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Human factors in mine mechanization

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Mechanization is an important strategy in the design and operation of modern mines. The objectives of mine mechanization are varied, but typically include improved safety, working conditions and productivity, and a reduction in direct mining costs. The successful application of mechanization typically results in fewer people being employed directly in the mining process although the actual overall impact on employment is complex. Work processes and work team dynamics also change significantly, requiring novel approaches to the design and management of production.

Although there has been a concerted effort, over the past few decades, to convert traditional mining methods in gold and platinum mines to more mechanized methods, these efforts have been met with varying degrees of success. It is evident from these past experiences that the complexity of implementing mine mechanization involves a range of human factors that make the implementation of mine mechanization a challenging endeavour for mining organizations. There is a need for knowledge to enable mining organizations to analyse the impact of all their new technology projects on human factors. This would facilitate collaboration among unions, mining organizations and the community, assist mines in making informed decisions when choosing a mine mechanization strategy, and contribute to adequate planning of human factors, thereby increasing the chances of successful implementation.

This paper reviews South African and other technology change initiatives in order to gain an understanding of the impact of the introduction of mechanization and technology on other industries and mining scenarios. The paper then introduces the methodology that this research will be using to develop a framework that will be used to determine the impact of mine mechanization on human factors.

Introduction

South Africa is a mineral-rich country and mining has played an important role in the South African economy for more than 100 years. In 2008, the mining sector in South Africa contributed 8% towards national gross domestic product directly. The industry directly employed an average of 518 585 employees within the same period, accounting for 6.1% of total non-agricultural employment in the economy. An additional 500 000 jobs are estimated to exist as a result of jobs created by associated industries that supply products or services to, or use products from, the mining industry as well as those jobs created by the spending multipliers of the mining sector[1]. In 2007 it was estimated that 5 million people were dependent on South African mine employees for daily subsistence[2].

Mechanization, in its broadest sense, is the use of machines to do work. Machines have been used in mines since mining began, primarily to improve working conditions, safety and productivity. In South Africa, the first use of powered tools underground at mining faces was the implementation of rotary percussive rockdrills to drill blastholes in gold mine stopes in the very early 1900s. These machines replaced manually powered hammer-and-chisel drilling of blastholes and improved drilling productivity significantly. More recently, coal mines are now mechanized to a significant extent, with concerted effort being directed, around the world, to developing remote controlled and autonomous mining machines. In South Africa, many platinum, chrome and manganese mines are using trackless mechanized mining equipment of continually increasing engineering sophistication.

Past experience with mechanization indicates that there are many issues, besides the physical technology and mine design and layout, which affect the success of mine mechanization projects. These include aspects such as change management and leadership, availability of skills, training requirements, organizational structure, management, work planning and operation of the mine, and relationships with supporting industries.

The objectives of mine mechanization are varied, but typically include one or more of the following:

- To improve safety performance by minimizing the number of people exposed to the most dangerous areas underground (which are typically at the mining faces)
- To facilitate the achievement of workplace gender transformation and the accommodation of workers suffering from HIV, by using machines to perform more physically demanding work
- To improve productivity (in terms of mass of mineral per employee)
- To reduce direct mining costs by concentrating mining activities
- To improve working conditions and the quality of work through the provision of more intellectually stimulating and satisfying work processes.

The successful application of mechanization typically results in fewer people being employed directly in support of the mining process. This can contribute to conflict between mine owners and organized labour movements. Mechanization can also be seen as having a negative impact on the communities within which mines operate.

A further significant impact of mechanization is that of the design and structure of the work practices in mines. Changing technology leads to changes in both the number of people employed directly in support of the production process, but also in their required skills and in the manner that work teams operate internally and interact with other teams and mine management. Equipment maintenance also becomes a much more critical aspect of successful production performance, employing far more people as technology advances, to the extent that maintenance can often contribute more to overall production cost than any other production activity.

The Centre for Mechanised Mining Systems at the University of the Witwatersrand has embarked on a research project to investigate the human factor impacts of mine mechanization. Ultimately, this research project will allow mining industry stakeholders to:

- Effectively analyse the impact of new technology projects on human factors
- Develop a potential for creating a better understanding of mine mechanization for all stakeholders which could increase collaboration between unions, mining organizations and communities
- Assist mines in making informed decisions when choosing a mine mechanization strategy and contribute to adequate planning for human factors, thereby increasing the chances of a successful implementation.

The early results of this work are described in this paper, which reviews local experience as well as experience in other industries globally.

Challenges affecting current mechanization initiatives in South Africa—the human element

There are many issues that affect the implementation of a new technology within any organization. In mining these include the technology, mine design, geology, systems, processes and the human element. Many of these challenges are interdependent but what is undeniable is that without fully understanding the human factors affecting the implementation, even the best technology is likely to fail. The challenges that mines have typically experienced are described below.

