

# 3D Simulation for Training Mining Equipment Operators

## 1.0 Introduction

**O**perator training for heavy equipment is an investment, and the return on that investment is optimum performance from the start with less machine downtime while everyone learns through experience. Well-trained personnel make a difference that's readily noticeable in uptime improvements and reduced maintenance costs.

Training personnel to operate heavy equipment continues to require real production machines in a real production work environment and the supervision of an experienced operator, with all of the risks and associated costs. Worse, scarce resources intended for production are not always available for training operators. And training problems are likely to become more acute due to increasing use of automation on the horizon e.g. remote-controlled equipment.

This is certainly true in the mining industry in particular, where the need to improve productivity has led to extensive use of mechanization and machines which have become progressively larger, more powerful, and more complex. As a result, they have also become increasingly difficult to operate productively. Such is the case for the hydraulic and electric cable-driven face shovels used for surface mining, and the electro-hydraulic articulated booms extensively used underground for drilling, rock-breaking and bolting; see Figure 1. In all cases, the tasks to be performed by the operator typically involves positioning (and perhaps orienting) the tool at the end of the boom using a combination of push-button, single axis levers, and two axis joysticks.

Such face drilling rigs for underground mining, commonly called "drill jumbos", are expensive single or multi-boom machines costing as much as \$1,200,000. Booms typically have six degrees of freedom (dof) to be able to correctly position and orient the rock drill (boom tip) at the rock face, in order to drill holes to follow the trajectory of the ore body e.g. up and to the right. Control is typically via 4 single axis levers plus 1 two axis joystick (along with an "anti-parallel" momentary push-button). Motion errors due to hydraulic limitations are partly compensated by the operator, depending upon his skill and experience. (Additional levers are used to control the drilling parameters.)

Clearly, operating such equipment efficiently is a key part of maintaining the mine's productivity, but learning the necessary skills is difficult and time-consuming. Indeed, according to one industry observer, as much as 160 hours of time at the controls is required to meet production targets.

When a new drill jumbo is purchased, the equipment manufacturer (head office or dealer) typically sends staff to the customer to provide on-site "hands-on" training for customer personnel. In order to maintain "reasonable" production levels, especially at the start, the trainers must spend part of their time operating the machine, while the trainees simply watch and learn. As a result, seat-time is limited; worse, it often takes time to discover that certain trainees are not well suited to this kind of work and never become fully proficient.

Clearly, if trainees could be better selected and better prepared for their seat-time in advance, they could better profit from the training provided by the equipment manufacturer when new equipment is purchased and delivered. In addition, a simulator could be used to help mine personnel maintain their operational skills, i.e. maintain the skills required to efficiently operate the booms and



**Figure 1: Drill Jumbo at work underground**  
(photo courtesy of Atlas Copco).

by Paul Freedman

Simlog

### Abstract

When it comes to mining equipment, "training" means "doing". But until recently, the only way to "do" was on a real production machine in a real production work environment under the supervision of an experienced operator with all of the risks and associated costs. New 3D simulation training products are changing all this by helping training staff better select the right personnel to train and by helping trainees better prepare for their "seat-time" in a way that is reliable, completely safe, inexpensive, and always available. In this paper, we shall describe such training simulation and then review some of the new products coming to market from companies such as Simlog.

### Sommaire

L'apprentissage par expérimentation est essentiel lors de la formation sur les équipements de forage minier. Jusqu'à maintenant, la seule façon d'expérimenter était sur une vraie machine en production, dans un environnement de travail réel, sous la supervision d'un opérateur expérimenté, avec tous les risques et les coûts associés à ce type d'entraînement. De nouveaux produits de simulation 3D pour l'entraînement sont en train de changer cette façon de faire en aidant les formateurs à choisir les meilleurs employés à entraîner et en aidant les employés à mieux se préparer pour les périodes d'entraînement sur les appareils en utilisant un procédé sûr, complètement sécuritaire, peu coûteux et toujours disponible. Dans le texte qui suit, nous décrivons un appareil de simulation pour l'entraînement de ce type, puis réviserons quelques nouveaux produits sur le marché tels ceux de Simlog.

rock drills without having to move the machine, set it up, prepare the drilling targets ("round"), etc.

