD) operation (from Thomson et al, 2003)

Although the cost per unit length of these MRD holes is comparable to the holes drilled from underground they have advantages over underground drilling that makes the trend towards surface-to-inseam drilling compelling. First, the surface holes can be drilled years in advance of the mining operations, allowing ample time for the gases to drain, eliminating any disruption to mining. Second, the drilling operations are conducted from the safety of the ground surface.

A significant problem with both the underground and the surface-to-inseam drilling is that no additional information about the formation is gathered during the drilling operations. If, for example, sensors were mounted on or behind the drill to monitor changing geological structure (faults, rolls, mylonite zones, dykes, etc) during the drilling operation then this new information could be incorporated to improve the performance of the mining system; this would help justify the drilling costs.

The University of Queensland is the major research partner in the Cooperative Research Centre for Mining Technology and Equipment (CMTE). This Centre has developed a novel, water-powered drilling technique that potentially can substantially improve the performance of both the underground drills and the surface-to-inseam drills. Furthermore, CMTE, with its research collaborators at the University of Sydney and CSIRO, is developing a suite of new geophysical tools that could provide information on the geological formation during the drilling process.

Figure 2 shows this new drill. It is supplied with high pressure water through a flexible hose which runs from the high pressure pump located on the surface over a take-up drum on a surface rig and connects the back of the drilling tool. The water is emitted through a number of nozzles that are aimed at acute angles off the tool axis at both the front and rear ends of the drill. The nozzles on the front are mounted in a swivel and angled in a manner that causes the front end of the tool to rotate, in a manner similar to a garden sprinkler. These are the cutting jets that excavate the hole. More than half the jet power is directed through stationary (non-rotating) nozzles at the rear of the tool. These jets provide the thrust necessary to advance the tool along the hole.

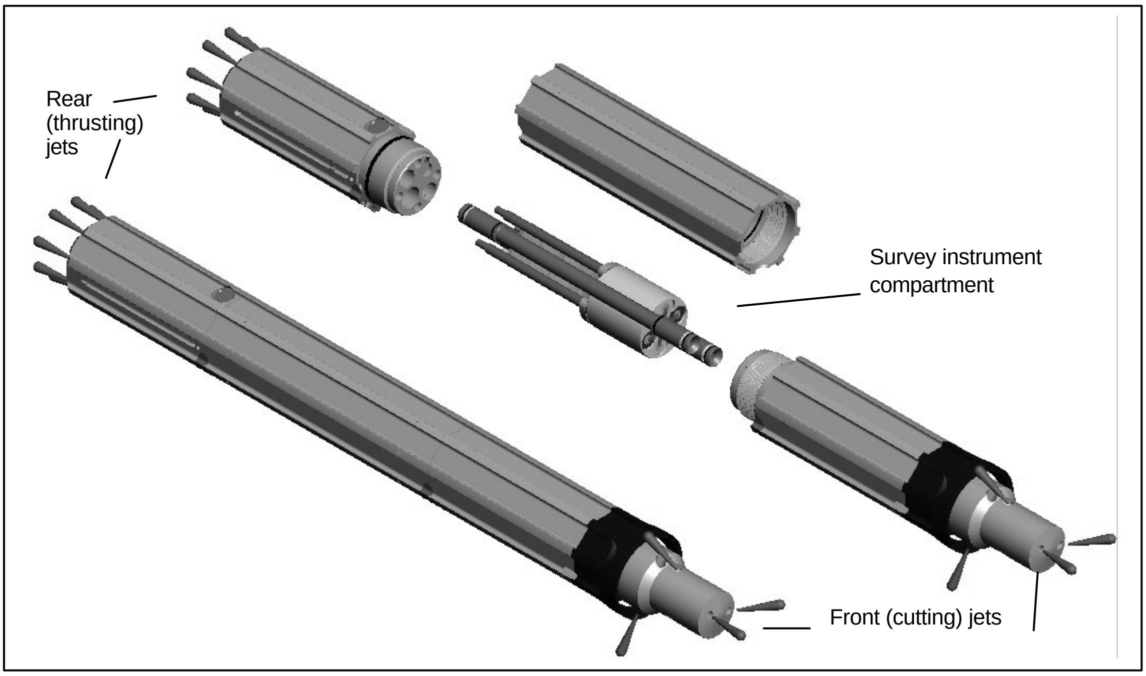


Figure 2 CMTE's water powered drilling tool assembled view (lower figure) and exploded view (upper figure)

Built into the drilling tool is a survey instrument that provides real-time, continuous positional data to the drill crew (Figure 2). Also built into the drilling system is a steering mechanism. Once drilling starts any deviation from a desired trajectory can be monitored using the survey instrument and steering corrections can be made.

