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Application of manufacturing management and improvement methodologies in the southern African mining industry

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Synopsis

A study conducted at 22 operating mines in the southern African region indicated that each mine employs about five management and improvement methods with roots in the manufacturing industry. All respondents reported the implementation of cost-saving initiatives, whereas 80% of the mines are affected by restructuring. TQM, Six Sigma, BPM, and TOC were found to be the most prevalent manufacturing management and improvement methods used. A mechanistic vs systemic evaluation of the suitability of these methods to bring about positive change in the industry suggested that complex, ever-changing mining systems are better served by a systemic flow-based approach, which is embedded in methods such as TOC, JIT, TPS, and Lean Production. These methods, however, lack industry presence, possibly because they do not effectively deal with the unique challenges associated with the mining environment. It is argued that successful mining business management and improvement depends on management's ability to deal effectively with mining industry-specific requirements, the integration of the geology-mining-plant system, and the implementation of systemic flow-based principles in all aspects of mining.

Keywords

mining improvement, continuous improvement, business improvement, manufacturing methodologies, mechanistic, systemic.

Introduction

The study aims to explore the use of manufacturing management and improvement methodologies in the southern African mining industry. Considering the unique challenges associated with mining operations, attention is given to the applicability of the most commonly used manufacturing methodologies in the tactical, operational, and strategic environments. The article endeavours to stimulate more research and debate in an unexplored field of study.

Study method

The study was conducted in two parts. Firstly, a questionnaire was circulated to 50 operational mines to establish how widely manufacturing methods are applied in the industry, which element(s) of the profit equation currently receives the most attention, and which methods are favoured. In the second part of the study, the database of the Mineral Resource Throughput Management (MRTM) programme, a Masters degree programme presented through the Geology Department of the University of the Free State (UFS), was consulted regarding the application of systemic flow-based principles at some of the mining operations evaluated.

Inputs were received from small- to large-scale operators in the precious metal (Pt, Au), ferrous metals (Fe, Mn, Cr), base metals (Pb/Zn, Cu), coal, and diamond industries, operating mainly in southern Africa.

Industry views

Strike actions in the industry, lower prices driven by lower demand from China, and increasing costs, among other reasons (PWC, 2014), have focused the attention of most mining operators on means to end and turn around the downward performance spiral experienced in recent years. In fact, the mining industry is expected to bring about a step change in performance through bold actions, new ways of thinking, and implementing innovative management methods and technologies (Mining Weekly, 2014).

Some mining operators and consulting firms in the mining industry are now again turning to management and improvement methods developed in and for the manufacturing sector in an attempt to resuscitate the industry. A case in point is a global mining operator with extensive interests in southern Africa that intends to adopt principles from manufacturing methodologies such as Lean Production and Six Sigma in order to establish a business environment that 'delivers continuous improvement (CI) on budget' (Anglo American, 2014). It is

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noteworthy that this operator already employs an extensive CI programme based on other manufacturing methodologies at all its operations. This announcement probably supports the notion in mining that the industry is still looking for a cost-effective, fit-for-use mining management and improvement method that effectively addresses the unique challenges associated with the mining environment.

Differences between the mining and manufacturing environments

Imagine a pharmaceutical producer adopting an approach of 'you supply the best raw materials/inputs you can and we will make the best medicine we can'. Through ongoing research into the management of the total manufacturing value chain, there is a lot that mining can learn from the manufacturing industry, but key differences between these two environments should be recognized and adjustments should be made where necessary. A systemic view of the mining value chain (Claassen, 2015), which emphasizes a focus on all dependencies in the system, on flow through the system, and the management of variability to achieve a stable and predictable environment, highlights the following key differences between mining and manufacturing.

Raw material quality variability

Stringent raw material specifications are enforced in manufacturing in order to limit variability throughout the value chain and, more importantly, to produce a final product within budget and specification, as alluded to earlier. Off-specification raw material is simply rejected in manufacturing or 'diluted' (blended with on-spec material) to a level where its impact on overall system performance is within acceptable limits. Everything about the raw material is known and its behaviour through the value chain can be predicted, *i.e.* processes can be set up within narrow operating limits to optimally process the materials/parts. This greatly enhances operational stability, predictability in financial performance, and the company's ability to implement its business strategy.

