HOW AUTOMATION AND KEY PERFORMANCE INDICATORS (KPI’S) CONTRIBUTE TO SUSTAINABLE DEVELOPMENT IN THE MINING INDUSTRY

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Abstract

The application of automated systems can make an important contribution towards increasing the efficiency and sustainability of large and small mining operations. Automation can improve the quality of work for employees by reducing exposure to unhealthy or unsafe environments, and its introduction into mining operations provides opportunities for training and capacity-building. Autonomous haul trucks ensure consistent driving conditions (smoother braking and accelerating) reducing fuel consumption which results in significant greenhouse gas (GHG) emission reductions. Furthermore, vehicle maintenance is more predictable and better-controlled. Automated systems increase productivity and efficiency, thereby making projects more economically feasible. Timing and social issues are major considerations when implementing automated systems. Understanding the social, environmental and economic issues surrounding automation and its contributions to the extractive industry prepares a mining project to be successful with this added opportunity of automation impacting on principles of sustainability.

Keywords: sustainability, KPIs, mining industry, management
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What is Sustainable Development?

Today the notion of sustainable development is a common discussion area in all industries and across society. Sustainable development incorporates long-term planning of environmental, social and economic issues that weigh opportunities for economic development and social progress. Since the 1960s, when environmental consciousness began to increase, the idea of sustainable development has evolved to include increased emphasis and sophistication around how to measure and monitor sustainability. In Our Common Future, a report developed by the United Nations World Commission on Environment and Development, written in 1987, defined sustainable development as:

“Satisfying the needs of the present generation without compromising the chance for future generations to satisfy theirs”

It is not easy for mining companies to achieve sustainability principles because their industrial activities involve the extraction of non-renewable resources; to this end, organizations face challenges in improving accessibility to and management of these resources. Moreover, mine operations face major challenges related to social and environmental impacts – such as safety, occupational and community health, greenhouse gas emissions, and planning for closure. As such, in the context of mining, sustainable development must relate to creating sustainable communities, protecting the environment, and restoration of land post-mining.

While grappling with these challenges over the last decade or so, mining companies have begun examining new technologies that can improve their bottom line, while considering the contribution of these innovations to sustainable development. The idea is that by implementing new and automated technologies, mining companies can improve their performance related to the three pillars of sustainability, i.e., economic prosperity, environmental quality, and social equity. These three pillars are used today as key performance indicators (KPIs), which can be developed, measured, and used to monitor sustainability. A positive sustainability measurement is valuable to an organization, and will be reflected in its profitability, shareholder value, and its social, human, and environmental capital.

What is Automation?

Automation is a discipline involving many variables and equipment that includes instrumentation, sensors, final-control-elements, control systems, networking, and communication. The main objectives of automation are to control the behaviour of dynamic systems and emulate the maximum physical and intellectual human capacity to improve productivity through increased accuracy. There are several degrees of automation: controlled systems, supervised systems, automatic systems and autonomous systems. With each degree of increasing automation, there is less human intervention during the related task (Royal Academy of Engineering, 2009). Automation plays an increasingly important role in the global economy, particularly at this time when there have been record increases in demand for minerals and metals, while available resources are becoming harder to access (due to location and harsh environments). Automation is being explored as an alternative for mining companies in order that they can access ore from difficult environments while reducing the exposure of workers to health risks. In these instances, automation can be cost effective, and can also help to streamline operations with increasingly accurate production systems.
Growth and Application of Automation across Industries

According to a new study conducted by the ARC Advisory Group, (a leading organization in manufacturing, logistics, and supply chain solutions) process automation systems are expected to grow globally by 9.6%, at a compounded annual growth rate (CAGR), and with an contribution of over $47 billion by 2011 to the world economic market. Asia is leading in large automation projects, with China driving the global demand for automation (Plant Engineering, 2008).

