The Role of Interactive 3D Low Fidelity Maintenance Trainers within the Mining Industry

Brett Clifton, Kevin Hayes and Dr Neville Higgins

Abstract. With the continuing advances in hardware and software technology low fidelity interactive 3D simulator platforms are becoming more accessible as an aid to equipment maintenance training. Deployment costs and development timelines have often undermined the commercial viability of interactive 3D low fidelity simulator systems. Despite technological advances in both hardware and software the development of 3D low fidelity training applications within the confines of realistic Commercial Off-The-Shelf (COTS) project requirements has often resulted in products that have either been unrealistically slow or over-simplified to the detriment of training effectiveness. This paper reviews and discusses the range of multimedia training aids currently used to support maintenance training; it then critically evaluates possibilities for introducing interactive 3D low fidelity systems within the mining industry that would be both commercially viable and effective at delivering the required training outcomes.

1. INTRODUCTION

With the continuing advances in hardware and software technology low fidelity interactive 3D simulator platforms are becoming more accessible as an aid to equipment maintenance training.

Whilst 2D multi-media training platforms, currently utilized throughout the mining industry, can provide high resolution, and an impressive level of graphical detail, it is argued that:

1. The learner is constrained to pre-determined views and gains little spatial awareness of the equipment.
2. Equipment that has several degrees of freedom, such as haulage or extraction machinery, is difficult to realistically represent within pre-determined views using 2D rendered images.

The use of interactive 3D low fidelity systems within the mining industry has thus far been hampered by hardware limitations and costs. The perceived benefits of 3D systems are frequently regarded as being undermined by practical issues related to costs and hardware.

The real time 3D rendering of equipment views puts significant demands on processor time and has often necessitated the use of expensive hardware. Platform deployment costs and development timelines have often eroded the commercial viability of interactive 3D low fidelity simulator systems. In the past, the costs associated with developing and deploying low fidelity 3D systems has not been considered to be significantly less than those associated with high fidelity systems and, because of this, low fidelity systems have been under utilized. Within the confines of maintenance training in the mining industry, low fidelity 3D systems are the exception rather than the norm.

A commonly held view is that despite technological advances in both hardware and software, the development of simulator training applications within the scope of Commercial Off-The-Shelf (COTS) project requirements has often resulted in products that have either been unrealistically slow or over-simplified to the detriment of training effectiveness.

2. VIRTUAL 3D TRAINING

2.1 Learning Concepts

The fundamental concept behind the term 3D Training (or Synthetic Environments/Virtual Training) is the acceptance that the subject matter is not real. In the training environment this approach has been used since the first analogy was devised to explain a concept that was not easily picked up by the Student.

The strength of the analogical approach is that it allows complex real situations (Training Objectives) to be broken down into a series of relatively simple ideas (Enabling Objectives) which, when pieced together, help the Student’s understanding of the whole. In some cases the Enabling Objectives themselves can be broken down into smaller and simpler tasks commonly referred to as Teaching Points.

These lower level educational building blocks are, generally, targeted very precisely at introducing a new skill or furthering an existing one. Different methods can be employed by the Instructor to try to optimize the efficiency of training any given Enabling Objective. However this is complicated by the fact that individuals tend to prefer, and therefore respond better to, one of four preferred learning styles:

1. Pragmatist – looks at the practical side of training in terms of how it helps perform the individual the task
2. Activist – learns by doing the task
3. Reflector – wants to think about any new ideas to clarify it in their own mind
4. Theorist – wants to know the theories behind the new skills
The prime task of an Instructor is to raise the skill and knowledge level of as many of his or her Students as efficiently as possible. Given the existence of the various learning styles, it becomes apparent that the trainer’s best approach is to use a number of different training styles and techniques and a variety of different training aids.

2.2 Maintenance Training

To understand the benefits of low fidelity 3D training applications for maintenance training, the first logical step is to look at the maintenance task that the Student is expected to perform post training.

This identifies for the Course Designer the Training Objectives that need to be broken down as described previously into Enabling Objectives and Teaching Points.

In mining operations, for example, the maintenance task is heavily dependent on the range of equipment maintained, organizational culture and the task or process breakdown of the overall maintenance program.

