

Assessment of maturity of mining industry simulation

P. Stothard*, School of Mining Engineering, The University of New South Wales, Sydney, NSW 2052, Australia,
*Corresponding Author email Phillip.stothard@curtin.edu.au

P. Swadling, Chief Engineer, Thales, Australia.

Abstract

Mining is a mature user of high technology. However, the maturity of mining simulation use is unclear. This paper compares mining to other industries to assess maturity. Simulation technology has been implemented at varying levels of complexity, sophistication and success. Rapid advances in hardware and software make low cost, mass market and high end small market computer based simulations readily accessible. When mining is compared to other industries, simulation acceptance appears immature, particularly in the areas of risk and hazard reduction, simulation design, operational command and control and a formal implementation framework. The question asked by this paper is: 'What is the level of maturity of interactive computer based simulation in the mining industry when compared to other industries?' The paper reviews some of the many interactive visualisations and simulations developed for the mining industry. The outcome is a basic qualitative maturity model of simulation in the mining industry as of 2010.

Keywords: Mine simulation, Simulation maturity model, Risk reduction, Virtual Reality.

Introduction

The question addressed by this paper is: 'What is the level of maturity of computer based simulation in the mining industry when compared to other industries?' The paper focuses mainly on the use of simulation for mine visualisation and training.

The method used to evaluate maturity is based upon a maturity model that considers the broad use of simulation, standards and regulations and community acceptance. Drawing on the comparison, an outline strategy for higher level engagement with the mining industry with respect to the adoption of sustainable mining simulation will be formulated and recommendations and conclusions presented on how to bring this strategy into action. The information presented in this paper can be later widened to other resources and infrastructure industries.

For the comparison, four industries are prominent that can be considered to be relatively mature. These are aviation, defence, health and rail. Anecdotally, aviation can be considered the most mature, followed by defence, rail and health. Defence is relatively advanced and experienced with respect to computer based simulation across a broad range of applications, provides a good benchmark and has many similarities to mining. Hence it is a good case study on which to base the mining appraisal. Rail is also very similar to mining demographically, but its maturity is less developed when compared to defence.

The primary objective of the maturity model is to engage the wider mining industry and demonstrate the need for a sustained and formulated approach to mining simulation.

Table 1 Simulation in mining papers

Organisation	Simulation	Purpose
AIMS	Underground and surface mine operations and equipment	Visualisation, safety, design, risk management, hazard identification and remediation
SIMRAC	Underground goldmine stope model	Safety and hazard recognition
Pennsylvania State University	Underground coal mine	Safety and hazard recognition
CSIRO	Underground coal mine data	Web based disparate mine data visualisation
NIOSH	Underground coal mine	Hazard identification and remediation
MIRARCO	Underground mine	Mine machinery, geology, geochemistry
MISC	Surface environment	Hazard awareness
THALES	Underground hard rock	Teleremote control
DMT	Operator training	Equipment operation training and visualisation
Tshwane University of Technology	Underground platinum mine	Hazard identification and remediation
UNSW	Underground coal mining, surface coal mining, uranium mining	Visualisation, hazards training, safe work procedures, environmental and social impacts, equipment training, site investigation
University of Queensland	Surface and underground mining	Visualisation, equipment operation, experimental analysis, hazard spotting

Mining simulators

A literature review was performed to identify the types of computer based virtual reality (VR) simulation technology that has been developed for the mining industry. The focus was primarily on publications by research and development organisations on the topic of interactive VR, on the premise that published research papers are a good indicator of activity as opposed to abundant commercial promotional material available on the web. Table 1 summarises the results of the search. Numerical simulators are not covered in this paper.

AIMS Research investigated the use of VR in mining[1], produced mining virtual worlds and described desktop PC VR hazard identification systems for mine safety training. Users inspected the virtual world, identified hazards and considered severity and probability[2].

