The Challenge of Technology Adoption and Utilisation in the Mining Industry – A Focus on Open Pit Mining Technologies

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Mining technology aimed at increasing productivity and safety has seen a rapid increase in adoption over the last few years and many of the large mining houses are showing an interest in the significant benefits of automation. A totally autonomous mine may be the end objective for some, however for the majority of operations there remains an opportunity to capitalise on the ability of existing mining technologies that have been used extensively for over 10-years. Many sites have seen quick returns from the most basic use of high precision GPS (Global Positioning System) machine positioning systems. Few sites would agree that their full potential, in terms of the breadth of available data and the fluid integration of the operational efficiency information being collected by these front-end systems, is being realised.

This paper will discuss:
- The primary definition and explanation of technology;
- Collective challenges facing mining customers and technology providers in driving the adoption and improved use of mining technology;
- The need for clear corporate objectives for technology use and phased plans to see to its incremental and deeper enterprise integration;
- The need for site champions, corporate change agents;
- Skills development challenges and the permanence of these skilled individuals at sites, to steward the expected use of technology.

Keywords: automation; human factors; knowledge; mining technology; skills; strategy

Introduction

Technology as defined in this paper refers to products, processes, tools, methods and systems applied or employed in the creation of goods and services and comprise four components (Khalil, 2000):

- Equipment – Physical structure and logical layout of equipment used to perform a required task;
- Knowledge – Basic knowledge of how to use equipment to perform a required task;

- Know why – Knowledge of cause and effect relationships and the resultant reasons for applying technology in a particular manner;
- Know how – Acquired knowledge and technical skill of how to do things well.

The latter three components of technology can be described as the human factors of technology.

Many human controlled processes or actions utilize some form of technology. In this paper, the mining technologies referred to represent stand-alone systems that are easily deployed on single machines, require minimal operator training or specialized skills for their use and can demonstrate immediate value add with minimal concomitant investment in terms of site change management.

The progression of Surface Mining Technology

In 1994, AQUILA and Caterpillar demonstrated the first use of GPS *(*Global Positioning System) on blasthole drills, shovels and dozers. After a number of early deployments at mine sites throughout the world, the technical viability and operational benefits this technology offered became widely accepted by the mining industry. Today high precision systems from companies like Caterpillar, Modular Mining Systems (Komatsu), Leica, and Wenco etc. are commonplace in mining. In many ways GPS was the spark that ignited broad interest in mining technology and enabled progress.

Drill operators now easily position rigs without survey support and accurately drill holes to designed depths. Shovels work mining faces 24 hours per-day regardless of weather conditions, maintaining accurate bench grades with the their operators continuously made aware of the boundaries between different material types. Significant benefits are derived from improved job understanding and improved operator ability. The fact that operators accurately execute jobs the first time, with minimal rework, survey or supervisory support, has been sufficient to justify the investment in these technology systems.

Companies like Caterpillar are committed to the development of autonomous open pit mining equipment. While automation may be the end objective for some operations, there remains a significant opportunity within the mining industry for both users and suppliers to exploit the current, proven technologies, to further optimize mining operations.

A mine is similar to a manufacturing facility in that; raw materials are acquired and processed to a finished product that is shipped to customers. In the mining production cycle this process begins with the drilling, sampling and blasting of the raw product. An optimal fragmentation consistent with loading, hauling and processing equipment is sought. Waste must be clearly differentiated from the key ore types and the ore loaded to vehicles that will deliver it to specific destinations such as a crusher or ROM (run of mine) pad from which it will be selectively blended to deliver a target feed to the mill for final site-based beneficiation, prior to shipment to markets and customers. A mine is, however, quite different from a traditional factory in the way it is managed. While the preceding steps in the mining cycle are neatly characterised, they are typically undertaken with comparatively minimal monitoring and generally poor quality control. The mining workforce is also challenged in terms of skills and the physical environment.

The objective of all operations should be to use, to the fullest extent possible, the existing technology with a view to: supervising, measuring and tracking the movement of people, material and equipment through the operation, targeting a scheduled output of known quality. With these core technologies in place, many of the benefits of automation can be realised as an intermediary step. Realistically, automation may not be the appropriate solution for many mining operations and these mines will benefit more by the adoption and effective utilisation of current technologies. Technology should be fit for purpose with the focus on the value adding ability and not used or applied for the mere sake of its existence.

