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How applicable is industrial engineering in mining?

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Industrial engineering is being looked upon in more and more industries as a discipline that can be used to improve the overall effectiveness of businesses. It is a holistic discipline that draws upon many philosophies, principles, methodologies and tools to optimize systems and processes to maximize the use of all resources, so as to provide a product of increasing value to the customer. Having said this, it is not a discipline that has traditionally been applied in mining and mining is arguably very different from traditional manufacturing sectors where industrial engineering has its roots. Two questions thus arise; how applicable is industrial engineering in mining, and how can industrial engineering principles be implemented successfully? This paper discusses some of the foundations of industrial engineering and how these are typically applied in practice. Critical success factors for implementation are also discussed. Case studies are then presented to illustrate where industrial engineering has been applied successfully in mining. These case studies highlight the approach used and critical success factors for implementing industrial engineering in a sustainable manner.

Introduction

Minerals are sold into a commodity market over which miners have little control. As mining methods mature and stabilize, efficient and effective operations will define a mine's competitive edge. Mines are realizing that in order to achieve this they need to focus on a myriad different aspects of their operations, from technology and the physics behind rock breaking, to the way in which people are managed. One of the aspects that is receiving increased attention is understanding the value chain: how the elements of mining join together to deliver value. It is these value chains that are at the heart of the discipline of industrial engineering.

The discipline of industrial engineering is difficult to discretely define or contain. The production and business processes with which industrial engineering concerns itself are intangible, and often exist without having been explicitly designed in the way a mechanical engineer would need to design a piece of machinery. In addition, these processes transcend functions and hierarchies within a business, so that industrial engineering does not necessarily have a clear 'homebase' within a company.

However, in spite of these vagaries and challenges, it is the authors' belief that in order for mining companies to become truly competitive, industrial engineering as a discipline should be as integral to mine operation as engineering, mining or geology.

Industrial engineering as a discipline

Industrial engineering is the integration of resources and processes into cohesive strategies, structures and systems for the effective and efficient production of quality goods and services[1]. It is involved with the analysis, design, planning, operation and management of processes within any environment from manufacturing and production processes through to service processes and engineering design processes. Good industrial engineering embraces a systems approach which encompasses all aspects of the organization both horizontally across the value chain as well as considering the key features which make up an organization such as people, organizational structure, technology, information, measurement systems and their impact on business performance. This is done through the use of fundamental principles and specialized tools and techniques.

Standardized work practices reduce variability in output and allow the different activities and sections in an organization to interface more smoothly. Standardization is the foundation that enables organizations to change and improve their processes. In an environment where the methods and plans used to perform work constantly change from one worker to another, or one day or shift to another, high levels of variation are a certainty. This variation firstly makes it impossible to plan adequately and secondly makes it very difficult to identify the root causes of problems. In addition, if any attempt is made to improve a poor work method, it will be difficult to implement changes and link them to improved outputs. Once flexible standards are in place, effective problem solving can be implemented.

Structured problem solving employs the scientific method in approaching process design and optimization. Hypotheses are formed, and then tested through disciplined experimentation and rigorous analysis of facts and data.

The Deming PDCA (plan-do-check-act) Cycle is used to ensure that this process not only prevents current problems but also encourages continuous improvement. The plan phase involves planning what is to be done regarding a problem or challenge. This can be an extensive process that involves collection of data and facts and stringent root cause analysis followed by the development of countermeasures to address the issues that were found. Do involves taking action based on the findings from the plan stage, possibly on a small scale, or in a pilot scenario. This ensures that the action taken is addressing expected root causes. The check phase is critical as this ensures that whatever action was taken in do actually delivers the desired results. Action is then taken based on these findings to reinforce and sustain changes that were put in place to prevent recurrence of issues and share knowledge or to take different action if the desired results were not obtained.

Industrial engineers are also often involved in process optimization projects that map processes out for a specific area and then use tools to identify value adding activities and waste. Techniques are then used to minimize waste and ensure that value is delivered consistently and continuously. Due to the complex nature of many organizations, these projects often involve the use of advanced techniques including computer simulation and other operations research methodologies.

Good industrial engineering sees the business as a whole. It is applied to any process within the business that is seen as adding value to the whole. This includes the production cycle and maintenance activities but extends to all auxiliary functions that would include office-based processes such as procurement.

