VRLoader – a Virtual Reality Training System for a Mining Application

Philip Swadling, Systems Engineering Manager
Thales Training & Simulation Pty Limited
e-mail address: phils@thalesgroup.com.au

Jo-Anne Dudley, Mining Engineer
Northparkes Mine
Jo.A.Dudley@north.com.au

Abstract. VRLoader is a simulation of a remotely operated Load/Haul/Dump vehicle used to transport ore within the Northparkes mine. This paper will provide an overview of the mine operations, including the training need that led to the development of VRLoader, and a discussion of the technical details of the design of VRLoader. The paper also focuses on the application of the system to the training task for which it was designed, including lessons learnt from the use of the system.

1. INTRODUCTION

1.1 System Overview

VRLoader is a simulation of a remotely operated Load/Haul/Dump (LHD) vehicle used to transport ore within the Northparkes mine. The system provides a simulated view of the mine's tunnels and a dynamic model of the motion of the LHD under the controls provided from the operator's chair.

A quadrant of the Northparkes mine is modelled, allowing the operators to practice traversing the mine tunnels at maximum speed, entering and leaving the drawpoints, and all aspects of operation of the remote controls in driving the vehicle, without risk of damage to the vehicles or the mine.

Statistics are gathered for the performance of the training sessions to assist with assessment of each driver’s progress.

1.2 Northparkes Mine

Northparkes Mines is a joint venture between North Limited (80%) and the Sumitomo Group (20%). North Limited is a wholly owned subsidiary of RioTinto.

Northparkes Mines includes Australia’s first block cave mine, Endeavour 26 Lift 1 (E26) Mine. The mine is located approximately 30km north west of Parkes in central western New South Wales.

2. THE NORTHPARKES OPERATION

1.1 The Mine

The Endeavour 26 orebody is the largest and highest grade of the orebodies discovered at Northparkes to date. The original mining reserve of 44 million tonnes at a grade of 1.5% copper and 0.5 grams per tonne gold will eventually yield 600,000 tonnes of copper metal and 20 tonnes of gold[1].

The present delineated ore dimensions are approximately 200 metres in diameter and over 800 metres in depth extending from just below surface.

Access to the underground operations is by a 1 in 7 grade, 5.0m by 5.5m decline from surface for person and materials access, with ore being transported to surface via a dedicated 520 metre deep hoisting shaft.

The Endeavour 26 orebody is mined using the Block Caving method of mining. Block Caving occurs when a sufficient area of rock is undercut to the point where the rock mass fails and breaks up without the requirement for drilling and blasting and continues to fail and break up whilst the broken rock beneath is removed.

The mine is being developed in two lifts, initially to 480 metres below surface accessing the first lift of 27 million tonnes, and later using a second lift, to the full depth of 830 metres below surface accessing 24 million tonnes.

Six kilometers of tunnels have been developed to create the extraction level for Lift 1. Underneath the 200 metre diameter by 480 metres high column of ore, some 130 drawpoints were excavated through which the broken rock is drawn. These may be likened to numerous outlets at the bottom of a very large silo (refer to Figure 1).

Feeding from the extraction level drawpoints are 4 Load Haul Dump (LHD) machines each of 6 cubic metre carrying capacity, transporting the rock an average distance of 120 metres to crushers located either side of the orebody. The rock is crushed to less than 180mm in size, then conveyed and hoisted, through the hoisting shaft, to the surface for overland conveying to the mills and concentration plant.

Development of a decline accessing Lift 1 commenced in late 1995. Two drill and blasted undercuts were used to initiate caving. E26 Lift 1 Block Cave has been producing at the design rate of 4.5Mtpa since September 1997.

The mining operation uses advanced communication technologies to remotely monitor and operate all fixed plant and some mobile equipment. The use of these and similar technologies has enabled Northparkes to achieve world level productivity from its employees and to exploit relatively low grade resources such as Endeavour 26 and make them profitable mining operations.

Figure 1 Northparkes Mine Layout
2.1 Mining Equipment

2.1.1 Overview

Equipment used underground includes six electric Tamrock Toro 450E LHDs (load-haul-dump underground loaders), two Tamrock secondary breaking rigs, two Krupp double toggle jaw crushers, a fully automated Siemens winder and an extensive conveyor system using Roxon plate feeders. All conveyors and crushers are controlled from the centralised mine control room. The block cave extraction level layout is split into quadrants, with each crusher servicing two quadrants.

2.1.2 Tele-Remote System

The LHDs, each fitted with a tele-remote system, were supplied by Tamrock Loaders OY of Finland. Nautilus International were chosen by Tamrock to design and supply the tele-remote system for the LHDs, which includes an antenna system in each quadrant of the mine extraction level.