Squelch[3, 4] described VR for training mine workers which depicts hazards that the user must identify and address. There was a good response and Squelch[3] remarked that a fully featured VR simulator would be achieved through a multidisciplinary team, consisting of a computer programmer, mining engineer, training specialist, graphic artist and psychologist.

Bise[5] noted that for VR to become a mine safety training tool, its attributes would have to be measured against other forms of delivery. The University of Pennsylvania developed VR based miner training programmes for hazard awareness. LeBlanc-Smith et al[6] reported a VR application for integration of disparate three- and four-dimensional mining datasets and demonstrated VR as a method to integrate disparate data. Virtual reality modelling language (VRML) and Java combined with a Netscape web browser were used. Filigenzi et al[7] began development of VR training software to help reduce the fatalities and injuries associated with mining accidents. Filigenzi et al[7] built a mine simulation that presented hazards. Orr et al[8] continued development of the virtual reality miner safety training (VRMST) that allows mine workers to practice evacuation procedures.

The University of New South Wales (UNSW) performed a scoping study and industry needs analysis to identify high risk equipment and processes that may lend themselves to VR technology. The project developed an enhanced hazard spotting simulation. The objective was to navigate an underground mine[9]. The project developed considerably over the 2000s to address the needs of the New South Wales coal industry. UNSW initially used off the shelf components, and eventually developed a scalable system that could present simulation on the various classes of visualisation system. The systems developed by UNSW were tailored to address the core competencies for mine workers and were developed in collaboration with subject matter experts. Many detailed simulations were produced and instructional design and cognitive load theory were considered in detail[10, 11]. Kizil et al[12] developed high quality VR modules for the Minerals Council of Australia. The aim was improved visualisation and hazard identification training for mine workers.

Kizil et al[12] concluded that inadequate or insufficient training was often blamed for most mining fatalities and VR training would reduce injuries and fatalities. However, justifying the use of VR in mining would be difficult without evidence and quantified numbers. Kizil's[12] mining VR simulations have been integrated into the Mining Education Australia (MEA)[13] curriculum.

MIRARCO approached VR differently and developed a VR lab (VRL) at Laurentian University. The system was aimed at visualising mine geoscience data and mining and mine safety applications. Visibility systems of a load haul dump (LHD) machine were also modelled[14].

Swadling and Dudley[15] described a training simulation developed by Thales for a remotely operated LHD. Operators can practise traversing the mine without risk of damage to the vehicles or mine. Statistics were gathered to assist with assessment. Swadling and Dudley[15] concluded that at a first glance, the mining industry appears to be an ideal candidate for the technology. However, the use of simulators in the mining industry appears to be sporadic due to the perception that simulation does not fit with the core purpose of mining production and is not the only way to get things done safely.

Deutsche Montan Technologie GmbH (DMT) developed VR technology to train mine workers for Deutsche Steinkohle (DSK)[16]. A VR training room was built that comprised of networked simulators. Photo realistic depictions of various machines operating in an environment allow trainees to study and participate in an interactive man/machine process as part of a group. The experience showed that a considered and systematic approach to operator training through the introduction of VR at a colliery produced significant improvements in operator training.

van Wyk and Villiers[17] assessed useability of VR developed to train South African miners and referred to International Standards ISO 1997, 9241-11 and 1999, 13407 for useability analysis. A VR system was developed following interviews with mine managers. The use of desktop VR and semi-immersive environments for training are considered by van Wyk and Villiers[17] to have application to the South African industry. However, more evaluation was required.

Lucas and Thabet[18] developed a VR mining conveyor belt simulator. The instructional based prototype was designed to familiarise trainees with the working environment around the conveyor belt and alert them to the related hazards. The module presents an automated walk-through or a manual walk-through and includes several conveyor systems. Hotpoints in the model are identified by flashing icons and are colour coded to indicate different types of information, including belt assemblies and components, possible hazards and safety issues.