This is where training innovation is required, and where "graphical" or 3D simulation technology can help. The term "virtual reality" is sometimes used to refer to graphical simulation which emphasizes user interaction in real-time with 3D models.) In contrast to computer-based ("multimedia") training which lead the user through a series of pre-programmed (question/answer) learning steps, 3D simulation means specifying how the virtual environment should respond to each of the user's possible actions. Informally, one does not specify "how the game will go", since that depends upon the stream of decisions the user makes.

In a nutshell, 3D simulation means learning by doing, but in a simplified and more carefully controlled way than is possible with the real machine in a real work environment. (This is all the more useful when learning operational skills, since so much more can be taught by showing and doing, when compared to traditional classroom instruction. In the educational literature, this is called "situated learning".

Moreover, graphical simulation can also be used to help select training candidates since anecdotal evidence suggests that 10-30% of trainees lack the necessary aptitudes (e.g.

hand-eye coordination) to eventually become fully productive operators.

But until recently, real-time graphical simulation was extremely costly, due to the nature of the computing platforms required. All this is changing as PC-compatible computers offer faster clock speeds, multiprocessing (e.g. dual CPUs), and improved 3D graphics with hardware acceleration.

And so, for the new millennium, low-cost “desktop” training simulator products are now appearing for the mining industry. One such example, to be described here, is from Simlog ([www.simlog.com](http://www.simlog.com)), a new Canadian company based in Montreal, Quebec, dedicated to heavy equipment operator training. Among their first products are simulators for training operators of forestry machines and mobile cranes.

## 2.0 Mining Equipment Simulation

To date, graphical simulation of mining equipment has emphasized safety training, not operational (skill-acquisition) training, just like the “full flight simulators” as manufactured by companies such as CAE Electronics in Montreal, Quebec. Here, the idea is to give pilots (who already know how to fly planes) a virtual environment in which to learn to new features of new aircraft and especially to learn to cope with difficult flying conditions and emergencies in the air.

Consider, for example, the “driving simulators” recently developed for training haul truck operators for surface mining operations. There are two such products on the market today, one from an American company Digitran and the other from an Australian company Immersion Technologies. Both simulators incorporate real haul truck controls and instrumentation, a 3-axis motion base to simulate road conditions and grades, sound, and wide angle graphical displays. In addition, they simulate the essential truck dynamics (engine, transmission, brakes, steering, etc.).

Like all driving simulators, including the transport truck simulator developed by the Swedish company Prosolvia, these simulators are intended to help students:

- master the controls, instrumentation, and displays of real haul trucks
- learn to cope with difficult driving conditions including skidding and cornering, equipment failure, etc.

As one marketing brochure suggests, the products simulate “how the truck skids on a wet haul road or interacts with other machinery on the mine site. Operators learn how to make split-second decisions that could prove fatal if they were not practicing on the Simulator”.

Note the emphasis on training for safe operation, since trainees must already have, of course, appropriate driving licenses. Stated otherwise, these simulators are not designed to teach trainees the basics of driving trucks, but rather to expose them to the particular difficulties associated with driving trucks for (surface) mining operations. (In the same way, full flight simulators are not designed for people who don't know how to fly planes already.)

The same emphasis on operating equipment safely is found in the hoisting cage simulator recently developed by two Spanish companies, ESM and Hunosa. (The hoisting cage is an elevator in a vertical shaft used to lower people and equipment down into the mine, and bring them back up to the surface.) This simulator was also designed for situational awareness and safety training, along with the evaluation of operator aptitudes and reaction times. Here, real hoist controls are used for operator inputs, and the simulator offers simple 3D graphics and sound; a trainer's station is also provided. Once again, learning to operate the controls (a series of simple levers) is a small part of the simulator-based training.

But experience to date at Simlog with simulating forestry equipment and mobile cranes has suggested that much more added value for training can be found precisely wherever the skills required to operate equipment are difficult to acquire. In such cases, the simulator can provide a virtual work environment ideally suited to the “drill and practice” at the heart of mastering most operational skills, especially where such

drill and practice is costly and potentially dangerous. The design of such operational training simulators is the topic of the next section.