Classification of open pit mining technologies available in the market

Open pit mining technologies can be described as fleet or machine management systems and are divided into two classes, namely: high precision (HP) GPS and low precision (LP) GPS to control either individual machines or the coordinated interaction of a machine fleet. These technologies are enabled by key infrastructures: GPS reference stations and radio networks or, more recently, wireless LANS which allow broadband real-time or near real time data communication between a data facility and the machines. These wireless LANS are more complex networks based on IP (Internet Protocol using TCP/IP) that in themselves, require specialised skills for design, deployment and maintenance.

Most fundamentally, the mining technology systems must provide the following parameters to adequately describe an event:

- Position (x, y and z coordinates);
- Event;
- Time of event;
- Resources involved;
- Raw material involved.

Prior to commercially available GPS-based machine control and guidance systems and communication networks, the time of events may have been captured but was seldom accompanied by the other required parameters, resulting in incomplete and sporadic data sets that were insufficient to drive process optimization. The combination of communication networks and GPS to capture event positions has resulted in the inclusion of time defining a 4D dataset (x, y, z and time). Thus what occurred at certain space and at a certain point in time is specified.

Collection of machine performance electronic data expands the data set by allowing analysis of operator efficiency, machine health and the influence of site conditions on machine performance.

The core LP and HP technologies have provided a foundation for a multitude of additional applications: machine guidance, dispatching and machine assignments, operator verification, operator performance monitoring, material tracking, collision avoidance, fatigue management, haul-road analysis, machine health and condition monitoring, optimal mine design based on machine performance, preventative and condition-based maintenance, failure prediction etc.

The Challenge of technology adoption and utilisation

Mining companies

Mining companies face a range of challenges in the adoption and utilisation of mining technologies. There is recognition of the benefits possible through technology but also, often a lack of appetite or ability to define and undertake the change management required to properly integrating new technologies. This phenomenon may be attributable to the nature of the mining businesses and commodity markets. Mining is a capital-intensive business with large barriers to entry into markets. These operations produce standard products including copper cathodes, zinc concentrate or gold bullion. Product innovation (meaning the mined commodity) doesn't contribute to operating mines, as the product itself cannot be improved upon. This begs the question: how does a mining company gain a competitive edge?

Operating mines can only gain a competitive edge through process and system innovation and the application of technologies that focuses on lowering the costs to produce the end product, improving safety and by assuring the quality of the shipped product.

According to Khalil, for a company to be successful, it must develop and adopt a Business Strategy that provides the guidelines on how it operates and the approved options available to exercise in reaching their long-term objectives. The core of the Business Strategy is imbedded in the mission statement, vision and the objectives that need to be realised. A mission statement specifies the reasons a business exists and the vision provides a snapshot of the desired future realities. A vision must be a milestone with a target timeframe for its realisation; it is otherwise, merely a "hope'' and will fail to provide the required challenge, accountability and inspiration.

A Business Strategy is formulated by considering internal and external factors to ensure that a company gains a sustainable competitive advantage. The purpose of a company's Technology Strategy is to gain a sustainable technological advantage that offers a competitive edge. The Business Strategy must respond to three fundamental questions:

1. In what business should the company engage?
2. How should the company be positioned in the market?
3. What technologies, marketing, production processes and resources are required to attain the desired position (Ibid)?

If a Technology Strategy is indeed fundamental to the Business Strategy (as would be evidenced by the growth in at least the ad-hoc adoption of mining technology in the mining industry) then a failure to develop a Technology Strategy, through which to widely communicate the objectives for technology within the Business, will lead to and explains the lack of technology direction and the failing in the ability of technology to deliver on the potential competitive advantage.

A common problem in the mining division of companies is the lack of aligned Business and Technology Strategies. Mining divisions need clear mandates and objectives to guide them in selecting the technologies required for them to achieve their objectives. Khalil suggests that the first step in developing a Business aligned Technology Strategy is to establish the company / mine's core competencies. Core competencies are the distinguishing collective sets of skills, knowledge, and technologies that a firm applies to assure its competitiveness. Core competencies are imbedded in the components of an organization's intangible or human technology elements as explained in the introduction: ''knowledge'', ''know-why'' and ''know-how''. Many organizations do not acknowledge these factors as ''technology'' and merely focus on the equipment or tangible component of technology. The human technology interfaces are the deciding factor, which will determine the successful application of the equipment component.