Globalization is the main factor that is compelling the growth of process automation systems, because as opportunities and partnerships expand there is increasing complexity around the management and distribution of diverse products and markets. As a result, competition has heightened and successful companies require efficient industrial plants, product quality monitoring, product availability, employee safety, corporate flexibility, and delivery performance. To this end, the only way to participate in this flat world is to incorporate automation into organizational processes, because the main characteristic of an automation system is to respond quickly to environment changes. Process automation products are expected to have robust growth as they are used across industrial segments, including food and beverage, manufacturing, water and waste industries, and metals and mining (Tekrati, 2008).

According to the British Department for Trade and Industry, the food and beverage industry has the highest growth of application of automation systems; this industry is using automation in components of the confectionery industry, packaging systems for ready-made meals, fish manufacturing, food processing, as well as for systems that handle and process vegetables (Food Processing, 2009). The main contributions of these systems are the reduction waste, improving quality control, increasing the shelf life of products, decreasing energy consumption of machinery and reducing work place accidents.

With the rapid growth of global population, there is increasing pressure to access and manage fresh water sources, which is another area where automation can have important positive impacts. For example, Networked Intelligent Controllers are intelligent and adaptive systems used to optimize water treatment processes. They allow staff to monitor and manage the entire treatment plant from a remote central control room. The system optimizes chemical ratios, enabling cost reductions, as well as helping in decision-making (Environment Federation, 2007).

In the manufacturing industry, there is increasing dependency on robotic systems and it is anticipated that this mechanization will continue to growth. In addition to assisting with quality control, productivity and ensuring economic efficiencies, robots have contributed to reducing health and safety risks of employees who were previously handling and exposed to explosive and toxic materials, such as automotive airbags, munitions, and radioactive parts (Plant Engineering, 2008).

Applications of Automation in the Mining Industry

Automation in the mining industry has been promoted largely to protect the health and safety of working conditions in mines. The introduction of automated machines has also lessened human error, for example reducing driving errors as a result of tiredness or reduced concentration at the end of a 12-hour driving shift. Automated technologies are being used in both large-scale industrial mines as well as small-scale artisanal mining operations. The equipment that can be automated ranges in size from 300-tonne mining haulage trucks, to automated monitors in small
placer operations. The scale of automation depends on many factors however, it is apparent from several case studies that operations at all levels of the industry are exploring opportunities to increase efficiency, safety, and production via automation.

Due to advances in automated tracking systems, control equipment, telemetry and robotics, there are major improvements expected in the precision and safety of mine machinery. For example, these advances have been incorporated into drilling operations, where automated drillers use wireless technology that allows an operator to set-up and drill remotely. This removes the worker from any dangerous zones such as the moving parts of a drill rig. According to Boart Longyear’s Product Manager, (Capital Equipment) Craig Mayman, drilling workers suffer the highest percentage of injuries in the industry. So, remote systems can contribute to achieving the goal of ‘Perfect Zero’ in safety performance. (Eavan Moore, 2009).

Similarly, in an underground mine, a semi-automatic load haul dump truck (LHD) equipped with onboard video systems front and back, allows an operator located on surface to view operations in real time, while a system of computer-controlled laser scanners assist the trucks in negotiating the haulage loop. An example of this approach is at the DeBeers Finsch Mine (a diamond mine in South Africa), where in 2005, they installed seven Toro 5OD (T50D) automated dump trucks and one Toro 007 semi-automatic LHD to transport ore to an underground crusher. Since its installation, the trucks have successfully navigated the haulage loop without any failures. The trucks operate at 25 km/h (about 16 mph), which is faster than a manually-operated truck. With no time lost for driver change over, the system allows Finsch to move about 16,000 tonnes per day (tpd) of ore, compared to about 15,000 tpd for manual operation. The economic value of the system is also improved due to reduced truck maintenance costs since the equipment is more consistently used and better managed under computer control. Accidents due to human error and poor-driving habits have been eliminated (Kral, 2008).

Automation in the mining industry initially focused on underground mines. It is important to realize that these new advances do not necessarily have net positive effects on profitability and their implementation does affect the design, and related costs, of underground mines. Regardless of automation, mine openings must be sized to allow haul trucks to enter and operate. Roof support and ventilation systems must be engineered with a high degree of safety since, although truck operators may be repositioned to the surface, maintenance personnel will still require access to the equipment. Underground mine design is complex and expensive, and as mines go increasingly deeper, these requirements become more intensive. Regardless of whether humans or robots are working at such depths, rock mass stability will still be required (Mercer, 1999). In the future, changes in the design and operation of a mine may be possible through equipment automation (lower-profile machines, different maintenance procedures, etc.), but until these issues are resolved, mining costs will still increase exponentially with depth. As such, at this time, automation is not a solution for all challenges faced by underground mining.