Due to the fact that processes often involve a variety of stakeholders it is also common for the analysis and design of processes to extend outside of the primary organization's responsibilities to those of other organizations that support them.

Industrial engineering has always, by definition, sought to improve the productivity and efficiency of a firm. However, over time, different approaches have emphasized different tools, techniques and philosophies. Industrial engineering arguably has its roots in Tayloristic scientific management, where technical experts analyse production methods and determine the 'one best way' of doing something. The discipline of production management that emerged in the mid 20th century took a broader systems view, considering the interaction of different functions within an organization and other disciplines, such as management science. More recently, improvement philosophies such as Theory of Constraints (TOC) and Six Sigma have come to the fore, along with the management philosophies and tools espoused in the Toyota Production System (TPS), and 'Lean' Management. (A glossary and bibliography is included at the end of the paper.)

Although industrial engineering has always advocated understanding processes by spending time on the 'shop-floor' observing and interviewing operators, it is not until more recently, specifically with the focus on TPS, that more serious engagement of the workforce in the actual improvement process has been introduced. In TPS, continuous improvement advocates that, 'Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organisation.'[2] This is at the heart of TPS and many believe that this is the key to implementing improvement sustainably in any environment.

Although many organizations have embarked on continuous or business improvement journeys in recent years, it is often the case that initial quick wins are not sustained and that further improvement becomes more and more difficult. Many firms successfully utilize tools from Lean, Six Sigma, or any number of other management philosophies to make easy productivity gains, but fail to show sustained and continuous improvement. Recent research has thus focused specifically on how to implement the theories in a sustainable manner.

It has been suggested by Ballé *et. al.*[3] that many applications of tools and techniques fail to take into account the conceptual frames which underlie the philosophies and in so doing, miss the point of applying the tools. They suggest four frames that need to form the base off which all business improvement initiatives are developed. These include:

- Understanding the purpose and linking initiatives to overall business performance
- Developing a culture of problem awareness and seizing opportunities for improvement
- Applying a rigorous and disciplined problem solving methodology at all levels
- Developing the skills and mindset in people that allow them to be effective problem solvers.

In essence the change in thinking has come about by acknowledging that there is a wealth of knowledge at all levels in an organization and that continuously fighting fires and making short-term plans to achieve production is not sustainable nor does it deliver continued improvements in competitiveness.

Consider the expertise and knowledge that resides in a rock-drill operator with twenty years of experience, or an experienced technician. This knowledge has the potential to solve problems and drive improvement, but only if given the opportunity and skills.

The function of management is not one of controlling and implementation of the 'one best way', or managing numbers and metrics, but rather one of mentoring and facilitating discovery. Improvement is effected through involving inquiry at every stage: How do you do this work? Do you do it the same way every time (standardization)? Why do you do this? Why is it important (purpose)? How do you know if it has defects (quality)? What causes these defects (problem awareness)? Why does this happen? How might this be solved? How can the results be measured (scientific method)?

Industrial engineering in practice

For those who have implemented initiatives over the years, it is largely undisputed that the techniques of industrial engineering are able to make a significant contribution to operating profitability. What is not so clear, however, is whether these benefits are sustained and ultimately further improved upon in the long term.

Industrial engineering is often applied as an intervention. It may be approached by bringing in a team of specialized consultants either to address specific issues or to analyse the organization as a whole. It can also be approached as a central, head-office type of function with a team of industrial engineers being used as a resource to the business for once-off or ongoing projects.

Although these interventions certainly add value and may be able to resolve a number of operational problems, they are often once-off in nature and even worse, gains made are often lost months later when the expertise and focus has been removed and production pressure once again drives behaviour.

It is the authors' belief that in order to effectively apply industrial engineering to sustain gains, employees must be engaged at multiple levels. The importance of their input in analysing problems and generating solutions is already well established. More than this, however, they need to actively be part of the PDCA process of experimentation and implementation of improvements.

In addition to delivering an improved organizational problem-solving ability, engaging workers can have far-reaching effects on morale. The Gallup organization reported benefits of employee engagement including a reduction in accidents, absenteeism, theft and an increase in turnover and customer service[4]. Their studies have shown that highly engaged teams can average up to 18% higher productivity and 12% higher profitability than disengaged teams. Work on self-directed work teams has shown that a wealth of knowledge and experience lies within the workforce[5]. The key is to know how to access and use this effectively.