Lonmin is a major South African platinum producer that has historically adopted aggressive mechanization targets. According to Hudson[3], the motivation for pursuing mechanization at Lonmin is improved safety, productivity and energy efficiency. Lonmin has reported several issues with its implementation projects ranging from equipment and supplier issues to human factors related specifically to the determination of appropriate cycle and standard times, learning curves, training, change management, and the setting of realistic production targets. Other implementation issues identified include experience and the presence of champions to drive the process, manpower planning, sustainability and capability of maintenance, and communication issues. In conclusion, Hudson has identified that the success of mechanized mining relies heavily on the development of a mechanized learning culture within the organization.

Anglo Platinum has employed a strategy of continuing modernization and implementation of new mining technologies. There has been a steady increase in the adoption of trackless mechanized mining in narrow reef mines over the last seven years[4]. According to Harrison[5], the aim of Anglo Platinum's mechanization strategy is to improve safety by removing operators from the face and to increase labour productivity and operational efficiency. Operational performance is critical to the success of a new approach to mining and Anglo Platinum mentioned several human factors that relate to ensuring high levels of operational performance[6]. Completion of the production cycle is critical and daily supervision and discipline are necessary to ensure that the mining cycle is completed within the planned time.

A shortage of skills was found to be a major contributor to failure in this regard. Harrison suggests that advanced planning is required to ensure that people with the appropriate skills are recruited and trained for mechanization projects. Once the project has begun, active learning becomes a real issue for operators and supervisors, and on-the-job training and mentoring becomes critical to achieving continuous project improvement and performance. A simple and achievable bonus system also needs to be designed. For overall success, a group-wide strategy is required to dictate and direct maintenance, labour and training strategy and development of a mechanization culture driven by management[4].

Gold Fields has pursued an active interest in the mechanization of its mines. The Gold Fields' philosophy is to remove its employees from the danger area, reduce the physical effort required for work, and reduce human exposure by minimizing the number of people and time required to do tasks. According to Roberts[7], Gold Fields has made the following observations about considerations for successful implementation of mechanised mining at its Kloof operation: attraction of people, union involvement, operator requirements, selection, training, change management, and setting of realistic production targets.

A comprehensive framework has been developed by Willis *et. al.* for the introduction of mechanized mining[8]. This framework includes various issues including some of the 'softer' human related issues. It is proposed that mechanization results in fewer, higher skilled workers being employed underground, higher face advance rates, fewer faces, improved supervision and control, improved communications, and improved environmental conditions. It is also proposed that, although safety improves, the risks become different. In addition, although fewer employees may be required to be physically involved in mining operations, there is an increase in employees in secondary industries to support mechanized mining.

Their framework proposes that in order for mechanization to be successful, a wide range of human factors need to be considered including change management by creating a need for the change, involvement and facilitating understanding. There then needs to be a primary focus on the human and organizational issues. Careful selection, training and mentoring of management, planning, maintenance and operators is required. In addition, there needs to be a change in the infrastructure, structure and systems of the mining organization to cope with the anticipated changes. The new behaviour needs to become part of the organization's culture and it is suggested that this needs to be reinforced by adapting reward systems to align with mechanization objectives.

It is clear that the need to understand human factors when introducing new technology is widely acknowledged. There is also significant agreement of the specific issues that need to be addressed.

The impact of mechanization initiatives in other industries

The implementation of new technology is not new to mining or to organizations in general. Technology has been introduced into many industries since the 1800s. Some of the challenges that have been experienced in these industries over the years are remarkably similar to the challenges currently being experienced in mining. The following section draws on a selection of the knowledge available that resonates with the challenges already highlighted in the South African mining context.

There are several studies that consider the impact of mechanization or the introduction of technology into the farming[9] and textile[10] industries. These studies focus primarily on the impact of this change on employment levels and the resulting changes in the communities in which the industries operate.

What is interesting to notice from these studies is that there is no specific mention of the skills and training needs of new technologies. Operational performance is also not specifically highlighted. This implies that these issues are not as relevant in these industries as is the case in mining. It is the authors' belief that this could, in part, be due to the way in which technology has changed the overall structure and process of the actual 'production cycle'. In both these industries, the new technology that was introduced does not fundamentally change the way in which the 'production cycle' is performed. There is also not as much interdependence between different parts of this cycle. The way in which work is carried out at a micro level has changed but the overall operational system remains similar from a process perspective.