Stothard and Laurence[19] described an interactive knowledge management system that uses interactive simulation to present environmental and social as well as production issues to undergraduate students in a Mining in a Global Environment course developed for MEA[13]. The course and simulation provide a site based experience for undergraduates and looks at the bigger picture mining issues that relate to mine sustainability.

The above chronology of simulations developed by researchers from around the globe shows that many simulations have been developed at various key locations. However, they have been developed in isolation, and only since 2006 have these researchers begun to work 'semicollaboratively' to promote simulation to the mining industry under the Simulation Industry Association of Australia (SIAA).

How can maturity be assessed?

Jones and Hutchinson[20] presented a broad overview of simulation maturity and suggested that aviation leads in maturity followed by rail, defence and health. This assessment is based upon application of legislation, statutory bodies, standards, documentation, staged learning via blended approaches, through to assessment and competency demonstration via tutor or observer.

There is also the consideration of interoperability that improves maturity from an operations perspective. In this paper, simulation maturity is assessed by examining the use of simulation in key areas of operations, which is the broad use of simulation within daily operations ranging from training, through to risk management and decision making strategies via simulation.

The qualitative model was developed by the SIAA, Resources and Infrastructure Special Interest Group, as a means of assessing the maturity of the use of simulation in the mining industry in comparison to other industries. The committee's assistance in producing this comparison is acknowledged. For the purpose of gauging and

demonstrating the maturity of simulation over the past six decades, the model is structured into three main categories: extent of use of simulation standards, regulations and infrastructure community acceptance. Each category criterion is described in Table 2.

Table 2 Maturity of simulation categories

Extent of use of simulation	Standards, regulations and infrastructure	Community acceptance
Single operator of high value asset: to what extent is simulation used to support training for individuals operating high value/high risk assets? Multiple operators of high value asset: to what extent is simulation used to support training for multiple person crews operating high value/high risk assets?	The availability of standards and regulations covers the following areas Equipment fidelity standards: the extent to which standards exist that define the level of fidelity and other capabilities required of simulations in order to make use of them for training	Public awareness: the extent to which people outside the industry are aware of the use of simulation in that industry Existence of community forums: the extent to which industry wide coordination bodies, conferences and exhibitions exist across the user and supplier community
Part-task trainers: to what extent is simulation used to support training in specific focused tasks?	Equipment interoperability standards: the extent to which standards exist that define the mechanisms by which different simulations can interact to train multiple crews	Extent of research literature: the extent to which academic research literature has been published about the use of simulation in the industry
Interactive computer based training: to what extent is simulation used to support knowledge transfer?	Formal acceptance: the extent to which simulations are accepted from a provider by using data based formal acceptance processes	Availability of products: the extent to which industry has developed simulation products to support the needs of the industry
Command and control training: to what extent is simulation used to support training for higher level decision making in an organisation? Decision support in operations: to what extent is simulation used to support operational decision making? Emergency management/threat response: to what extent is simulation used to support emergency situation response? Planning/construction aid: to what extent is simulation used to support planning for future activities?	Usage standards: the extent to which standards exist that define the way simulation can be used Data standards: the extent to which standards exist that define the data required to support simulations. Operation standards: the extent to which standards exist that define how simulations are to be operated and maintained Simulation curricula standards: the extent to which standards exist that define how simulations are to be integrated in an overall training curriculum	Availability of data: the extent to which data is available to support the development and qualification of simulations
Simulation integrated into curricula: to what extent is simulation directly embedded into training curricula, as opposed to being an after-thought?	Governance standards: the extent to which standards exist that define how simulations are to be managed in an organisation Certification authorities: the extent to which authorities exist that require external approval before the use of a simulation Operator training regulations: the extent to which regulations exist that define how simulator operators are to be trained and certified	

Maturity assessment

A maturity assessment was made via a maturity model. The data obtained for the model was acquired by assigning a 'score' out of 10, with 10 being the maximum, 0 being the minimum, with respect to maturity in the assessment areas described above. Each assessment is also assigned a weighting to reflect the relative importance within the category. The result is a weighted score out of ten for each category. The total for each category, for each industry can then be compared for current and past practice.