For underground drilling applications one of the principle advantages of this water powered drill over conventional directional drills is a much faster effective drilling rate. This is achieved by a combination of a faster instantaneous rate – the research team has routinely recorded instantaneous drilling rates in excess of 5 m/min – and greatly reduced looses during drilling – since the drill string is a continuous hose no time is lost in making up tool joints and, since the drill survey data is continuous, no losses are incurred in making survey measurements. To date these advantages have been demonstrated only by drilling in highwalls because the equipment has yet to be approved for underground use.

For surface-to-inseam applications the potential benefits are even greater. Because the drill is attached to a flexible hose, rather than rigid drill rods, it can be directed around sharp corners. The drilling system that CMTE has developed to take advantage of this is called tight-radius drilling (TRD). The system (Figure 3) works by first drilling a vertical well and reaming out a cavity (1.8 m in diameter) at each seam horizon. These operations are performed using standard conventional drilling methods. An erectable arm is then lowered on rigid drill pipe into the cavity of the first seam to be drilled. The hose is then paid out drill to lower the drill into this arm with the arm in the vertical position. The arm is then raised to a horizontal position and rotated to point in the compass direction where drilling is to take place. The high pressure water is then applied to the drill causing the drill to leave the arm and start drilling in the coal. The survey data is transmitted back to the surface and steering corrections are applied as necessary.

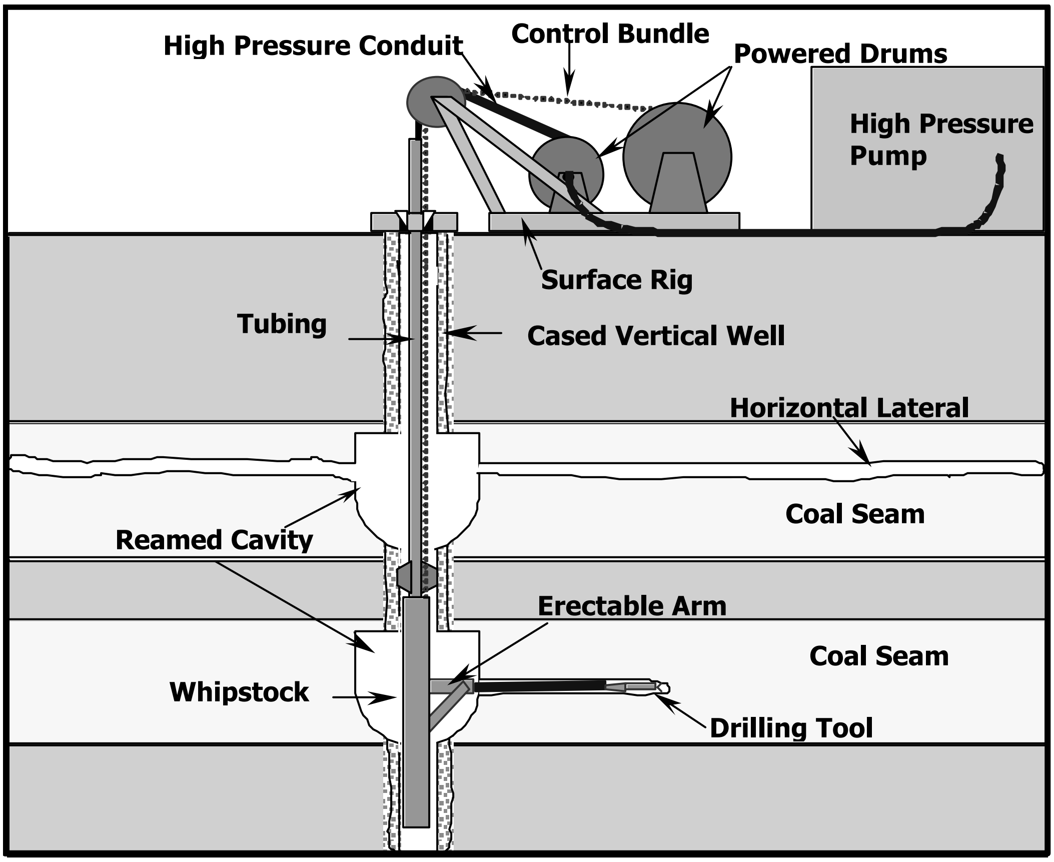


Figure 3 Schematic of tight-radius drilling (TRD) operation

Thomson et al, (2003) described the advantages of TRD over MRD:

- TRD allows for a single vertical well (conventionally drilled) to service any number of lateral turnouts, including multiple seams. This provides for a very high ratio of metres drilled in coal versus metres drilled in barren ground.
- De-watering can be achieved by using a simple rod and plunger style pump located at the bottom of the vertical well. MRD requires the placement of an adjacent vertical well (in addition to the horizontal well) to de-water the seam.
- The capital cost of down hole equipment is likely to be significantly less than with MRD systems.

However, the key advantage of TRD technology over MRD is the ability to target multiple coal seams (of variable thickness) from a single central well (working away from the position of maximum geological control).

TRD has been used to drill out coal seams from three vertical wells, one at (what was then) BHP Mitsui Coal's Moura mine, and two at Anglo Coal's Grasstree mine. Gas drainage from these holes has been excellent. At Moura the peak gas flow was measured at 1 TJ/day (28,000 $m^3$/day) and, some four years later was still producing about 0.3 TJ/day (10,000 $m^3$/day). At Grasstree one of the holes was strategically located adjacent to a shaft that was being sunk in order to degas the shaft bottom area to facilitate mine development. This development is now taking place and, pleasingly, only low gas values have been found underground.

### *1.2 Spontaneous Combustion Research – Bulk coal self-heating tests*

A 2-metre, adiabatic column (Figure 4) is used in the Division of Mining and Minerals Process Engineering at The University of Queensland to monitor the self-heating of 60 litres of as-received or as-mined coal up to temperatures of 250°C (Beamish et al., 2002, 2003).

This type of testing is able to produce results that closely simulate the conditions that exist in industry. The information obtained from the column is also ideal for teaching the fundamentals of spontaneous combustion in particular the use of gas ratios as indicators of the status of a heating. Results are directly applicable to hazard management of spontaneous combustion during mining, transport, storage and building spoilpiles.

Since late 2001, 20 test runs have been completed with a 100% success rate. From these tests it is clear that the column has a number of significant advantages. These are:

- The test is performed on as-received bulk coal (60 litres or 40-60kg of coal depending on packing density used) up to a maximum temperature of 250°C. This maximum temperature has been progressively established to maintain strict safety standards during testing.
- Tests results are available in days, with a full history of the self-heating development of the coal (Figure 5). The longest test run to date has taken 28 days to complete, with the majority of tests taking less than 14 days.
- Moisture transfer effects are clearly visible, particularly in the early stages of heating development (Figure 5), whereby there is a significant temperature increase towards the top of the column due to moisture condensation in the coal pile.
- "True" off-gas is liberated and monitored from the self-heating process of the coal, including any moisture driven and gaseous feedback reactions leading to "fire-stink".
- Hot spot development and propagation can be quantified (Figure 5).
- Direct impacts of changes in airflow rate, particle size, air temperature and starting coal temperature can be assessed.
- Effects of the presence of pyrite and seamgas can be assessed.
- Simple coal quality relationships can be determined for any mine that can also be related back to small-scale adiabatic $R_{70}$ testing.
- Mine strategies to control self-heating can be assessed, including: ventilation changes, inertisation, and inhibition.