In mining, the ore and associated host rock quality as well as the ore to waste ratio in the plant feed can vary considerably over time due to variable ore (intergrowth, texture, mineral associations, *etc.*) and orebody morphology (seam dip, faults, roof and floor conditions, *etc.*). In most cases all the raw material is also processed (from drilling and blasting to beneficiation). In general, limited information on the ore and orebody exists (limited exploration data on ore and orebody morphology) and the behaviour of the ever-changing ore/waste package in downstream processing is generally difficult to predict. Mining operators therefore often find it difficult to set up processing equipment correctly and to maintain optimal equipment/processing set-points. In addition, the effects of key processing performance drivers such as ore and waste hardness, intergrowth, grain-size distribution (ore morphological factors), *etc.* cannot be blended away, *i.e.* a mixture of hard and soft ore does not yield a medium hard ore and a blend of coarsely and finely intergrown ores does not produce medium intergrown ore. If hard and soft rock are treated simultaneously in a comminution circuit, the hard rock is typically under-ground and the soft rock over-ground, which has an adverse impact on downstream extraction performance. Variable raw material quality results in the production of lower product volumes (sacrificing ore and product extraction for the sake of quality) and/or poorer product quality due to misplacement, which in turn directly impacts the profitability of an operation. This adversely affects an operation's ability to accurately predict its financial performance and to implement its business strategy.

It could be argued that *raw material variability in mining creates a complex network of geo-processing (geology-mining-metallurgy) dependencies, which in turn impact the overall business performance. Treatment of variable raw material qualities in mining differentiates the industry from manufacturing. It is also noteworthy that the ripple effect of this variability runs through the entire mining value chain if not properly addressed*. This argument also suggests that without a proper understanding of the impact of geo-processing variables on run-of-mine, concentrate, and product quality, any business improvement and management approach may not yield the expected outcome.

Ability to control production processes

Compared to manufacturing processes, most mining operations suffer from a lack of process control (Peace *et al.*, 1998). In manufacturing nearly all inputs, processes, and outputs are rigorously monitored and controlled. In mining, an attempt is made to achieve as high as possible level of control. It should be noted that most of the ore morphological factors (specifically physical characteristics of ore and waste) mentioned earlier cannot be detected with online instruments, and the focus is therefore mainly on grade (chemical composition), which assists the operator to some extent, *i.e.* plant feed quality/grade in many cases does not accurately predict optimal process/equipment set-points and performance as alluded to in Table I.

Combining the impacts of variable raw material quality and quantity (ever-changing geological environment), the difficulty associated with measuring ore treatment parameters (Table I), variable equipment performance (whole production line is not static), variable human performance (limited automation), variable mining conditions (conditions around production line continuously evolving), variable market dynamics, and an ever-changing legislative environment on mining performance, it is not hard to understand why complex, ever-changing mining environments are more difficult to manage and improve than simple, stable environments found in most manufacturing processes. Complex, ever-changing environments experienced in most mining operations probably require a unique management and improvement approach to ensure optimal performance in a sustainable manner, as will be discussed later.

Compliance with plan and strategy

High levels of operational stability and predictability generally experienced in the manufacturing environment allow the implementation of strategic and operational plans with a relatively low level of risk, *i.e.* operations follow the plan. In mining, where operators need to deal with highly variable geological and processing conditions, this approach can introduce more variability into the system, as a result of a misalignment between plans and what the geo-processing environment allows, where geology is a given and processing

Table I

Summary of important raw material variables mostly not detected with online instruments in some ore treatment processes

Separation process	Raw material parameter not measured and controlled	Geological driver
Comminution	Hardness, grindability	Ore and waste mineralogical composition/ associations, Ore and waste texture Weathering effects Ore and waste porosity Intergrowth Grain size distribution Element/mineral deportment
Screening	Particle shape Particle size distribution	Depositional environment Ore and waste texture Ore and waste composition
Dense medium separation	Density Density distribution Particle shape	Ore and waste mineralogical composition/ associations Ore and waste texture Weathering effects Ore and waste porosity Depositional environment
Flotation	Particle size and size distribution Mineral liberation size Mineral surface chemistry Particle porosity Competing species	Ore and waste mineralogical composition/ associations, Ore and waste texture Weathering effects Intergrowth

methods are fairly fixed once implemented. It can therefore be argued that *the plan should be subordinated to the value generation potential of the geo-processing environment*. This may also imply that the chosen mining business improvement and management approach should enable the establishment of a stable and predictable operational environment in order to successfully implement the strategic and operational plans, *i.e.* a stable geology-mining-plant primary value chain and supporting functions is a prerequisite for the successful implementation of a strategic plan in the mining environment.