That said, and irrespective of the subject matter, any maintenance task can, in general, be broken down into the following subtasks:

1. Replication – being able to reproduce the reported fault,
2. Identification – being able to accurately diagnose the source of the fault,
3. Rectification – correcting the fault by taking action appropriate consistent with the policies of the maintenance establishment and best practice,
4. Confirmation – checking to see that the identified fault has been cleared.

Each of the four stages requires a mixture of generic and specific physical and mental skills.

One approach commonly taken is to train Students to have a broad and in-depth understanding not only of the maintenance task but also of the science behind the equipment that they are dealing with. The maintainer needs to understand and appreciate the context within which the maintenance is performed so as to ensure that correct procedure is followed.

This means that the structure of a standard training course will include Training Objectives that can be typically grouped into the following Training Categories:

1. Initial Theoretical Training
2. Instructor Led Training
3. Systems Appreciation
4. Fault Diagnostics Training
5. Recognition Training

6. Equipment Familiarization
7. Scenarios Simulation
8. Visual Appreciation
9. Hand/Eye Co-ordination
10. Spatial Appreciation

2.3 Available Training Methodologies

No one approach will ever be a panacea for maintenance training within the mining industry. To deal with the Training Categories listed above a number of different types of training methodologies have been used, and shall continue to be used, each with their own strengths and, therefore, purposes.

Computer Based Training (CBT) is a well understood methodology which enables a Student to work through training material at their own pace. It can be designed to present information in different formats and with varying levels of Student interactivity. As the computer is providing the instruction the scope for dealing with Student questions, or requests for clarifications and examples, is limited. The ability for the Student to progress at their own pace and to revisit topics and the interaction required makes CBT a versatile tool that can be used for teaching generic background theory and specific operating principles without the need for Instructor input.

Computer Aided Instruction (CAI) technology assists Instructors deliver lessons benefiting from the multimedia capabilities of computers. The instructional content is provided by the Instructor which means that there is more flexibility than with CBT to cope with Student questions, clarifications and discussions. Again this approach is best suited to teaching generic background theory and specific operating principles.

Emulation has developed within the past decade in response to the increasing need to train equipment operators and maintainers in increasingly complex, integrated systems. Emulators are computer based functional representations of the system or equipment platform with which the Student can interact as they would with the real equipment. To this extent Emulators can already be seen to be a form of Virtual Reality (VR).

The prime purpose of the Emulator is to provide the Student with an understanding of how a complex system or piece of equipment functions as an integrated set of sub-systems and to allow the Student to practice procedures in a safe environment.

The main strengths of a good Emulator is the inclusion of a number of instructional features, such as fault replication, Student record and replay, and “snooping”, that can only be achieved on a “virtual” system. There are also significant cost advantages and safety implications of software, rather than hardware based, practical trainers. Replicating or simulating certain
faults on real equipment could be both damaging to the equipment and potentially dangerous for both the Student and Instructor.

Of course, at some stage in the maintenance training curriculum, the Student has to become familiar with the physical aspects of the tasks to be performed. Issues such as ease of access to components and handling considerations related to the maintenance tasks must be effectively addressed. At the moment physical Part Task Trainers (PTTs), or the real equipment, is often used to cover this area of the training. The availability of real equipment, and the costs associated with taking it out of production to meet training needs, is clearly an issue here.

The main disadvantages of PTTs are the costs associated with maintenance, upgrades, storage, managing of safety issues and achieving a satisfactory level of Student exposure to the PTTs. The costs associated with PTTs, although typically a fraction of actual equipment costs, can still be substantial. PTTs can also be extremely costly to modify, this can be particularly difficult when there are type variants across a range of equipment that a Student is required to master.

The exercise of matching the available training applications to specific Training Objectives is heavily dependent on each particular situation and is beyond the scope of this paper. For the purposes of this paper it is useful to consider a typical distribution without the use of low fidelity 3D training applications as shown in the Table 1 below.