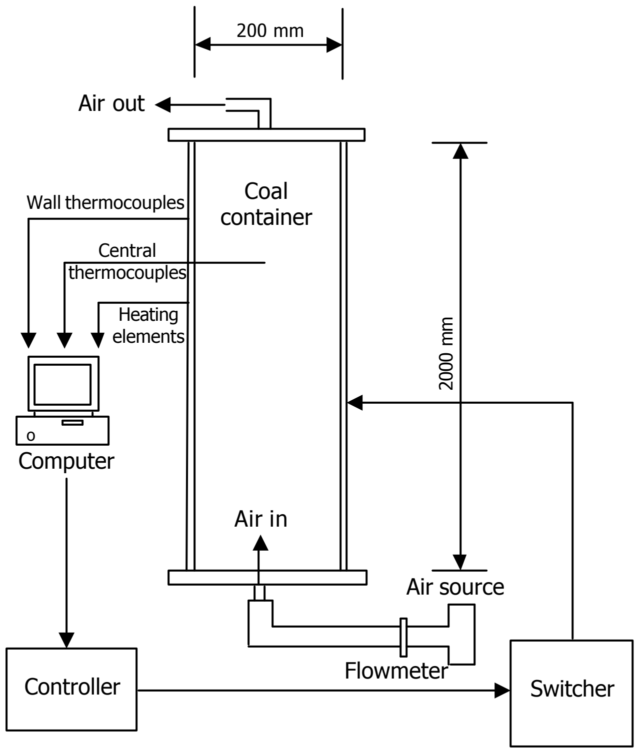


Figure 4 Schematic of UQ 2-metre column self heating apparatus (modified from Arief, 1997)

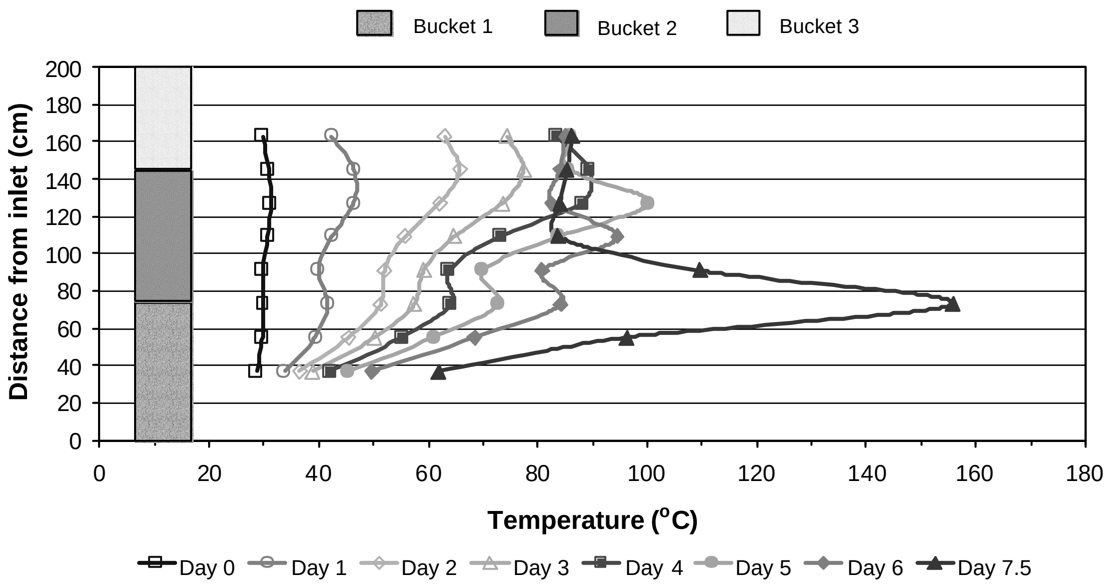


Figure 5  Column temperature profile showing hot spot development

## 2 Technologies to reduce physical and mental stress

### *2.1 Truck driver alert system*

> "A 290 tonne truck drifts across the centreline of the haul road and hits another truck head-on. A load of overburden is absent-mindedly dumped into the crusher, shutting down the mine for 12 hours. And yet another haul truck drives through a curve in the road, rupturing a pipeline and dumping 322,000 litres of raffinate on the ground. These incidents, and countless others, had three things in common. First, all the operators were well trained and experienced. Secondly, they had excellent safety records. Thirdly, they were all working the back end of the night shift."

(Sirois, W., 2003)

The haul truck alignment monitoring and operator warning system seeks to prevent accidents caused by driver fatigue. It warns the driver when the haul truck deviates from a specified operating corridor, and it also alerts other trucks of the potential hazard. The work has been performed by CMTE's research partners at The University of Sydney.