The weightings and scores currently entered in the model are derived from a qualitative assessment by experienced simulation practitioners. The results are still under development but present a good start toward quantitative assessment even though they are qualitative at the moment. Figures 1–3 show the results of an initial assessment in chart form. The immaturity of mining when compared to other industries is clear.

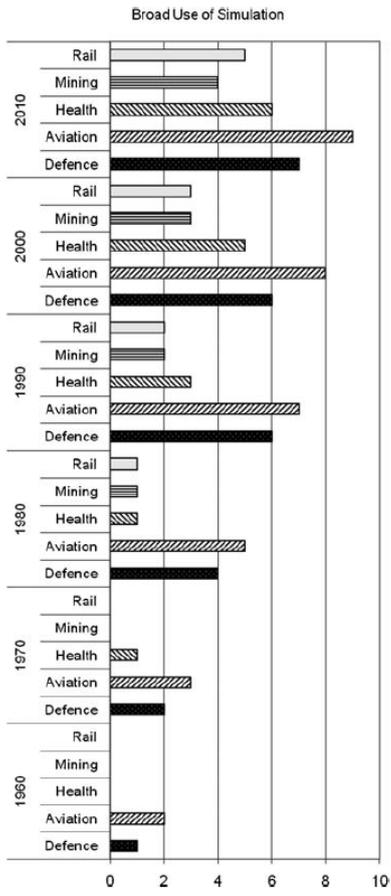


Figure 1. Maturity of mining simulation: broad use of simulation comparison.

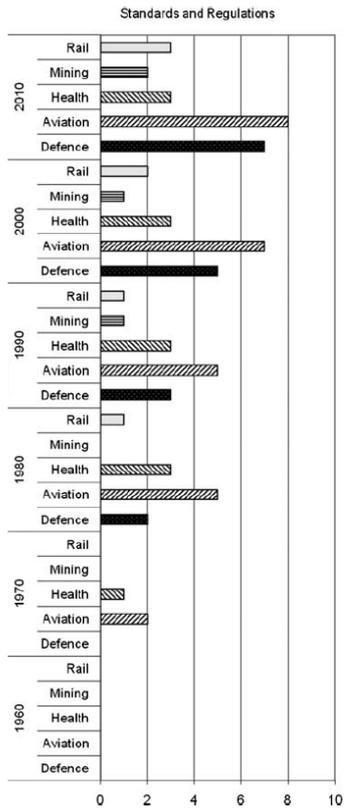


Figure 2. Maturity of mining simulation: standards and regulations.

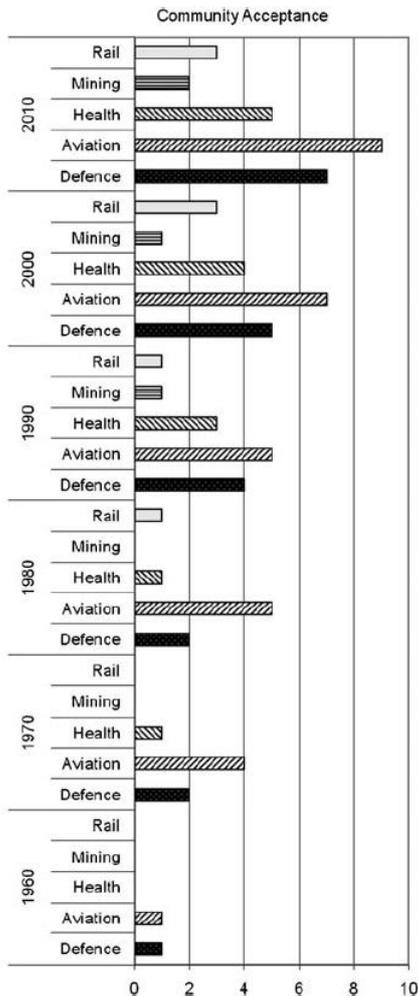


Figure 3. Maturity of mining simulation: community acceptance

Industry comparative analysis

Why perform comparative analysis?