Industrial engineering in mining

By its nature, industrial engineering can be applied to any aspect of the mining value chain including exploration and the design of new mines to daily production and maintenance of existing mines; from the physical extraction of the mineral bearing ore in the reef to the final processing of the commodity which is sold to the customer.

Industrial engineering is not only applied to the more traditional 'production' or 'maintenance' aspects of the process but can also be used to improve auxiliary and support processes such as the supply of spare parts to an underground maintenance team or the project management involved in designing or implementing a new mine or new technology within an existing mine.

This paper will focus on the actual implementation of industrial engineering as a discipline within mining rather than specific cases or areas where industrial engineering can be applied.

A review of successful mining examples

Various case studies have been described in the literature that discuss the implementation of industrial engineering as part of business improvement initiatives. All of these cases have delivered positive results. The focus of the discussion in this section is the key features of the implementation process.

Rio Tinto Aluminium started on their business improvement journey in 1995 after realizing that a more structured approach was required for long-term sustainability[6]. Along their journey, Six Sigma was implemented,which changed the culture of the organization from one that rewarded a firefighting approach to one that focused on being in control of processes and being able to identify issues and implement pre-emptive measures. They then decided to extend the business improvement initiatives to the workplace by implementing Lean, which encouraged continuous improvement at an operational level by engaging everyone. They report that Lean has achieved 'good and sometimes spectacular results improving productivity and efficiency at all sites, including the mining site.' Their journey has taught them that in order to make business improvement sustainable a strategic company-wide approach was required to ensure a culture change across the organization.

Rio Tinto's Weipa mine in Queensland, Australia also implemented Lean as part of their business improvement journey[6]. They did this by using a resident external consultant and carefully trained coaches and advisers from within the organization who were assigned to functional divisions. One of their main initial objectives was to establish information centres for all business areas that gave employees access to production data, enabling them to see and understand how all teams were performing. The consultants and coaches empowered teams with the necessary skills and tools to take ownership of their own improvement initiatives. Critical to the success of their project was training of all employees using a top-down approach. Courses were attended by a vertical slice of the organization to ensure participation and understanding at all levels. Through access to information and training, communication has improved and the workforce is now empowered to identify and solve problems at a workplace level. They are also more willing to contribute to identifying and solving issues that are affecting production. The process has united operational and maintenance teams by providing a common purpose and sense of ownership.

In the case of PT Inco's Sulawesi Island Mine in Indonesia[7], Alexander Proudfoot reported significant initial efficiency gains as a result of an intervention project but have highlighted the core importance of an employee engagement programme to facilitate achieving more in a shorter time as well as sustaining gains in the longer term. They describe how the initial mine suffered from a culture of 'silo mode' where operating teams never met to discuss barriers to performance in a constructive manner. Through a process of training and coaching they were able to engage employees by giving every employee a clear understanding of their own individual contribution towards achieving business goals and the contribution made by their team and department.

Jon *et. al.*[8] discuss the implementation of Lean in mining from a generic perspective. Although they see significant value in implementing an organization wide strategy they warn that in order for this to be successful the intervention requires leadership from senior management, buy-in from all levels, high investment in training and the use of change agents. They also mention that implementing such a strategy takes a considerable amount of time.

There are clear themes that emanate from these examples. It is clear that in order to stay competitive mining companies are focusing on continuous business improvement as a strategic driver. This means moving away from short-term fixes to a culture that aligns all employees with the purpose of the organization and empowers them to effectively contribute towards achieving more.

One more specific point that requires mentioning is that all these companies are on a long-term journey with their initiatives. This is not something which is implemented every couple of years as part of some new 'Project X'. Companies grow and develop programmes and initiatives that best suit their needs and culture at the time.

Approaches to sustaining business improvement

In this section, the authors examine two approaches to implementing more sustainable business improvement initiatives. The first, from Anglo American Thermal Coal, utilizes dedicated in-house on-site business improvement resources. The second, from Sandvik trans4mine, examines how an external consulting team can lead sustainable improvement.

Anglo American Thermal Coal approach[9]

Anglo American Thermal Coal began their current journey of business improvement in 2005. During this they have achieved significant benefits and have grown in maturity in their approach to business improvement. Several initiatives along this journey have not been successful and it is through these experiences that Thermal Coal has developed the current approach that they are using.