In an open pit mine, constraints related to truck size are not as stringent (although haulage road width and bench width create limitations), therefore driverless haulage trucks are now being developed for these operations. Wireless communication, object-avoidance sensors, on-board computers, GPS systems and artificial intelligence approaches enable haulage trucks to drive themselves, or to be driven by an operator at a control panel well-away from any danger. Knowledge about position and velocity of the vehicle can prevent accidents and reduce cost of maintenance and replacement. While driverless haulage trucks are not immune to breakdowns, increased consistency and scheduled maintenance will increase the lifetime of machine
components, leading to longer periods between maintenance, and therefore reduce costs associated with maintenance. Lost production can be minimized or eliminated as unpredicted breakdown frequency declines (Bennink, 2008). Lost production and time are real costs that can be reduced through automation.

In addition to increased safety and more accurate control of maintenance, driverless haulage trucks operate more consistently – tires, brakes, and other components subject to wear failures that are properly used and maintained, will have longer operational lifetimes. Fuel consumption is reduced when a truck is driven in a stable, consistent manner. Currently human-operated trucks have significantly fluctuating fuel efficiency as drivers have a large degree of influence over fuel economy. Humans tend to become tired towards the end of a 12-hour shift and are less consistent with their driving. By one account, "Operators typically influence overall fuel economy by as much as 35%" (Bennink, 2008). At the start-up and shut-down of each shift, significant fuel use results as the trucks idle during the change-over of drivers.

"An entirely automated mine (ensures) minimize(d) idling. Idling is detrimental to fuel economy and can consume anywhere from 0.5 to 1.5 gallons of fuel per hour. Fuel economy improves up to 4% with (50 to 25%) reduction in idle time. Excessive idling not only wastes fuel, but (also) contaminates oil and (increases) carbon intake to the combustion chamber of (the) engine (Bennink, 2008).

By reducing fuel use, greenhouse gas emissions, and operating costs, autonomous haulage trucks directly contribute towards the principles of sustainability.

An example of a mine that is augmenting its operations through automation is Rio Tinto’s Pilbara mine, an iron ore mine located in Australia. In December 2008, Komatsu’s FrontRunner Autonomous Haulage System started trials at this mine with driverless trains and trucks controlled from Perth, 1,300 kilometres away. All truck navigation at the mine is remotely controlled (Eavan Moore, 2009). However, with large automated projects such as this one, communication problems can arise. There is a large amount of equipment relying on control technology and wireless systems that can result in bandwidth and latency issues. All communication networks have bottlenecks that constrain data-transfer. As the amount of data approaches this limit, individual equipment behaviour may be delayed, significantly impacting efficient and effective operation of the trucks and the overall system. Therefore, while a mining company may be attracted to implement automated systems, to take advantage of many efficiency improvements, in a large operation with a lot of automated equipment, complexity problems can be severe and so, further research and key performance indicators are needed.

New technologies are also being adopted by small scale and artisanal mining operations. While the processes are not highly-computerized, the implementation of automated and powered equipment can have a positive impact on the quality of the workplace, increasing safety and reducing toxic emissions into the environment. Automation will continue to evolve and its application in all scales of mining operations will be incorporated in order to advance mining company’s contributions to sustainable development.

\[1\] Lost time is not always accounted for as a specific cost, as a mine will often contract equipment in order to meet production targets.
Application in Environmental Monitoring Systems

One way that automation can contribute to the principles of sustainable development is via environmental monitoring systems using computerized instruments with wireless communication. This allows a mining company to accurately monitor and analyse variables, such as ground water levels, acid rock drainage, water flows and quality, waste water flows, underground ventilation, temperature changes, and soil conditions.