In order to draw lessons from the comparative analysis, it was decided to select one of the more mature industries, which has valid points of similarity with mining. After a review of alternatives, aviation appears to be the most mature industry, however, defence was chosen over aviation because defence and mining have similar issues to manage. For example, the monolithic structure of defence is similar to many large mining companies, although there are actually numerous mining companies.

The way that work is organised in mining is such that people generally work in small teams and multitask. The team has a leader and the highly regulated (on-site) structure means that decisions move up and down command chains and operate within strict guidelines derived from job safety analysis and risk reduction procedures with the aim being to minimise personnel and financial risk.

Mining is a dynamic environment that changes constantly and quickly; hence the risks that miners have to assess and manage are continually changing. There is also a turnover of personnel that in some cases can be months which presents issues of sustainability in mining relating to safety, economy, efficiency, community acceptance and environmental impact. The issue of sustainability of simulation for mining is discussed briefly later in the paper.

The following sections review common issues between defence and mining and also the defence approach to simulation, much of which would directly apply to the implementation of simulation in the mining industry.

Discussion of common issues

Defence must ensure that capability is maintained and that a relatively small force is used to maximum effect. Modern mines are lean operations that must use high technology equipment, highly skilled personnel and complex infrastructure effectively to maximise the sustainability of the resource and return the maximum benefit to all stakeholders. Efficient use of resources is essential.

Retention of knowledge and experience is also essential, and industry must learn from past and current events to ensure that mistakes are not repeated. The goal is zero fatalities and injuries, again a key aspect for community engagement and sustainability and long term viability of a mine site.

Many mine sites in Australia are remote and mining personnel may only spend a year or so on site before they move jobs. When personnel rotate, there is a need to retrain and also retain knowledge that at present can be lost. The worst case scenario can manifest as 'Corporate Amnesia' where past mistakes are repeated and best practice and sustainability are not maintained.

Potentially high risk operational environments that impact on people, infrastructure and reputation are central to the business. The need for highly trained, well-motivated, multi-skilled and transferable workforces is essential for the effective operation of both defence and mining. The need to be able to take experience from one site and transfer it through 'what if' scenarios to an existing or 'Greenfield' site effectively and sustainably is essential to mining and defence.

Lessons learnt from defence approach to simulation

Defence is a mature user of simulation that invested in simulation with a vision for long term use: 'Defence exploits simulation to train for, prepare for and test military options for Government wherever it can enhance capability, save resources or reduce risk' (Defence Policy for Simulation)[21]. The approach is summarised in the 'Defence simulation roadmap (2006)'[22] that presents target states and initiatives to optimise simulation use by 2021. The roadmap acts as a guide for evolution of changes to simulation governance and addresses the right level of standardisation and control that yields trust in tools, quality of the data, how they are adapted and in the contribution they make to the primary defence outcomes. The roadmap translates the strategy into actions by identifying challenges to the use of simulation, and summarising factors that shape the response to the challenges. Key measures that cut across simulation capability are presented for achieving the vision for simulation.

In the 'Defence policy for simulation'[23] six strategies are considered to have direct application to mining. As a common reaction to the hazardous operating environment, both industries are looking to automation or remote control equipment to mitigate this hazard. This approach also has the potential to increase efficiency of operations and reduce equipment design and manufacturing costs. It also removes personnel from high risk areas.

For risk assessment and operational evaluation, there is a potential need to expose personnel to hazardous situations and the preference is to prepare personnel for this within a safe and 'forgiving' yet compelling environment. The defence analogue in this instance is mission rehearsal. The mining example is emergency response or new mining method evaluation.