### Table 1.0

<table>
<thead>
<tr>
<th>Training Requirement</th>
<th>CBT</th>
<th>CAI</th>
<th>Emu.</th>
<th>PTT</th>
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<tbody>
<tr>
<td>Initial Theoretical Training</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
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<tr>
<td>Instructor Led Training</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>System Appreciation</td>
<td>Yes</td>
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<td>Fault Diagnostics Training</td>
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<td>Equipment Familiarization</td>
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<tr>
<td>Scenarios Simulation</td>
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<tr>
<td>Visual Appreciation</td>
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<tr>
<td>Hand/Eye Coordination</td>
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<tr>
<td>Spatial Appreciation</td>
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### 2.4 Synthetic Environments

One possible definition of synthetic environments could be:

“A computer-generated environment that, to the person experiencing it, closely resembles reality”

If the definition is left at this then Emulators are clearly an example of synthetic environments. For the purpose of this paper, however, the above definition will be extended to:

“A three dimensional environment generated by a computer at run time that, to the person experiencing it, closely resembles reality.”

This environment can further be defined as:

- Immersive/high fidelity – where extra computer peripherals such as goggles and gloves are used to produce the effect of being inside the computer generated environment,
- Non-immersive/low fidelity – where the environment is displayed in a conventional manner on a display screen and interactions through standard computer input devices e.g. a mouse or joystick.

Therefore an interactive 3D low fidelity maintenance training application can be described as a photorealistic simulation:

- Of either a real or planned environment,
- That can be experienced visually in the four dimensions of width, height, depth and time.
- That provides a Student centered interactive experience of equipment and complex environments.
- That accomplishes real-time rendering with the potential for tactile and other forms of feedback.
- Where the environment is displayed in a conventional manner on a display screen or a number of screens and interactions through standard computer inputs e.g. touch screen, mouse or joystick.

The key feature that synthetic environments bring to computer based training applications is a real time rendering capability. The value of synthetic environments is that they can offer experiences that would otherwise be inaccessible to the Student, either because such experiences would be too expensive, too dangerous; occur at the wrong time, or in the wrong location.

The key reason for using synthetic environments within the context of maintenance training is to enhance Student computer interaction by utilizing the Student’s natural talents for analysis and pattern recognition. By making information easier for the Student to assimilate, the Student becomes more
immersed in what is presented and can therefore determine what action should be taken rather than simply evaluating presented information.

By providing the Student with a sense of position, direction and depth, as the Student moves virtually within the scenario the visual display and auditory landscape is interactively and dynamically rendered and refreshed to reflect the Student’s position and perspective in time and space relative to the objects within the scene.

As in the case of Emulators, the ability to represent reality on a computer does not, in itself, provide a training aid; the real value comes from the instructional features that surround it. Synthetic environments can, therefore, be most effective when it they are interconnected with, and merely a component of, a complete suite of training applications.

Low Fidelity 3D Training Applications and Theoretical Training

The advantages that low fidelity 3D training applications can bring to the theoretical and conceptual side of maintenance training is the ability for the Student to become familiar with the physical layout of the subject matter. When training on specific pieces of equipment this could involve 3 dimensional models which can be viewed from any angle and, potentially, set in motion to illustrate their operation. For integrated systems, such as mining equipment, this is more likely to involve a 3 dimensional model of the equipment which enables the Student to “walk around” the equipment and gain a spatial awareness of the system. With reference to table 1, therefore, low fidelity 3D training applications can be used to extend the applicability and effectiveness of CAI and CBT.

Low Fidelity 3D Training Applications and Practical Training (Emulation & PTTs)

With regard to practical training, Emulation and PTTs have very different prime roles. Emulation is geared towards the cognitive aspects of dealing with complex, integrated systems while PTTs focus on the spatial awareness and physical task aspects of the maintenance task.

The main area of impact that low fidelity 3D training applications have on this arrangement is that an element of the spatial awareness training provided by the PTTs can be replicated on the Emulator.

There is a prevailing perception that for 3D virtual training applications to relieve PTTs totally of their worth as a training aid, the rendered environment would have to be so extensively immersive that the cost benefits of moving away from a physical hardware mock up of the actual equipment would be minimal.

Experience in other industries, including aviation and defense, however, has repeatedly demonstrated that the business benefits of low fidelity 3D training applications typically do exceed development and deployment costs. The deployment of low fidelity 3D training applications within a maintenance training curriculum provide real cost savings and an increase of training effectiveness.

The addition of low fidelity 3D models provides the Student a fully interactive equipment view, enabling a closer representation of the equipment as it allows the Student free access to any number of views.