The system (Figure 6) uses a scanning laser to detect existing guideposts by measuring the time of flight of the laser light pulses. The pulsed laser beam is deflected by an internal rotating mirror so that a fan-shaped scan is made of the surrounding area. The system then calculates the distance of the haul truck with respect to a virtual wall formed by the guideposts in real time using an embedded processor (Figure 7). When the truck veers too far off course, the system issues a series of staged warning signals to alert the operator including both visual and audible alarms. Special infrastructure in the form of three guideposts close together can also trigger the audible alarm to signify strategic locations such as intersections.

Figure 6  Haul truck operating with the system at Comalco's Weipa mine

The system is integrated with other sensors, including GPS, to provide speed and location of the vehicle. Warning lights are placed on the roof of the truck and these flash when the alarm is activated to warn on-coming drivers of a truck veering off course. This is an improved safety benefit for all other trucks in the fleet and gives the other drivers an opportunity to take evasive action.

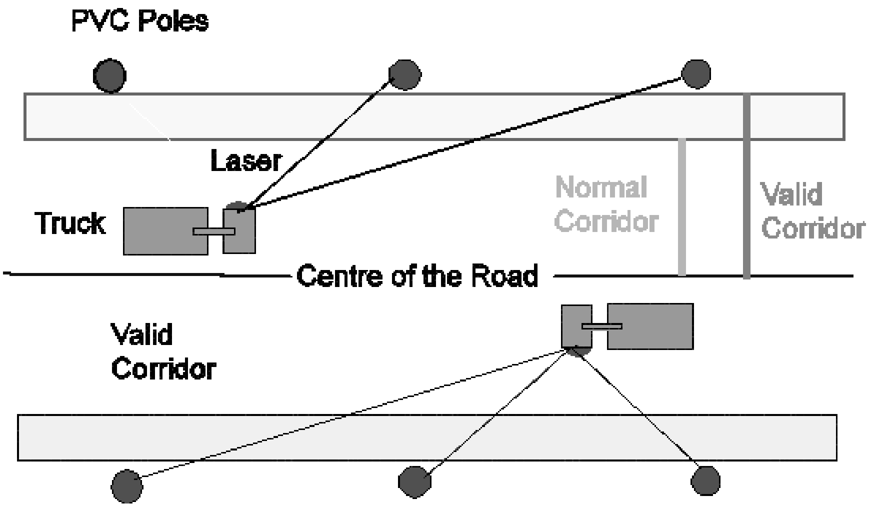


Figure 7  Schematic illustrating how a truck monitors the infrastructure to determine its position across the road.

The system logs 12 hours of real-time information relating to the position of the truck in relation to the road as well as time stamped alarm events and raw sensor data for the last period of operation.

Field trials of this system have been completed at Comalco's Weipa mine. The mine was sufficiently impressed by the performance of this technology that they are currently negotiating to purchase 13 of these systems for their truck fleet, *2.2 Haul road-truck monitoring system*

The term 'road roughness' refers to variation in a road surface profile that induces unwanted vehicle vibrations. These vibrations accumulate to fatigue both the vehicle and the driver. In particular they contribute to chronic lower back-pain, which continues to be a significant workplace heath and safety issue.

One of the projects currently being undertaken in the Division of Mechanical Engineering at The University of Queensland is to develop and test a technology that allows the truck sense the quality of the haul road that it runs on with a view to reporting when the road has deteriorated to the point where repair should occur.

The principle determiner of haul road quality is the level of deviations of the road from its designed form at the characteristic dimensions which affect vehicle dynamics, ride quality, and dynamic loads. Over a typical section, the road profile can be viewed as a sum of sinusoidal waves of different length, amplitude and phase. The different wavelength produce different vehicle vibrations ranging from heaving, caused by long wavelengths, to sharp impacts and jarring caused by short wavelengths, such as might be associated with spilt rock or potholes.

Associated with these vibrations are forces that are initiated at the tyres and which propagate through the vehicle structure, fatiguing components of the truck and reducing ride comfort. As a general rule, the intensity of these forces increases with increasing road roughness, vehicle speed, and vehicle mass (mass here changes when the vehicle is carrying a payload). It is to be recognized that different vibrational frequencies will affect the driver in different ways and to different extents, as will different levels of force at those frequencies.

Work in this project has two streams. The first has been the development of a virtual mining truck that models the Caterpillar 785B using ADAMS dynamic modelling software. This virtual mining truck can be driven over arbitrary road profiles and is capable of accurately replicating motions that the driver would experience and then correlating these with road surface quality.