Another industry that has been driven by technology change over the last 100 years is the banking industry, where technology has changed almost every aspect of the banking organization including processes, systems and the overall approach to banking as a whole. Booth[11] describes how technology transformed the Midland Bank in the UK. Specific challenges experienced included a shortage of skilled staff, specifically at senior management levels, unrealistic timelines for implementation of new technology and inadequate contingency management. The process required banks to acquire new knowledge and adapt existing knowledge. In general there was a continuous struggle to create and transfer knowledge.

Experience in Italian banks once again emphasizes the importance of skills and competencies. Canato and Corrocher[12] highlight that skills are critical to the success of new technology implementation. Three levels of technological competency are identified: those that refer to operational activities; aligning technology with business needs and project management; and those relating to strategy, planning and control. This implies a shift in the required skills at a very fundamental level. It was also found that a change in technology cannot be implemented as a separate innovation but needs to be fully integrated into the business.

Impact of mechanization on the British coal industry

Trist *et. al*. report extensively on the introduction of mechanised longwall mining in the British coal industry in the 1950s[13]. They report that, when traditional work organization associated with previous partially mechanised methods was used for mechanized longwall methods, sub-standard results were achieved that included, rates of productivity below system potential, inflated face costs, poor management-labour relations, low levels of job satisfaction and high levels of worker absenteeism. The findings indicated that, when the socio-psychological factors associated with new technology are not thoroughly understood, then expected improvements are unlikely to be achieved and very often there are losses rather than gains.

A proposed new method of work organization was identified; the composite work method. This method developed as a result of understanding that the primary task of a face system is the daily completion of the production cycle and not the maximization of tons produced. It was found that by using a conventional work organization approach, workers were encouraged to maximize their part of the cycle, often to the detriment of the cycle as a whole. Production was optimized by changing to an approach that maximized cycle completion. They called this a shift towards a machine-centred work culture.

The principles of the composite work method are based on task continuity and the ability of the team to be flexible and adapt their work to ensure cycle completion. It is acknowledged that in the mining environment the conditions in which workers operate are constantly changing and that rigid tasks, cycles and methods are often unable to cope with this.

In the composite work method, workers are structured in teams. Each team comprises experienced and competent workers who need not be competent in every task but the team as a whole must be competent in the entire cycle. Teams are also formed across shifts, which encourages teamwork across shift boundaries and ensures that cycles of production are not optimized on a shift by shift basis. A composite remuneration package complements the work organization. This includes a basic component and an incentive component that all team members (from all shifts) share equally based on production tons.

As a result of this work method, workers developed systematic methods for the rotation of shifts and tasks. Having experienced all phases, workers are more readily able to evaluate the state of the cycle and adjust work pace and pattern of deployment to each situation. Workers also become acutely aware of the consequences of sub-standard work on other phases within the cycle or subsequent shifts.

Another key feature of the composite work organization related to management and responsibilities. In a conventional work organization overall cycle responsibility was taken at a level three hierarchical steps in managerial rank from the face, with supervisors and foreman having only shift responsibilities. This once again reinforced a sub-optimized approach not focused on overall cycle completion. The composite work organization moved the responsibility of cycle completion to the face workers. Maximum machine running time depends on rapid and effective ways of redeploying people and adapting activity to changing demands, which requires a self-regulating team with decision-making authority and formal communication systems within the team. Team leaders were then the link between their own team, other team leaders and the management of the face.

As a result of the interdependence of different aspects of the cycle, anticipation and counteraction became more critical skills required by team leaders and management. As

production became more continuous, managers became more focused on providing conditions that permit faces of high potential productivity to achieve maximum output. The managers could no longer be supervising the detail of the work of face groups.

It was also observed that critical to the success of mechanization was the actual implementation process of the technology change. A move towards mechanized mining is inherently complex, particularly regarding the structuring of shifts and tasks. It was therefore important that teams developed a learning ability through experimentation and that they were able to disseminate the experience gained. The implementation of new technology also needed to be approached and protected as an operational experiment until technical success and social adaptation had been successfully achieved. Mechanization was not successful when treated as an ordinary training and development project working under the stress of a demand for full production. Teams needed to be carefully selected and planned and populated with the most experienced and skilled people. These teams were then used to coach upcoming teams. And finally, for successful change, it was found that continuous and active leadership was required from the highest level within the organization.

Future work

The review of past and current mine mechanization initiatives has indicated that the following human factors are the most relevant to mechanization and its effect on employees and work organization:

- Organizational structure
- Shift cycles
- Roles and responsibilities
- Core competencies
- Skills
- Performance management
- Culture
- Organizational learning
- Employment numbers.

In the work planned, detailed case study research will be used to develop a practical framework that can be used by mining companies to address the many challenges and opportunites that are currently being faced in mechanization initiatives.

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