One such initiative involved an intervention using a team from an experienced management consulting company. Although the project showed a number of initial benefits, these were not sustained after the consultants left the mine. The initiative involved a team from the consulting company operating in parallel with the normal mine operational team to 'prove' that benefits could be achieved. This approach meant that the new way of working was forced onto the operational team and that the mine team gained no understanding of the approach used to make the changes.

Thermal Coal's current approach involves placing one to two industrial engineers at each mine operating as asset optimization managers. These engineers report directly to the general manager of the mine but have no line function. The asset optimization manager's role is to act as a facilitator on site as well as providing expertise where required. Experience has shown Thermal Coal that the type of individual who is placed in these positions is a critical success factor in the rollout of asset optimization. As a result, Thermal Coal prefers to employ industrial engineering university graduates. In addition, a stringent interview and testing process is used to ensure that the individual has the right personality, skills and experience to facilitate and drive improvement at the mine. Engineers also report functionally to a central asset optimization team who provide guidance and technical support.

The approach used by the asset optimization team involves an intensive initial analysis of the entire mine value chain to ensure that initiatives are aligned with business strategy. Carefully designed measures are then used to track performance and identify opportunities for improvement. These opportunities are then turned into projects at the mine.

Once projects are initiated these are owned by line management, managed by the mine asset optimization manager, aligned to business KPIs and included in performance contracts. Projects follow a structured approach, pulling in experienced cross-functional teams and ensuring that solutions address the root causes of problems.

It is key to have senior management support for the programme and an understanding of what the purpose is. This often involves highlighting the need for change and how asset optimization will enable the mine to achieve operational excellence. Thermal Coal sees this step as one of the most critical in ensuring long-term sustainability of the business improvement programme. Although Thermal Coal has experienced resistance to change in certain instances, this is being tackled by increasing understanding of the process at all levels.

Thermal Coal has also attempted to engage employees at lower levels by implementing a suggestion box type of initiative. They warn that this can become very difficult to manage and suggestions can prove to be useless unless everyone understands the impact that their roles have on the value chain and other areas. This highlights the need for employees to gain a good understanding of the purpose and process of problem solving. A support structure also needs to be put in place before initiatives such as this can be implemented successfully.

The current approach used by Thermal Coal has delivered very successful results. The asset optimization department is currently actively tracking 86 improvement projects throughout Thermal Coal. In addition, there is a career path for an industrial engineer within the organization with tasks varying from continuous improvement initiatives to strategic decision making and modelling.

Sandvik trans4mine approach —Chelopech mine, Bulgaria[10]

Sandvik trans4mine is a division within Sandvik who enter into a partnership with a mining customer to increase system and process efficiency. Sandvik trans4mine has been assisting mining companies to improve mine performance for several years. Initiatives have been approached in a consulting type of role to improve not only performance of Sandvik machines but also the entire production cycle. A team of an industrial engineer and operational specialists are used who apply a systems approach to understand the relationships between activities and departments with the ultimate aim of optimizing cycle efficiency. Various tools and techniques are used in conjunction with a project management approach including work-study, TOC, simulation and other specialized, in-house developed tools. Once constraints and shortcomings are identified, projects are put in place to address these.

Although the Sandvik trans4mine team is typically able to deliver significant improvements in operational performance, the long-term success rate, once the trans4mine team leaves the mine, has varied greatly. What Sandvik trans4mine has realized, is that due to the consultant approach that they have been using, sustainability of their interventions depends largely on the ability of the mine's human resource base once the project is completed. It is for this reason that Sandvik trans4mine are developing a new approach to their interventions. The new approach follows a three-tier methodology which starts by identifying basic errors and setting up projects to address these, then moves onto the implementation of a measurement system and continuous improvement framework. The final tier involves a fully integrated culture of continuous improvement within the mine itself. It is Sandvik trans4mine's vision to use this new approach to implement continuous improvement at South African mines in the future.

Sandvik trans4mine is in the process of using this new approach at Chelopech mine in Bulgaria. Chelopech mine is in the process of ramping up production from 1 million tonnes per annum (Mtpa) to 2 Mtpa from 2010–2012. In order to achieve this, the Sandvik trans4mine team will be assisting the mine to perform a systems audit, identify system deficiencies and develop an Excel production model together with a dynamic simulation tool. The simulation and model will be used to predict future fleet requirements based on current mine performance and to identify opportunities for improvement (in order to optimize fleet requirements and associated operational costs).