With the natural progression of mining technology over the years, the skills and knowledge requirements of the workforce has changed from physical and routine to more abstract and cross-functional, with increased IT elements. Technology has changed the role of the worker by codifying their tacit process knowledge into automatic routines and computer programs. The role of management is evolving in response to the workforce re-skilling, up-skilling or de-skilling, and the impact on the workplace culture (Abrahamsson *et al.*, 2008).

The human technology interfaces are more complex than the technology embedded in the ''knowledge'', ''know why'' and ''know how''. The success of any technological application is dependant on the continuous improvement, performance culture, drive for excellence and passion. This defines the need for both corporate and mine site-based champions. Corporate champions are the senior individuals that assure the strategic alignment and belief that the technology is essential to executing the strategy and realising the vision and objectives of the company: They need to have credibility and the influential power to spread the gospel.

Successful mine site-based champions typically have the following characteristics:

- Are strategically aligned and believe that the vision will be realised;
- Are in substantial decision making positions with the required amount of authority;
- Are non-transitory individuals who have worked at the specific mine-site for an extend period and will remain in place long enough to see to (i.e. champion) the realisation of the vision;
- Passionately believe in the ability of the technology to add value and/or improve safety;
- Have a can-do attitude;
- Have clear reasons and objectives for applying this technology and will challenge the users of the technology to validate / demonstrate (quantify) the benefits realised.

From the descriptions of corporate and mine site based champions, it is clear that champions are scarce individuals, often thinly spread across any organisation, in the labour market that has prevailed in the mining industry over the past few years. Without a suitable on mine champion, the introduction of new technologies and the required change management, it is unlikely to realise its full potential benefit.

The equipment component of the technology will not solve the problem or challenge at hand, it is simply the enabler. As described in the primary definition of technology only when knowledge is applied do we realise the promise or potential of technology. Passionate, skilled and committed people are required to apply this technology to generate value and solve problems. These people contribute a different skill set than conventional mine management and technical personnel. The change management required to successfully introduce and engrain mining technology systems is often under estimated by mining companies and is not recognised as a critical success factor.

Before any commitment to technology, a specification on all components of technology (Equipment, Knowledge, Know-How and Know-Why) needs to be developed as foundational to a total systems approach: commissioning, training, operation, and maintenance. The next step will be to conduct a gap analysis on each of the components of technology throughout the life cycle. This process needs to be facilitated by an on mine champion and the sizes of the intangible (human element) gaps will determine the probability of the technology being applied successfully. The tangible or equipment gaps can be easily bridged with capital and the only time constraint once the go ahead has been given will be the time to produce and deliver the equipment to site. The intangible gaps will require capital to be bridged, the extent to which is determined by the position of their current skills on the learning curve, the aptitude of the current skills and the time required to master the newly required skills or to externally acquire suitable skills (Mallett *et al*., 2008).

There are multiple mining technology users and customers in a mining company. Everyone from the CEO down to the operator needs to know their role and the implications of their actions. Mining companies may seek guarantees on the ability of mining technology systems to deliver value (e.g. productivity improvement and cost savings), but the suppliers are often hesitant to give such guarantees, arguing that the while they can and will guarantee the performance of the physical or tangible component of the technology, which is now mature and proven, the question of what improvements or benefits a customer realises is more a function of the commitment to its use. The risks of not realizing benefits are embedded in the ''Knowledge'', ''Know-How'' and ''Know-Why'' of the customer, which collectively defines their ability to adopt and leverage new technology.

OEMs and Technology Supplier challenges

Caterpillar and Komatsu (via Modular Mining Systems) are the dominant OEM (original equipment manufacturer) providers of mining technology systems. Caterpillar, through their Connected Worksite Division provides a complete spectrum of mining technologies that can be deployed on both Cat® equipment and other mining equipment. The other technology suppliers (key amongst that include companies like Wenco and Jigsaw) are non-OEM system developers.

Some customers seek a single supplier for delivery and maintenance of a total site technology solution while other customers (typically the more experienced mining technology users) are comfortable in selecting and integrating the "best of breed" system components from two or more technology suppliers. As the core technologies that underpin much of the mining technology have matured (e.g. GPS / GNSS, 802.11 TCP/IP wireless networks, IT standard databases and reporting tools) Caterpillar and other technology providers have moved the product designs to use open standards and enable the flexible deployment of their products with competitive technology offerings. The decision on whether to pursue a solution set based on customised integration of different suppliers' technologies is often made on the basis of risk management and the ability to hold one party accountable for the success of the complete technology system. While selecting a single supplier for the technology solution imposes a certain dependency on that supplier, it also offers, especially in the case of an equipment OEM, the fluid leveraging of vast intellectual property. As technology use progresses toward a greater integration and derived value from the technology front end (e.g. machine control and guidance systems), an increasing need arises for a single source to exercise coordinated control over the realisation of the desired ''solution set''.