The Zhangji Mine, a coal mine located in China, has installed automation equipment to decrease environmental accidents and maximize environmental management. The production and environmental monitoring information is collected synchronously and incorporated into production statistics and environmental management systems. The mine uses an Ethernet network for its system, which conducts real-time monitoring, transmitting relevant data to a server, and then seamlessly uploading it to the management system. This provides the mine with integrated information to ensure that no environmental hazards arise near the operation. The centralized monitoring network collects all environmental information, such as gases, ventilation, temperature, and other factors to ensure safety of personnel (Moxa Products).

In 2006, the Andina Mine, a large underground copper mine in Chile, selected ABB Group, a power and automation technologies supplier, to integrate about 15 different automation systems that monitor and control equipment, including fans, compressors, chutes, electric machines, dust suppressors, as well as large systems and networks for water, air, ventilation, vibration measurement and analysis, traffic lights, and closed-circuit TV. The data is gathered by an isolated automation system, operated from a control room forty kilometres from the mine. The idea is to make quantifiable improvements in key performance indicators, such as availability, reliability, energy efficiency, safety and security (ABB, 2006). It is evident that automated systems provide companies with the ability to monitor and control environmental impacts of their activities, contributing to effective management of the environmental pillar of sustainability.

Sustainability and Key Performance Indicators (KPIs)

Environmental Performance Evaluation (EPE) is a management process to facilitate decision-making regarding an aspect of an organization’s performance by selecting indicators, collecting and analyzing data, and assessing this information against performance criteria. Key Performance Indicators (KPIs) are important for an organization to achieve sustainability principles because they align the organizational activities with clearly defined targets and benchmarks. KPIs are tracked continuously and must be easy to understand. They provide a comparison over time for all indicators. There can be many different types of indicators related to environmental, economic and social performance.

When automating certain aspects of a mining operation, it is useful to incorporate KPIs, as they will ensure the new technology is being evaluated with respect to relevant indicators that measure the positive and negative contributions of the automated machinery. Automation does not always improve all KPIs and in some operations, automation may result in a deficit in certain KPI measurements. For example, cycle times of automated haulage trucks may increase if the driving speed is reduced for safety purposes. Despite this deficit, if the equipment operates without stoppages for breaks or shift-changes, overall production can be improved. With testing and
gradual implementation, the KPIs may change as the system performance becomes better understood and certain constraints are relaxed.

KPIs allow a company to take a snapshot of “before” and “after” implementation of automated systems, providing an opportunity to make informed decisions and make any necessary changes. New KPIs may be created to meet the adjusted needs of the upgraded system. In this way, automated technology and KPIs improve management decision-making, an important aspect to ensure a company is on the path of sustainable development.

After selecting and adjusting KPIs, a mining company can generate intricate reports, such as the Global Reporting Initiative (GRI) Sustainability Report. These reports include a variety of performance indicators, such as flow of capital among different stakeholders, impacts of operations on communities, employment, labour and management relations, occupational-health-and-safety, training and workforce education, diversity and equal opportunity, and environmental indicators. With automated systems, the improved consistency leads to more accurate tracking of performance and trending in the chosen sustainability indicators. This enables goal-setting and increased pride and motivation within the company to obtain improvement in the desired targets. An easier and more transparent reporting system can emerge as a result of automating part or all of a mining operation.

**Economics of Automation**

Implementing autonomous systems in a mine will affect the economics of the operation and its supply chain, which will in turn affect related businesses and communities. The economic impacts of implementing an autonomous system can only be seen on a case-by-case basis, and as these systems have not been rolled-out throughout many mines, there is limited information about the specific or industry-wide impact of automation in the mining industry. In the context of discussing the contributions of automation to sustainable development, Gibson (2005) points out that economic growth should be directed towards enhancing environmental and social sustainability. This means that companies and government should intervene in the current economic market such that financial gains that result from automation are used to encourage innovation and efficiencies that benefit the environment and society, and are not use create more ecological damage or dramatically deplete natural resources. There is ongoing research and development of these technologies for very specific purposes therefore, it is possible to assume that mining companies see advantages for implementing autonomous systems in controlled environments.