In many instances in defence and mining, there is a need to collaborate and communicate effectively with organisations that are local, national and international to achieve successful outcomes. Managing communications between disparate teams is a challenge, and interoperability is highly important. In mining, this relates to community engagement and acceptance as well as the need for teams to work together effectively.

Finally, the need to attract, educate and retain the right people is essential to success. Without the right people, both defence and mining would struggle to survive. The MEA has approached this issue from a mining graduate

perspective quite successfully[13]. An acute issue in mining and similar industries is a 'skills shortage' as described by Hunter[24]; this is a long term complex issue that has serious implications. Simulation can help address this issue, but detailed discussion of a skills shortage is beyond the scope of this paper.

Employing and managing simulation effectively

Within mining, there are examples of simulations developed for training and education, but very little work is evident on the larger scale sustainable implementation of simulation into curricula. At university level, simulation is used in mining courses, for example, MEA's mining engineering courses.¹³ However use within training courses on mine sites is still very sparse. The realisation that simulators can be utilised for many purposes is not yet fully understood or appreciated.

Increasing appropriate use of simulation

Scoping studies have been performed that looked at the application of simulation to the mining industry[9],[25] and an area that simulation has not yet embraced in mining is the use of simulations to develop collaborative environments for the development of best practice risk assessments. At present, focus is upon building simulations 'on the fly' and then fitting them into training; however, a more appropriate approach may be to develop high resolution models of the mine environment from which safe work procedures and risk assessment processes can be developed and then these environments and procedures can form the basis of competency based training. A more detailed need analysis for a specific type of simulation or serious game is also needed to identify the appropriate technology and simulation approach for a particular task. Game playing in high risk environments may not be appropriate unless the instructional design behind the computer game is educationally sound. Simulation aims to replicate real life and in real life, a person cannot play games on a real site: risk taking behaviour is unacceptable.

Combining simulations to achieve greater benefit

The review of simulations developed within mining presented earlier shows that each system uses a different platform and software. Combining simulations to greater effect is currently not achieved because simulations have been developed in isolation. Combining systems and making them interoperable via standards is a challenge that must be met. There is a need for standardisation and an interoperability layer to be developed and implemented in a much more structured manner. International and Australian Standards do exist, but they are not always adhered to by commercial providers of simulation equipment for the mining industry. The VR simulations described earlier are all based on different platforms. When mine planning, geotechnical, geology, geophysics and mine modelling and automation software are all considered, interoperability and combination become even more important.

Ensuring adequate trained and skilled personnel

The use of simulation requires change management, and implementation must be accompanied by engagement with personnel who will use the simulation. There is a need to develop educational processes that teach people the value and application of simulation technology. People trained effectively in simulation use will grow in confidence and add value and refinement to the simulation. The use of modern educational theory techniques is also essential for long term sustainability of simulations and their acceptance by education providers. Carefully designed human factors and human computer interfaces are essential to engage personnel in the use of simulation. Simulations must be easy for users to use and integrate into their normal daily operations.

Ensuring that simulations are supported through their life cycle

Simulation technology advances rapidly and can be superseded quickly. The rapid increase in capability is shown in the examples cited in Table 1. The need for effective support through the simulation life cycle is essential, so that simulations take advantage of updated systems models, techniques and infrastructure. Purchasers of simulation technology also need to be educated in the need for life cycle support of their simulations to ensure maximum return on investment.

Securing access to data to support simulations

Data are extremely important. Mining companies are amenable to share mine data and data access per se may not be a problem; however, securing and validating quality data and managing it effectively may be difficult without a formal structure.

Commitment to the above strategies is considered essential. Defence recognised the need for collaboration and partnerships with other organisations in order to achieve its objectives, and that simulation technology changes rapidly. Mining must also recognise this need for company and provider collaboration to ensure that sustainable simulations are developed. Otherwise, the tendency will be to continue to develop simulations in isolation. The result will be proprietary, non-interoperable and unsustainable simulation systems.