## 3.0 3D Simulator Design For Operational Training

In general, the nature and complexity of the hardware components of a training simulator are largely responsible for the final cost to the customer. Incorporating elements from real machines can make the simulator “feel” more realistic, but they also add complexity and cost. More importantly, when it comes to learning the basic skills to operate heavy equipment, such elements don't always make training more effective. Indeed, training “transfer”, i.e. helping trainees come up to speed as quickly as possible on real machines by preparing them first on training simulators, is a key part of the cost-effectiveness analysis of adding simulation aids to existing training programs when their use is not mandated by governmental authorities.

Consider 3D graphics, or the richness of the visual presentation; this is directly related to the choice of computers which drive the simulation: as the scene becomes more detailed, more computing horsepower is required to “render” the visual elements in real-time, driving up cost. But the need for perceptual realism is largely dictated by the kind of training to be provided. Indeed, human factors research about scene quality for flight simulators suggests that different kinds of visual properties are important for different kinds of tasks. For example, recent experiments have reported that real-time interactivity can be more important than pictorial realism for certain manipulation tasks. Indeed, when objects are in motion, image resolution may be reduced while still providing adequate perceptual cues. This suggests that the “basics” can be learned with even simple visual displays.

Audio feedback can also contribute to training. Along with reproducing the essential sounds of the machine at work, extra sounds can be used to provide additional feedback to the operator e.g. to signal undesired contact/collisions among objects.

But recreating the visual and audio elements of the real work is just part of the story. In order to ensure that the operational skills acquired on the simulator transfer to the real world, the simulator must faithfully reproduce the natural behavior of the machine and the “rules of interaction”. By “natural behavior”, we mean that the simulated hydraulic pistons of the boom, for example, should move in their cylinders with the same speed, and over the same distances, as the actuators in real machines. Reproducing such natural behavior means modeling the physics of how objects behave in the real world. In addition, we typically require collision/contact detection, whereby simple bounding volumes are associated with key objects to detect collision/contact “on-the-fly”, in real-time, and with no prior knowledge of how the objects move.

Of course, putting together all of these ingredients (3D graphics, sound, natural behavior, contact/collision detection) in a way that delivers true training added value is in itself a challenge and a recent survey of training simulators developed for the military pointed to two key weaknesses that simulators often exhibit.

Firstly, their training effectiveness is difficult to establish. This means that little or no data exists to describe and especially quantify the benefits of simulator-based training (when compared to training without simulators). Secondly, such systems are typically designed with an eye to machine simulation, not training per se. Stated otherwise, the emphasis is placed on reproducing the operational environment and natural behavior of real machines (an airplane, a tank, etc.) with little attention paid to how people can best learn to operate them.

Consider the analogy of learning to drive a car. Imagine how much simpler and quicker the process would be if we could learn to master just the steering wheel, then just the pedals, and then combine the two skills. Simulators that are well designed do just that, by breaking the learning of the essential elements of machine operation into small “steps” which build upon each other, in addition to varying the difficulty of the simulated task and the sophistication of the simulated machine behavior. In this way, learning is accelerated. By reducing the “cognitive load” at each step.

In the next section, we turn to the development of such a simulator to help train operators of underground mining equipment.

## 4.0 Drill Jumbo Operator Training Simulator

With these observations in mind, Simlog recently completed the development of a drill jumbo simulator for training underground mining operators in collaboration with Atlas Copco Construction and Mining North America based in Sudbury, Ontario; see Figure 2.



**Figure 2: The Simlog simulator with enclosure, colour monitor and operator console.**

The Simlog simulator recreates the essential components of the real drill jumbo control interface using industrial levers, joysticks and pushbuttons. The simulator also includes proprietary interface electronics, a single PC-compatible computer, and a conventional color monitor (which may be replaced, where desired, by more costly video-projection technology to obtain a larger field of view).