Of late, there has been a resurgence of mining industry interest in automation and specifically automated haulage. The deep level of machine system integration required to automate a haul truck and deliver it as part of an autonomous production solution, will likely require site standardisation on the truck OEM's mining technology solution suite. At some levels, technology products from competing providers can be integrated with one another to satisfy a customer's ''best of breed'' desires (e.g. use of Caterpillar CAES and AQUILA systems with their other fleet management systems). The complexity of developing, implementing and supporting an automated haulage solution requires not only much deeper systems integration, but also single point responsibility.

Returning to the importance of the corporate Business and Technology Strategies, mining companies may loose sight of, or fail to define the objectives for the total technology system and descend to focusing on the physical components of the technology, rather than the pursuit of the systemic or corporate level challenges that the on the on-board machine elements of the solution are in place to enable. Suppliers are thus challenged by customers to develop technology that may fail to deliver on its potential or corporate expectations.

Mines should focus on the technologies they are in a current position to, or expect to be positioned to utilise. Asking OEMs and suppliers to develop technology simply because something can be done, does not mean it will find successful use or drive customer value. A good example of this was the Cat autonomous haulage program in the 1980s, which was first to demonstrate the technical viability of an automated mining truck. Having seen the technical viability demonstrated, mining customers were challenged to undertake the significant change management required to leverage and benefit from this technology. Today, a more technically adept mining industry is again faced with the option and challenge of introducing automated mining systems, as both Caterpillar and Komatsu pursue autonomous haulage solutions with renewed purpose. More importantly, the OEM's customers are challenged to understand their needs for autonomy versus the more mature mining technology systems that in many cases have yet to yield their full potential, due to ineffective use of, and integration of these systems as part of a corporate Business and Technology Strategy.

Nonetheless, some mining companies are dedicating capital, full time resources and mine sites, to making autonomous mining technology a success. While the piloting of such complex technology will not be without its challenges, these companies are already frontrunners in open pit mining technology by being among a select few participating in collaborative technology development and field validation.

Examples of application of mining technologies and critical success factors

In 1996, Fording Coal (now part of Teck) was both an early adaptor of High Precision GPS drill guidance systems and a visionary in terms of recognising that the immediate benefits to the drill's operation, are but a fraction of the total possible corporate benefits realisable. If the company plans beyond success of the onboard drill system alone, and considers it as only one piece of a total system which when operating in concert with the allied mine planning, survey and business systems, they application of the technology will deliver further reaching value.

Fording created a detailed corporate level plan to develop a complete ''drilling and blasting system'' (DABS) with an objective of saving $6M per year through improved blast results and shovel diggability. The low hanging fruit from the drill system was easily harvested; the elimination of manual staking and freeing of survey resources to work on more important jobs. The drill patterns were accurately executed and overall drilling costs reduced. These benefits were sufficient to justify the investment in the drill systems, but did not cause the company to stop with these basic successes. DABS called for and saw to the development of; software tools to allow automatic gathering and processing of rock hardness (or Blastability Index) data from the AQUILA systems, visualisation and analytical tools to allow the blasting engineer to use this data in selecting explosive and issuing hole specific loading instructions and ‘’strategic information infrastructure upon which to base continuous improvements and opportunities’’ (Skinner *et al*).

The DABS required a strong corporate vision and the will to assemble and manage a multi-disciplinary team of participants from mine engineering, mine operations and mine maintenance, at each of the Fording mine sites. Mine engineering was the key business unit partner and provided the vision, benefits, requirements, operating specifications etc. Mine operations provided implementation and testing with support from mine maintenance. Significant time was invested in the analysis of the system requirements and its high level design. While some groups found this frustrating and were more inclined to a ‘’just do it’’ approach, strong corporate leadership, forced acceptance of a methodical design approach and the sites were eventually won over by the long-term benefits this drove in terms of the DABS corporate adoption by being able to demonstrate incremental benefits along the way to the realisation of the full system capabilities.