The 'Defence simulation roadmap (2006)' also identifies several key themes. That simulation is widespread and about people. This applies equally to mining, the success or failure of a mine operation depends on its people. The technical challenges are not insurmountable. Mining simulations are common even if they are disjointed at present. The technology to produce them is now commonly off the shelf. The difficulty is defining what is required and building it to a controlled specification that allows return on investment to be monitored. The big simulation issues are not technological. The key issue is the sustained implementation of simulation into an industry via a structured and regulated approach, preferably via a coordinated industry wide initiative. Increased engagement with the mining industry, service providers and academia is required.

Academia brings new ideas and theories to simulation that can form the basis of sustainable and effective simulation technology. A major challenge for mining is to develop strong governance to ensure that the strategies in simulation are implemented effectively to meet wider demands. Simulation must meet the real needs of the industry in the form of risk reduction and improved efficiency.

The challenge is to provide the impetus for change across the wider industry at high level, to achieve the simulation vision for 2021 outlined by defence. Much of this vision is directly relevant to the mining industry.

The culture has to change. Change will be required by mining personnel at all levels. The issue requires a 'topdown' approach. High level industry managers must engage with the simulation industry to develop sustainable simulation technology to improve mining operations and long term sustainability

Issues and conclusions

Having examined the overall status of simulation in the mining industry, and assessed its maturity in relation to other key other industries, there is an opportunity to discuss some of the issues that are affecting simulation use in mining.

Mining has developed simulations in pockets and only recently has collaboration commenced via the SIAA Resources and Infrastructure Special Interest Group. This situation must change. Development and implementation are ad hoc and often mining simulation does not follow a road map or strategic plan. A major immediate initiative should be the development of a National Strategy, – by mining companies, – in the first instance to implement simulation in a manner similar to defence (and where appropriate, aviation). It should be noted that the majority of the initiatives that led to the current mature state of simulation in aviation were in fact led by industry sponsored forums, under the umbrella of industry associations such as the International Civil Aviation Organisation and the Royal Aeronautical Society. There may be an opportunity for the AusIMM or similar body to play a part in this initiative.

Some of the immediate issues that could be addressed are as follows:

Introducing simulation without detailed analysis in some cases and without considering the need for change management. Sometimes, there is a lack of Training Needs Analysis prior to introducing the simulation.

Too broad an approach trying to address everything at once with one simulation instead of a number of smaller modular interoperable simulations.

Lack of understanding of how simulation would affect mine operations, risk assessment processes, training techniques and the trainers themselves. Personnel may feel like they lose control. There is a particular need for the adoption of modern instructional design in training courses and simulation courses.

There is a perception that the time taken to train or evaluate a situation in a simulator, e.g. time away from site, can tend to cause progress to seem be slower, especially when more interactivity is required as users become more engaged and ask questions, etc.

Little real evaluation of what simulation can add to broader mine site operations.

As noted in the maturity analysis, the use of simulation in the mining industry is fragmented, lacking coordination and standardisation. This can be contrasted with the aviation industry, where industry wide groups are chartered with achieving consensus on technical standards, training approaches and operation. In defence also, there has been a significant effort spent in defining uniform policies and standards for the use of simulation to ensure that uptake is sustainable and relevant.

The benefits that the mining industry would achieve from using these industry domains as role models would be significant. If the mining industry establishes a broad industry forum, which is chartered to define a range of standards equivalent to those in aviation, including standards for simulations themselves, as well as how they are used, significant savings could be realised, and the 'state of the art' advanced more rapidly as simulation developers were provided with more certainty in regard to expectations. Mining needs a clear strategy in relation to developing the maturity and sustainability of simulation technology in the long term.

At the end of the day, the goal of any industry is to achieve economically and environmentally sustainable returns, with minimum safety risk to workers. Simulation can assist in all these areas, if used wisely and implemented strategically. Mining companies must lead this initiative in a coordinated manner in the first instance.

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