**Impact of Mining Automation on Society**

The decision to implement an autonomous process in a mining operation must consider a myriad of changes and impacts that such technology will have on employees and on the community at large.

Internally, the largest concern about automation is its impact on employment and the numbers of employees hired to work at a mine. Automated equipment will do work that was formerly performed by people, and so, addressing the shifting roles and responsibilities of a company’s employees is of prime importance (Mottola, 2009). Automated equipment is ideal to replace repetitive tasks, allowing operators to take on the responsibility for more than one machine at a
time, leading to improved multi-tasking abilities and creating work cycles with greater reliability and quality (Poole, 1999). Automation also provides new training and employment opportunities for mine personnel. Prior to automation, a driller was required to know how to diagnose and fix hydraulic or electrical problems in order to fix them on site. With tele-drilling, the equipment can self-diagnose and operators (now supervisors) simply need to call in maintenance personnel as required. The drill operator needs a different set of skills to handle the specialized tasks related to automation and the new technical challenges. New job categories must be developed to manage intelligent information systems to link mine planning systems with the machines themselves. This information in turn must be relayed to technicians and authorities responsible for decision-making (Poole, 1999).

A company must balance the opportunities and perceived threats of automation and its impact on employment. The first step is through clear and regular communication with stakeholders – within the company and doing outreach to the community – to indicate their reasons for wanting to use automation and the expected impacts on overall operations (Boutillier, 2008). The company must be open to feedback about the impressions, concerns, and ideas of personnel from all levels of the company.

A company can monitor and measure the impact of automation on society by using KPIs related to personnel productivity, workplace quality, safety issues and reduction in hazardous exposure and overall safety. This allows the company to set targets for improving working conditions for employees as a result of automation. KPIs can be implemented at the operational level, as well as at the management level, in order to assess if automation is easing processes throughout the company. It also provides an opportunity to engage the affected employees in the implementation process.

One way to manage personnel and community transition into an automated system is through training. Training programs should be developed to provide the new skills that employees will need to operate, monitor and maintain the automated equipment. If automation is being used to expand operations, a company should also have a long-term employment scheme that considers the evolving positions that will enable smooth and successful transition and growth. Replacement of employees will occur in any automation program, but it must be done in a way that involves attrition or turnover issues, not the dismissal or lay-off of affected personnel. In a new mine the implementation is somewhat easier, while with an existing mine there are more challenges related to addressing people’s perception and providing proper training.

Automation should not be viewed as a solution in itself and failures have occurred due to limited preparation of the employees and community, as well as a lack of management commitment to the long-term implementation cycle. By its very nature, automation means a fundamental change in how the overall all mining process will operate. As such, the change is dramatic and can be traumatic. In 1998, INCO’s Sudbury LHD and Drilling Automation program was withdrawn because of insufficient teamwork across the organization, between internal research and development groups with divergent philosophies, and a lack of support from head office (Mottola and Holmes, 2009). Studies are now being done to assure the success of autonomous mining by focusing on the integration of people, technology and process. This research explores critical success factors, like executive sponsorship, stakeholder assessment, teamwork and internal communications (Mottola and Holmes, 2009).
In communities where automation is being implemented, often there are cultural barriers and fears related to the idea that an automated process will result in fewer jobs for the community. Employment is an important contribution that a mining company creates for a community, and this forms an important part of the corporate-community relationship, reputation, and social license to operate. When automation enters the system, a long-term strategy and extensive outreach and education program is necessary. While automation will impact the workforce, opportunities exist to compensate these changes through training and specialization of skills, or by expanding the mine life bringing economic input to the region for a longer period of time. At this point, automation is being implemented in only a few mines and the experience of interacting with and educating communities and the workforce is still new and evolving.

**Ethical Considerations of Automation**

Just as medical doctors pledge the Hippocratic Oath, so do all engineers promise to perform according to their ability and judgment in order to do no harm. This commitment to ensuring the safety of society is being taken to new levels with the growth and impact of automated systems. This growth of automation across many industries is starting to raise ethical questions, particularly related to responsibility and intention. Presently, most legal systems primarily take a human-centred approach to their perception and conception of legality, however there is an increasing need to explore the issues surrounding rights and responsibility in relation to robots or hybrid agency (humans responsible for automated systems) (Nagenborg et al, 2008). For example, in the mining context, what would be the legal outcome if an autonomous haulage truck killed or impaired a person?