The new approach follows the structured Six Sigma, DMAIC (define-measure-analyse-improve-control) methodology. From the outset there is a clear sense of purpose and the goals that are to be achieved are quantified. An initial audit is carried out at the mine in order to assess their performance in a range of predefined areas. Measurements are introduced to prompt identification of problems and improvement projects are identified in critical areas. Mine employees are fully involved at all stages of this process to gain support for the initiative and to draw on the wealth of knowledge and experience that they have. Through this process, the mining team also gains a full appreciation of the problem solving methodology that is being used.

Once the improvement projects are identified, they are then owned and managed by the line management of the mine. Sandvik trans4mine sees this as a critical component of the new approach. The Sandvik trans4mine team now act as coaches who guide the mine team in the problem solving process. They also provide expert and specialized support where required. Although they are actively still part of the Chelopech-trans4mine team, the transfer of skills is now the focus in order to ensure long-term sustainability. In some cases Sandvik trans4mine may have a very good idea what the answer to a particular problem is going to be but are ensuring that the mine employees follow the process so that they learn for themselves.

According to Sandvik trans4mine project manager, Mike Andrews, to date the process appears to have been adopted well, particularly considering the social background of former Soviet Bulgaria. The team has ensured that local Chelopech stakeholders become the process owners and the methodology ensures that root causes are addressed as opposed to symptomatic influences. At present the Chelopech-trans4mine team is implementing comprehensive measurement systems. The above initiatives are all contributing to assisting the mine in achieving its expected ramp-up from 1 million tonnes per annum to 2 million tonnes per annum; currently Chelopech mine is achieving (and at times exceeding) its planned ramp-up targets and has continued to reduce operating costs. The Chelopech-trans4mine partnership is ongoing and is planned to continue throughout the ramp-up period with the ultimate goal of Chelopech independently carrying out the implemented processes and methodologies on a sustainable basis.

Parallels

Although the approaches used in the two case studies above are quite different there are many similar key features that are enabling a more sustained approach to business improvement and the implementation of industrial engineering. These are:

- Linking all initiatives to the overall purpose of the organization
- A move to long-term sustainability and away from short-term, quick fix solutions
- Involvement and support from a senior level
- Following a structured process to identify root causes and solve problems
- The use of industrial engineers as coaches and facilitators
- Drawing on local knowledge and expertise to solve problems
- Imparting knowledge gained and problem solving skills to all levels of the organization
- Linking initiatives to performance measures
- Involving employees in the setting of targets.

Conclusion

As a summary, it is believed that the following points can enable mines to improve operational efficiency in order to become truly competitive:

- Industrial engineering needs to become an integral discipline in mining operations
- Structured problem solving needs to replace short term firefighting to achieve production targets
- Engagement in the process and its ownership needs to involve everyone within the organization.

Glossary

DMAIC (define-measure-analyse-improve-control)—project methodology used for improving existing business processes as part of the Six Sigma approach. It is inspired by Deming's PDCA cycle, and is similar in its emphasis on measurement, scientific experimentation and validation. Like PDCA, the DMAIC methodology is sometimes referred to as the DMAIC cycle, emphasizing that improvement is an ongoing continuous endeavour.

Lean— can be summarized as the pursuit of perfection by achieving customer value through processes that are stripped of waste using a cycle of continuous improvement. Waste is defined as the expenditure of any resource for any purpose other than creating value for the end customer. Lean encompasses a broad range of tools and techniques that are used to achieve this goal. It was originally derived from the Toyota Production System.

Operations research—branch of industrial engineering and applied mathematics that utilizes advanced analytical methods, mathematical modelling, and numerical tools to arrive at optimal solutions to complex decision making scenarios.

Theory of constraints (TOC)—overall philosophy applied to operating and improving an organization developed by E. Goldratt. It defines the goal of the organization as making more money by increasing throughput, reducing inventory and reducing operating expenses. TOC philosophy contends that just a few bottlenecks, or constraints, limit the organization's ability to achieve this goal. Techniques are applied to identify, manage, and mitigate or exploit these constraints.

Toyota Production System (TPS)—holistic management approach used by Toyota in their pursuit of zero defects using a culture of relentless continuous improvement.

Six Sigma—a business management approach that seeks to remove root causes of quality defects and minimize variability within business operations. Six Sigma follows a structured improvement methodology (see DMAIC), and uses specific statistical methods for the analysis of quality and variability.

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