Simlog's simulator offers 3D graphics which combines the visual presentation of the boom and drill face with a unique series of artificial (non-real world) cues in order to improve the presentation of depth on the two dimensional computer display; see Figure 3. Indeed, human factors research suggest that such

visual cues greatly improve the presentation of depth. In addition, the Simlog simulator carefully reproduces the natural behavior of the rig and the essential sounds of the machine at work, along with the required contact/collision detection.

Work is now underway to harness the power of the graphical simulation by designing a pedagogical framework based on "modules" to lead the trainee step by step through the basics of drill jumbo operation. Indeed, it is this incremental introduction to the full complexity of the machine that makes the simulator such an effective training tool. Along the way, "performance criteria" are used to measure the trainee's progress and evaluate the (simulated) work being performed. All of this data is then stored in the simulator database on a per trainee basis.

For example, one such module is devoted to mastering the drill jumbo controls (levers, joysticks, and pushbuttons). A series of holes to be drilled ("round") is displayed on the rock face and for each trial, just one is identified as a target hole. A cylindrical "tail" extending from the target hole identifies the specified drilling orientation. Now the trainee must use the controls to position the rock drill tip such that drilling would occur, with the specified orientation, at the drilling position. The trainee's performance is measured by the following criteria: time to complete the trial, errors in position (horizontal and vertical), errors in orientation (pitch and yaw).

Finally, the simulator will also offer (as all Simlog products do) a Web-based interface for the trainer to monitor at a distance the progress of trainees by reviewing the data files in the simulator's database. In addition, the same interface can be used by the trainer to perform various administrative duties such as creating a new class, adding a trainee to the class list, etc. Just now, work is underway to develop some statistical analyses to help the trainer compare trainees in the same class, and compare classes against each other.

As for the anticipated added value of the simulator for training, we can look to our previous experience in the forestry industry. Indeed, the training challenges of the mining sector resemble those of the forestry sector in at least one way: the machines, by themselves, are insufficient since in both cases, operational resources are required (mine or forest).

**Figure 3: A closer view at the 3D graphics of the Simlog simulator.**



Consider the results of extensive field trials conducted with Simlog's forestry machine training simulator prototype at an operator training school in Quebec in 1997 and 1998; all told, almost fifty students each received about 25-30 hours of simulator-based training. Note that forestry machines typically have just four directly controllable degrees of freedom, not six, and as a result, positioning and orienting the boom tip is simpler. (The control interface is also simpler than for the drill jumbo: there are just 2 two axis joysticks.)

When grouped together, the results of the four separate field trials clearly demonstrated the added value of simulator-based preparation before the seat-time (about 150 hours per student) in the woods. On average, about 25% more wood was harvested over the same training period and students were 10-15% more productive at the end. As for the costs of equipment maintenance due to training, they were down about 25%. In addition, tests demonstrated that as little as 3 hours on the simulator was sufficient to evaluate aptitudes of training candidates in order to identify those people not suited for this kind of work.

It's with these results in mind that we anticipate the training value likely to be provided by our drill jumbo simulator, the first in what will become a series of products to help train mining equipment operators.

## 5.0 Conclusions

Interactive graphical simulation (sometimes called "virtual reality") means creating a synthetic (artificial) perceptual experience which corresponds to a real perceptual experience. In this article, we began by describing the essential ingredients of such simulation for training and then presented an overview of simulators now available to help train mining equipment operators, including a new product from Simlog, Canada's leading training simulator specialists.

Looking into the future, it's wise to remember that 3D training simulation is still in its infancy. Simlog, in particular, is committed to working with industry stakeholders to develop new products wherever heavy equipment operator training can benefit. In addition to simulator development, Simlog also provides complete training services using its own products, under the supervision of training professionals. Such services may be provided either on the customer premises or in our corporate offices (at a reduced rate).

### About the Author

**Paul Freedman** holds degrees in Engineering Physics and in Electrical Engineering from the University of Toronto, the University of British Columbia, and McGill University.

He was for many years Lead Researcher at the Centre de recherche informatique de Montreal, one of Canada's leading research institutes in information technologies.

In 1999, he left CRIM to found SIMLOG and commercialize innovative 3D simulation technology developed at CRIM for training forestry equipment operators.