The next example refers to an anonymous low volume open pit mine. This operation requires a complex, manually intensive, grade and quality control system, due to the high degree of variation in the orebody. Selective mining is conducted by loading out 10m benches in four 2.5m lifts. There are seven material types, each with its own destination and in addition, penalty elements are also considered for ore material. The beneficiation process is unique and the plant design requires minimal variability within a predetermined feed grade range to ensure optimal recovery is achieved at the lowest possible cost.

Currently, shovel operators load ore with the assistance of spotters and demarcated loading polygons. Material tracking is done manually and data is captured by tally sheets that are manually entered into a database. This manual material tracking and grade control system is dependant on a high degree of human supervision and monitoring which makes it unreliable and onerous to manage. This manual solution causes a lag in reporting that induces a hidden cost, as mine management is unable to act swiftly on opportunities or problems. The mine has a comprehensive data reporting system, but the bulk of data is captured manually. The technical personnel are fully engaged in data collection and entry, that the further analysis, creating actionable information and reporting is neglected and the opportunities for continuous improvement are forfeited.

Historically, the actual grade ROM zinc head grade at the operation has been consistently below the ROM zinc head grade predicted from assay results. This difference between the actual and theoretically achievable yield implies inadequate monitoring of the ore mining process, resulting in either ore loss or dilution.

The following solution has been proposed to improve control and quality assurance:

- HP GPS loader and shovel guidance systems to enhance selective loading ability at loading faces and stockpiles;
- LP GPS material tracking on trucks;
- Grade control and mine planning interface HP and LP GPS enabling material tracking from the loading polygon to the final ore destination

Additional functionalities proposed:

- Machine health and condition monitoring;
- Operator monitoring;
- Ancillary fleet monitoring;
- HP GPS drill guidance and monitoring.

This system will have the benefit of improved management control resulting in:

- Improved grade control and assurance;
- Improved productivity;
- Lower fleet operating cost;
- Increased optimisation opportunities identified in future as result of improved understanding of the mining process.

This solution was presented to a multi-disciplinary team of technical experts. The proposal was found to be technically sound, as the technology proposed is mature and proven, however the decision was made to delay the project. This decision was based on the excessive risk of project failure or ability to realise the full potential benefit of the technology as a result of the skills shortages and lack of a mine site champion.

Conclusions and recommendations

Mining companies, OEMs and suppliers need to recognise the challenges that exist in the adoption and utilisation of mining technology. Installing and commissioning a system is simply not enough to ensure it yields its full potential benefit or even basic benefits.

A vision with a time frame needs to be set as it instils an inspiring objective and not merely a hope of realisation. It is crucial to identify the technologies required to realise the vision. The vision will determine the destination of the technological journey and milestone objectives or targets along the way. Mining companies and operations need to prioritise their technology needs based on their business and technology strategies and must leverage their core competencies with technology to gain success. It is important to ensure that technology solutions are fit for purpose and have realistic objectives or milestones. 80% of the 50% solution is better than 15% of the 100% solution.

Mining companies, OEMs and suppliers together must embark on the technology journey. Each party needs to define their role and responsibilities along the way. All technology stakeholders must plan for the skills development and process changes that occur with natural technological progression (Hebblewhite *et al*., 2008).

It must be emphasised that only focusing on the physical equipment or hardware will not guarantee success. Any technology comprises of four components and a deficiency in any of the components brings about an increased risk of failing to achieve the set objectives and underutilising its full potential to maximise the return on investment. The human factors imbedded in the technology cause the most uncertainty and have the largest influence on its successful application. Operational and corporate champions are the most important role players in applying technology and minimizing the human risks. Operational champions are the scarce individuals that have been at a certain operation for a substantial amount of time with a passion for their work. There exists a requirement for developing technology career paths similar to project management career paths and a strategy to retain these skills. OEMs cannot be charged with providing a guarantee as to the "value'' of technology that is mature and is proven, they can only guide and assist with application but committed use is key. It is the responsibility of mining companies to ensure they have a well defined strategy in addition to operational and corporate champions before pursuing any technology.

The next breakthrough in mining technology systems will not be on the equipment or hardware side, but rather on the level of the human element. This will allow capitalising on the currently available technologies, with only the physical capabilities of the technology limiting a mine's ability to identify, monitor and control the multitude of inefficiencies we know exist in the mining production cycle, from pit to port. It is recommended that mining companies and OEMs and technology suppliers focus on developing skills to alleviate the human risk embedded in technology.

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