One of the main cost advantages of a low fidelity 3D training application is its ability to run on standard COTS hardware. Issues and costs relating to deployment, maintenance and upgrading will be more efficiently handled, in regards to both time and costs, if the hardware and software components of the solution are more generic than specialized.

Low Fidelity 3D Training Applications within the Mining Industry

Advanced high fidelity and low fidelity training applications, like those used extensively in the aerospace and defense industries, are relatively new to mining but they are becoming a key part of mine-site training programs.

Mining equipment owners are striving to get maximum returns not only from their investment in high cost equipment, but also increasingly high priced personnel. There is enormous pressure on mining and resource companies to achieve these objectives without compromising safety.

The following factors typify the modern mining workplace:

- Increasingly complex operating processes
- High safety standards and increasing mechanization
- Rising equipment costs
- Greater pressures to increase productivity and reduce equipment downtime

Mining operators are faced with a growing need to optimize existing equipment performance in the face of lengthening delivery lead times for nearly all primary mining equipment.

Maintenance training for modern mining equipment requires Students to learn procedures, which integrate diagnostic skills with remove and replace skills.

Typical modern mining platforms are complex systems, employing multiple computer processors, sensors, and displays linked by networks of digital buses. These highly complex systems often make use of this digital equipment to provide on-board diagnostics. Maintainers also frequently use advanced test, maintenance, and diagnostic equipment to troubleshoot these systems. However, even though the built-in tests and the numerous automated in-system checks provide invaluable information, there is still the need at certain points in the diagnostic process to find
components, disconnect cables, examine the
equipment for damaged connectors, and/or do
electronic troubleshooting using standard support and
test equipment like multi-meters, break-out boxes, etc.

It is becoming increasingly common in other industries
to see computer-based virtual maintenance training,
typically using low fidelity 3D rendering combined
with 2D images, as an adjunct to more expensive
constructive and live hands-on training.

Low fidelity 3D training applications ensure that
Students are familiar with equipment maintenance
procedures before they are required to operate on the
real world equipment, greatly reducing the actual
hands-on training time required and ensuring the
greatest transfer of needed knowledge and skills.

The use of low fidelity 3D training applications speeds
the development of superior operating and risk
aversion skills.

Low fidelity 3D training applications decrease the
requirement for hands-on trainers and actual
equipment (or mock ups) for institutional training,
providing sizeable savings in classroom
implementation and life-cycle costs for businesses.
Low fidelity 3D training applications lower equipment
usage for training and thus reduce the requirement for
equipment to be taken off production lines for training
purposes.

An additional benefit from lower training usage on
operational equipment is a reduction in the wear and
tear on this equipment due to training – i.e. a reduced
maintenance of the maintenance equipment!
Additionally Instructors are typically able to
effectively train classes with a higher Student to
Instructor ratio. This is becoming more important as
there is an increasing shortage of qualified Instructors
in the classroom due to the prevailing skills and labor
shortage within the mining industry.

When considering the development and deployment of
low fidelity 3D training applications, organizations
should strive to ensure that the solution uses COTS
hardware and software components wherever possible.

Advantages that are connected to a COTS based
solution include:

- Flexibility: components can be combined in
to various configurations; the capabilities of
the application can be altered or augmented to
meet changing requirements.

- Reusability: A component can be re-used in
various configurations to support another
capability or to augment/modify an existing
capability.

- Extensibility: The system can be extended
with new features

- Communication: If suitable interfaces are
offered, the components can communicate
with each other and with other applications.

**Conclusion**

Synthetic environments are not, in themselves, a
training aid but an enabling technology that can be
used within the arsenal of technologies available to the
Instructor. Whilst high fidelity immersive systems are
becoming typically associated with operational
training within the mining industry (and will continue
to remain so) there is an opportunity available to
deploy low fidelity 3D training applications to
maximize the effectiveness of maintenance training
within the mining industry.

The use of Low fidelity 3D training applications is a
cogent and highly cost effective method of providing
maintenance training within the mining industry. It
allows the Student to train at their own pace and
allows them to make the inevitable mistake without
injury or property damage.

A COTS based low fidelity 3D training application
should be considered within the context of a complete
maintenance training solution that will typically
include a variety of training systems, each type of
training application being utilized appropriately within
the context of the required performance outcomes.

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