The antenna system is directly connected to a desktop PC located in the underground control room, with each quadrant allocated one of six channels for tele-remote control. The remaining two channels are designated as auxiliary channels and are allocated to the eastern and western sides of the extraction level.

In each quadrant there are six antenna systems, each system consists of a panel antenna, a whip antenna and an intelligent antenna system control unit. The panel antenna is used for the video signal and the whip antenna is used for the control signals. The antenna system control unit is connected to the communications network slave via a single coaxial cable and a serial data link consisting of multicore datalink cable. The primary role of the network slave is to connect the tele-remote control PC to the antenna system with the highest signal strength.

There are six operator stations situated in the underground control room. The operator stations include the tele-remote control chair, remote video monitor, Nautilus control PC and screen and a 21” SCADA screen. In addition to their personal screen, it is possible for all tele-remote LHD operators to view SCADA mine equipment information using a colour projector in the control room.

The tele-remote PCs are situated next to the operator stations in the main control room underground. Each PC has a lock with only one key that is associated with a set of control frequencies, making it impossible to simultaneously operate one LHD from two stations.

A system of infrared barriers is used to safeguard personnel and other equipment from the tele-remote LHDs.

2.1.3 LHD Description

The LHD vehicle has an overall length of just over 10 metres, a width of 2.7 metres (measured on the bucket), and a height of just over 2 metres (without cabin). The block cave extraction level layout is split into quadrants, with each crusher servicing two quadrants.

The bucket can be raised to a maximum height of 5.6 metres. The bucket has a volume of 6 m$^3$. The empty weight of the vehicle is 33,000 kg, and the maximum load carrying capacity is 12,000 kg.

The LHD is powered by a 160 kW electric motor. The wheels are driven via a torque converter and a gearbox with eight speeds (four forward and four reverse). Steering and bucket movements are hydraulically operated.

Figure 3 shows a side view of the LHD. Note that the cabin (seen above and to the right of the rear wheel) can be removed for remote operation. In practice the cabin is left on the machine, allowing for maintenance and manual operation.

Figure 4 shows a view from above. The articulation point of the vehicle, about which the vehicle is steered, is indicated in the figure.
3. THE TRAINING REQUIREMENT

3.1 Needs Identification

Before commencing tele-operation, safety consultants were commissioned to facilitate a weekend workshop with operational personnel from the mine. Team Leaders and LHD operators as well as mechanical, electrical and engineering personnel were involved. The hazard identification and risk assessment process identified a number of critical areas in manual LHD operation and for tele-remote operation of LHDs.

The consultants report[2] identified the systems that need to be in place to maintain the IR barrier, SCADA and tele-remote system standards. The report identified operation of the control system as a safety critical activity, and recommended that it be undertaken only by trained, competence-assessed personnel. It was recommended that a training system to be developed to ensure all operators are knowledgeable and competent to operate the system.

A competency-based training system for the tele-remote systems was therefore implemented. The training consisted of:

a) Examination of Standard Operating Procedures for level access and other critical procedures for safe tele-operation.

b) A physical examination of the operating environment, including a barrier check, level lockout, SCADA liaison, tele-remote chair pre-start and operation of the LHD in tele-remote mode (1st gear).

c) Practical assessment of the tasks above.

All underground operators were required to complete this training. The training approach advocated continuous improvement.

3.2 Training System Requirements

In order to provide the recommended training system, Northparkes required a system that would allow the evaluation of an operator’s skill with criteria more selective than just speed. The philosophy developed was that a consistent speed with no damage is preferable to a fast operator who has many small crashes or occasional large crashes. Use of the system was also required to provide familiarisation with the tele-remote’s controls and absence of physical feedback given during real tele-remote operation.

4. THE TECHNICAL SOLUTION

4.1 System Architecture

The simulator is hosted on a SGI O2 computer, which is located in the same control room as the tele-remote stations. The simulator program emulates the functions of a tele-remote LHD and provides the operator visual feedback on LHD operation and location in the simulated mine whilst recording their performance. The operator uses the same console as is used for controlling a real LHD. VRLoader interfaces to the operator console by “eavesdropping” on the serial interface between the tele-operation chair and the radio transmitter/receiver system.

4.2 Hardware

The SGI O2 host is configured with an R5000 CPU, 128 Mb of RAM and an SGI video output option.

The video output of the O2 is configured to produce an NTSC video signal.

4.3 Software

The simulator is written in the C programming language using SGI Performer[3].

The software is divided into a number of modules. The time budget allocations for each module are indicated in Figure 5. The calling sequence is shown in Figure 6.

Figure 5 Software Module Time Budgets

4.3.1 Instructor Station

The Instructor Station module checks for keyboard input (X-windows events) from the instructor.
4.3.2 I/O Module

The I/O Module is responsible for acquiring operator inputs from the Nautilus chair (or a flybox) and loading the Operator Controls data store.