The second stream of the work focuses on estimating the forces acting at the interface between tyre and road (Figure 8) and then using these forces as statistical classifiers of road quality. These force estimates can be made using the sensors already fitted to existing trucks as part of the general management haulage systems, augmented by a small number of inertial sensors (accelerometers and rate gyroscopes).

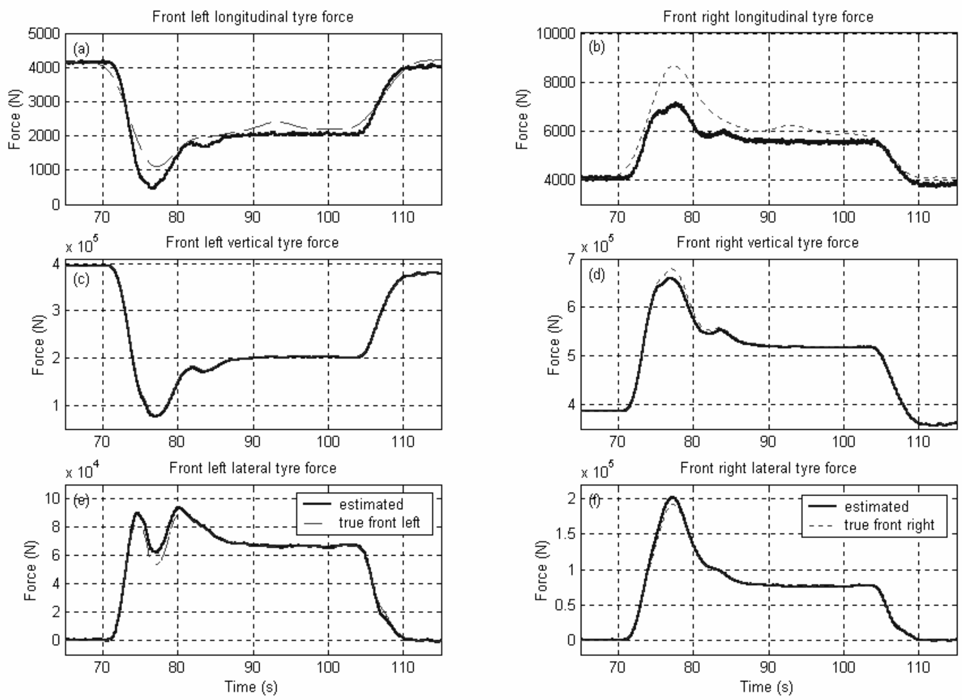


Figure 8 Plots of tyre force estimates during a coast down manoeuvre. The broken line is the true force, the solid line the estimated forces.

To date the technology for force estimation has been tested by using the virtual mining truck as a proxy for a real mining truck and it has been demonstrated that road surface quality can be established accurately from estimates the road-tyre interaction forces. This work is described in Siegrist (2003). The next phase of the work is the implementation and testing of the tyre force technologies on a physical truck. This work is currently underway.

### *2.3 Proximity sensor for trucks*

Figure 9 illustrates the damage caused when an off road haul truck runs over a light vehicle. Unfortunately, because of the poor driver visibility in these large trucks, this type of accident occurs all too frequently with, often fatal, results. The U.S. National Institute for Occupational Health and Safety (NIOSH) has reported that well over 100 incidents of off-highway trucks driving or backing up over pedestrians or light vehicles occur in the United States each year, resulting in over 20 deaths.

A commercial product has been developed to address this problem. This system is based on radio tags; however it may be too passive to guarantee the level of warning that needs to be generated.

CMTE's Sydney University researchers have started a new project with Phelps Dodge to demonstrate the reliability of using a variety of sensors to monitor movement in the truck blind spots.

Figure 9 Damage inflicted on a light vehicle when run over by a haul truck

## 3 Virtual Reality for Operator Training

Virtual Reality (VR) is a simulator. The person experiencing VR is surrounded by a three-dimensional computer generated representation – a virtual world. They are able to move around in this world and see it from different angles; they can reach into it, grab it, and reshape it.