One of the major drivers for the implementation of automated systems is health and safety, and it will be important that there are measures taken and sufficient education to help people adjust their behaviours around machines. Automated haulage trucks are highly complex robots with sophisticated software, different in many ways from other trucks or vehicles. Proper awareness, training and on-going education will be necessary to change people’s perceptions and ensure proper safeguards are in place. Developers and producers of the machines and software will need to be in the fore of training and awareness, in order to receive feedback and learn from the early stages of implementing autonomous systems (Nagenborg et al, 2008).

Despite years of innovation and testing, no machine is perfect; all technologies are liable to fail or misbehave at some point, and the ethical or legal issues that arise from such an incident will be unprecedented (Royal Academy of Engineering, 2009). It will be important that legal systems are up-to-date with the advance of technology to address these questions in order to have guidelines of how to assign responsibility or divide the degree of responsibility for any harm that may occur on account of a machine. In addition to receiving support from the legal system, the insurance industry will need to determine how to deal with agency around automated machines and vehicles (Royal Academy of Engineering, 2009).

Although automation is in the early stages of implementation in the mining industry, public engagement about the benefits and concerns will help raise awareness and address both positive and negative perceptions about these machines. Robots are useful not only for conducting specific tasks, but also they provide insight into human behaviour and value systems (Royal Academy of Engineering, 2009). Regulations surrounding automated machines will likely undergo many manifestations around the world, and it will be important that governments,
companies and communities share best practices as they gain experience with automation and automated systems.

**Recommendations**

The field of automation is changing at a rapid pace and is revolutionizing diverse industries; therefore, it will be increasingly important for experience and best practices to be shared. There are many lessons to be learned from both the successes and failures of implementing autonomous systems. To be successful, an automation project must identify and analyze levels of interest, expectation, priorities, and influence of stakeholders in the early stages, as well as, develop a management plan which incorporates quality control, risk management, communication plans, and exit strategies. Furthermore, managing stakeholder expectations through the executing and closing project phases is integral.

Public outreach and education is one of the most important recommendations for companies in their project management plan. Education and acculturation will need to happen internally, and raising awareness will help to improve the public’s perception of mining automation. Companies will benefit by working collaboratively with government and judicial systems to determine how ethical and legal issues arising from automation should be handled. Stakeholders involved with developing and using autonomous systems need to clearly understand their roles and responsibilities in case any accidents occur. Preparing companies down the supply chain well in advance before implementing an autonomous system is recommended, and companies should also prepare specific risk assessment and exit strategies, that need to be communicated at a broad level.

**Conclusion**

It is increasingly important for mining companies of all sizes to consider advances in automation and to evaluate how automated equipment can contribute to sustainable development. Automation allows a company to reduce accidents and environmental impacts and also leads to improvement in workplace efficiency, production, and cost effectiveness. An automated system relies on a highly integrated system, ranging from complex communication systems to targeted management scorecards. Likewise, sustainable development is a concept that incorporates ideals of environmental, social, and economic prosperity and longevity in a holistic, long-term, and integrated approach. While automation is not a solution to all challenges related to sustainable development in mining, it is a holistic-thinking tool and process that creates opportunities for closer monitoring of the environment, efficient use of capital and costs, and the elevation of social intellectual capital. A mining company that makes key decisions about operations on an ever-diminishing sampling time can benefit from automated systems as more information is readily available more frequently, facilitating long-term thinking that incorporates the goals of sustainability. It must be remembered however, that technology offers only part of the solution. New approaches to financing, managing and maintaining systems must be developed, as well as approaches that involve local communities to show there is sustained growth and economic prosperity. While at first glance, automation appears to devalue labor by replacing people with machines, in fact, automation leads to advancement in intellectual capacity and higher-skilled mine operators. Automation leads to an improved quality of life and better workspace for people, as risks and exposure to unsafe environments are minimized.
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