![Software Calling Sequence Diagram]

Figure 6 Software Calling Sequence

4.3.3 Machine Model

4.3.3.1 Overview

The Machine Module software performs the following tasks:

a) Maintain and update the state of the LHD vehicle.
b) Handle the pause state by freezing the position of the LHD.
c) Determine the eyepoint and bucket & loader articulation positions for the Cull & Render modules.
d) Determine intersections with the tunnel walls.
e) Track information for the student records.

The state information includes position, orientation, velocity, acceleration, steering articulation, bucket articulation, bucket weight, camera selection.

The vehicle is modelled as having either a mass corresponding to an empty bucket, or a mass corresponding to a full bucket. The mass changes in response to the activities of the trainee.

The quantification of the severity of the crash uses a linear function of the modelled mass of the vehicle and the square of the velocity normal to the plane of the collision face.

4.3.3.2 Vehicle Dynamic Model

The vehicle dynamic model is derived from data contained in the LHD Operation and Safety Instructions manual[4].

The manual provided information on the force applied to the wheel as a function of time and selected gear. It also provides the rolling resistance for the fully loaded and empty cases. Figure 7 shows the graph of force vs. time for each gear.

Data is also provided for bucket raising, lowering and tipping times, maximum articulation angle and inside and outside turning radius.

![Machine Model Data Graph]

Figure 7 Machine Model Data

4.3.4 Image Generation - Cull

In order to reduce the time taken in the Performer Cull process, a pre-cull operation is performed.

To achieve the pre-cull, the layout of the mine was divided into segments, then each segment analysed off-line to determine the portions of the mine that would be visible from each location. The result was used to generate a look-up table, which is read by the software and the result used as the input to the standard Performer cull.

During real-time operation, cull examines the vehicle position and eyepoint and determines the set of mine database segments to be rendered. It also selects the part of the LHD that is visible.

4.3.5 Image Generation - Render

Render draws the view from the eyepoint, using the database segment list from Pre-cull, and the eyepoint and bucket articulation from the Machine Model.

4.4 Mine and Vehicle Visual Database

4.4.1 General

In order to provide a true representation of the mine, as-built mine design files in electronic DXF format were used to create a model of the south west quadrant of the extraction level. The DXF format plan view of the
quadrant (from as-built mine surveys) was loaded into the Multigen modelling package and integrated with drive cross sections. Digital photographs were taken of the walls and floors and applied to the polygon surface created in Multigen.

The model of the Tamrock Toro 450D and boom linkage were modelled accurately using engineering drawings and photographs.

4.4.2 Polygon Budget

As a precursor to the database design, a benchmark was done on an O2 at 25Hz using 100% of the CPU. The benchmark indicated that an O2 could draw about 1000 polygons at the required frame rate.

The software design budget was to allow 40% of the CPU to be dedicated to the rendering process. As noted above, the video output of the O2 was configured to produce an NTSC video signal, which operates at a 60Hz interlaced field rate, (therefore 30Hz frame rate). Therefore, the polygon budget was calculated as follows:

\[
\text{Polygon Budget} = 1000 \text{ polygons} \times 40\% \text{ CPU time} \times \frac{33\text{ms}}{40\text{ms for frame rate}} = 330 \text{ polygons per frame}
\]

Result: the available polygon capacity is 330 polygons per frame.

4.4.3 Tunnel Design

A decision was made to reduce tunnels to straight segments. The profile of the tunnel was designed using eight segments, as shown in Figure 8. In addition, four polygons were allocated for the floor. Therefore each straight tunnel section is made up of a 20 triangle T-mesh.

![Figure 8 Tunnel Profile](image)

About the worst case view in the tunnel complex will give visibility of 12 tunnel sections, which equates to 240 triangles.

4.4.4 Polygon Allocations

Bases on the above design decisions, the following polygon allocations were made:

a) 240 polygons for the mine tunnels
b) 30 polygons for signage, etc
c) 60 polygons for the LHD model

5. RESULTS

5.1 Method of Operation

A new operator record is added to the database each time the simulator runs. The student’s name is typed in at the beginning of the session. Information recorded in the database includes:

- a) Session duration
- b) Average speed of the LHD
- c) Buckets moved in the session
- d) The total time that some part of the LHD “scraped” along the drive wall
- e) The number of damage incidents in the session and an estimation of damage severity (on a scale of 1-5).

At the completion of the training run the operator’s performance information appears on the screen. Damage severity estimation is a combination of LHD speed at the time of impact and impact angle with respect to the drive wall. The estimation is designed so that a small collision at a high speed has a similar severity to a more substantial collision at a low speed.