VR multimedia training, an example of which is shown in Figure 11, can dramatically reduce the cost of delivering training by decreasing learning time for trainees and instructors. It obviates the need for expensive and dedicated training equipment (physical mock-ups, labs, or extra equipment for training purposes), and travel expenses. Perhaps most significantly, it reduces the need to take multi million dollar machines out of service to conduct in-the-seat training. This approach is finding increasing commercial application, see, for example, Williams, et al, 1998.

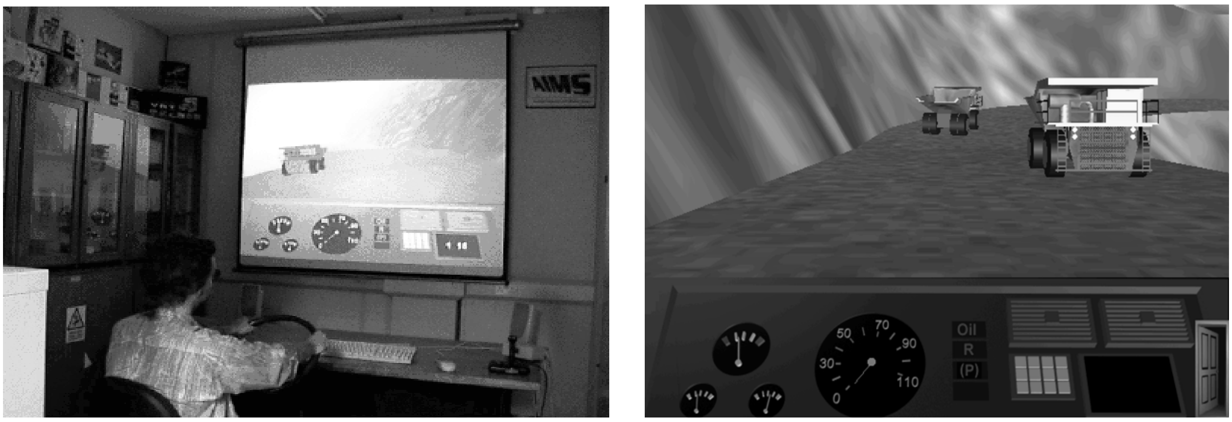


Figure 11   AIMS' open pit truck simulation VR model, from Williams et al, 1998

The University of Queensland's VR research group has developed a virtual barring down simulation system to provide improved hazard identification training for underground workers, primarily in relation to rock related hazards during barring down exercises. The major aims of this simulation are to:

- Expose a trainee to various hazardous situations without actually risking his/her live;
- Take the trainee through a mine and test his/her ability to do a risk assessment in hazardous situations whilst tracking his/her individual scoring progress.
- Provide training in highly dangerous operation of scaling down rocks.

The trainee is required to successfully negotiate his/her way around the model identifying the hazards and selecting appropriate corrective actions (Figure 12).

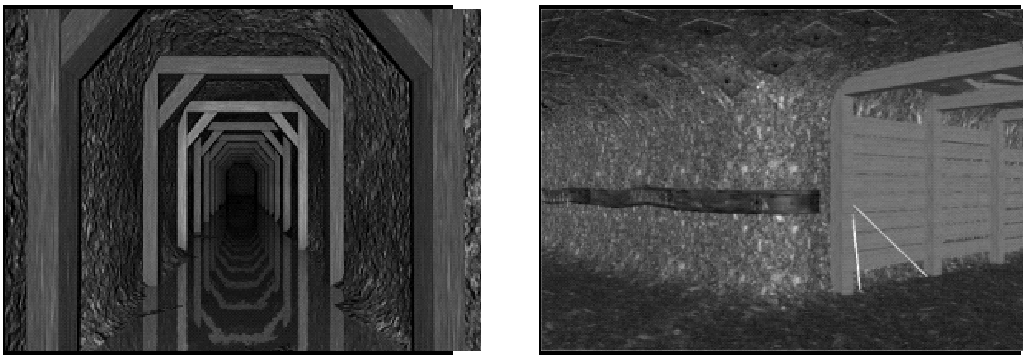

Figure 12   Barring down simulator

## 4 Conclusions

A wide range of safety-related technologies are being developed at The University of Queensland and its related research centres. Some of these technologies are in an advanced state of development and are already being adopted by industry. Others, are still in the research and development stage. All show promise in helping to improve the safety performance of mining operations.

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