The best operators on the simulator were chosen to be the first tele-remote operators. No operator that had not used the simulator for a minimum period was permitted to operate the Tele-Remote LHD. The criteria used to judge the “best” operators was the lowest number of wall scrapes and crashes experienced during the training sessions, with overall productivity also taken into account.

5.2 Benefits Achieved

One of the major benefits of preparing operators with a training simulator is control familiarisation. VRLoader is designed to utilise precisely the same controls as the tele-remote chair supplied by Tamrock. During the initial commissioning period, Nautilus technicians were impressed with the operators’ ability to quickly adapt to the control of the LHD. Initial productivity information supports this anecdotal evidence.

VRLoader also gave LHD operators the opportunity to develop a feel for remote operation, which required operation without the usual sense of perspective and other sensory feedback gathered during manual operation.

The simulator was well utilised prior to the commencement of tele-operation.

5.3 Analysis of Results Achieved

Experience at Northparkes has shown that operators that perform and produce well on VRLoader also perform and produce well under real tele-remote operating conditions. Interestingly, as most operator’s tele-remote hours increase, their tele-remote productivity approaches that recorded on the simulator.

Whilst this may appear to indicate that the simulation did not provide adequate training, there are two factors that would explain this result:
a) Even though the operators knew what the controls did, and the simulator controls closely imitated the type of proportional control the tele-remotes are equipped with, there was a significant amount of peer pressure not to damage an LHD. This pressure would not have been present in the training sessions.

b) There is a mechanical difference between each loader that is associated with the hydraulics on the individual machine. The simulator was modelled to the Operator Manual data, as noted above, and so probably did not match any specific machine.

Therefore, it would be quite difficult, if not impossible to get the simulator to simulate each individual machine’s steering/bucket control characteristics. So when an operator changes machines or when changing from simulator to machine, the operator has to get used to this change.

In light of the above results, it is possible to say that the simulator allows evaluation of an operator’s potential on the LHD as well as familiarising them with controls.

To assess results of the simulator, records of the 11 tele-remote operators were examined. The measure chosen to estimate the operator’s care of the machine was distance covered per wall scrape second. The three operators of the tele-remote LHD with the highest distance covered per wall scrape second have not reported damaging the LHD at all when driving in tele-remote mode. These operators also have good productivity results on both the VR simulator and in actual tele-remote operation.

Use of the simulator limited costly physical damage to the LHDs when operators were training. The automation of all LHDs at Northparkes is a priority for safety and productivity reasons. The technology is available to allow Northparkes to reach this goal so it was decided to postpone tele-operation of LHDs until automation systems are installed, thus eliminating the possibility of unnecessary damage to machines.

6. LESSONS LEARNT AND CONCLUSION

6.1 VRLoader Specific Lessons
One of the negative aspects of a virtual reality training tool is that operators’ expectations of immediate performance may be high. An operating standard was adopted to counteract this potential.

In Northparkes’ specific situation, the simulator could have had a better (easier to operate) instructor interface.

6.2 Application of Simulation to Mining
VRLoader represents the first application by Thales Training & Simulation (TT&S) of simulation technology to the mining industry. The project was the culmination of a significant effort by TT&S marketing staff to create an interest in the technology.

At first glance, the mining industry appears to be an ideal candidate for the use of simulation technology. There is a strong focus on production efficiency and safety, and the equipment in use is almost always expensive to acquire and repair. Furthermore, due to the need to maximise production, there is little, if any, time available on the equipment to allow for operator training. However, use of simulators in the mining industry remains sporadic.

The authors offer the following suggested reasons for this situation.

a) Pressures on technical staff in the industry does not easily allow them to concentrate on much else other than safe production – there’s a lot of talk about “core purpose” and “main objectives” (and simulation isn’t yet the ONLY way to get things done safely).

b) Simulation technology still may seem like “pie-in-the-sky” and hasn’t had the opportunity to really prove itself in the context of the mining industry.

c) Situations change so quickly in the mining industry that a simulated scenario for today may not be applicable tomorrow.

d) The switch to training using simulators requires a step change in thinking.

e) A simulator is still “removed” physically from the real thing. For Northparkes, that’s exactly what was wanted, as operators would feel exactly that when they changed to tele-remote from manual operation.

f) In the Northparkes situation an operational person was in charge of the simulator and maintenance people were in charge of tele-remotes. Crossing the great divide may have affected simulator use.

6.3 Conclusion
VRLoader represents an effective use of simulation technology in the mining industry. Significant benefits were achieved in the areas of operator selection and training. The potential for greater use of simulation technology in the mining industry remains.

7. REFERENCES
4. Toro 450E Operation and Safety Instructions, Tamrock Loaders, 1996