Value generation and value capture

In manufacturing, value is added to the raw materials/parts by processing and/or combining them with other raw materials/parts up to the final product. From a mineral resource management perspective, mining operations aim to minimize losses/value attrition from the moment the ore is first handled at the face to the final product, as illustrated in Figure 1, *i.e.* to capture as much value (Priem, 2007) as possible from the orebody for the effort, time, and money invested.

A drive to limit value attrition throughout the mining value chain as shown in Figure 1 inevitably focuses attention again on the geology-mining-plant interrelationship and the need to understand its dynamics better. This in turn implies that the chosen management and improvement model(s) should enable mining operators to establish all geo-processing relationships and effectively manage them. However, the chosen approach should also be able to establish a balance between value capture (supply side) and value generation (demand side) through the development of niche/alternative products and customers where possible (Johannessen and Olsen, 2010).

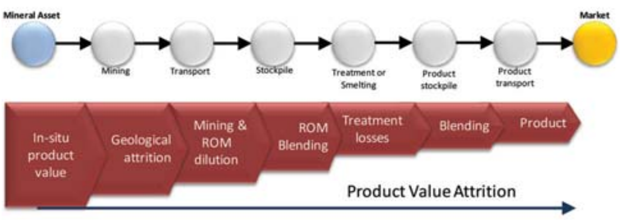

Figure 1—Value attrition typically experienced in a mining value chain from the mining face to the final product

Primary production chain characteristics

Figure 2 attempts to compare at a high level typical manufacturing (motor vehicle) and mining (simple case for opencast mining and ore to metal production) value chains if the product development and reserve definition stages are excluded, respectively.

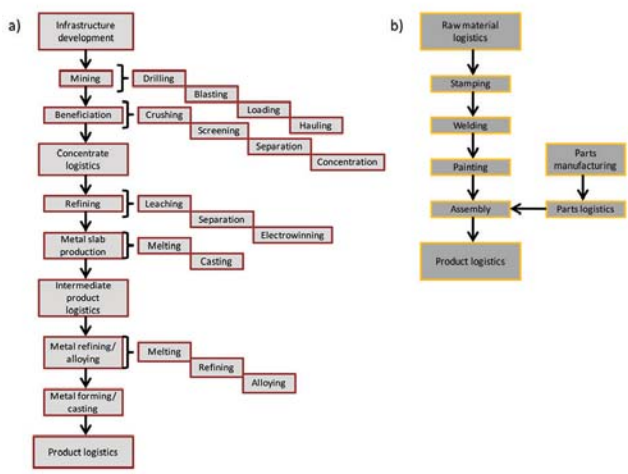

Figure 2—Simplified schematic illustration of (a) a typical mining value chain and (b) a motor vehicle manufacturing value chain

It should be evident from Figure 2 that more dependencies and interdependencies exist in the mining value chain. One can then conclude that if a more complex network of dependencies and interdependencies is combined with other mining value chain characteristics mentioned earlier (variable raw material quality, dynamic mining value chain sensitive towards mining conditions, less automation/limited process control, and an ever-changing legislative environment), then a different approach towards managing mining systems compared to manufacturing chains may be required.

Mechanistic vs systemic view

Before the applicability of the above-mentioned management methods in the mining sector is evaluated, it is essential to recognize that people generally adopt either a mechanistic or a systemic/organic approach towards managing their environments, as indicated by Burns and Stalker (1961). The authors describe organizational designs for simple, stable environments as mechanistic and designs suitable for complex, changing environments as organic/systemic in nature. They argue that these designs and views support management's will to gain power, domination, and control over the natural environment and labour. Furthermore, the designs and views can be seen as products of two different approaches (mindsets and behaviour) to enterprises operating in a continuum between simple, stable environments and complex, changing environments. Burns and Stalker (1961) indicated that simple, stable environments are easier to control and performance is more predictable than for complex, changing environments. The latter require a more flexible (less rigid structures and management practices) approach, the deployment of resources where needed most (opposite of centralized services), fit-for-use solutions (less standardization due to variable conditions), and a systems view (*consideration of dependencies and interdependencies in the system in a flow context*) of the business. Simple, stable, and predictable environments in turn can be effectively managed using a functional approach (silo approach), best practices (benchmarking), and strong hierarchical authority.

Evaluating the effectiveness of manufacturing methodologies employed in mining

The mining industry poses unique challenges to its leadership compared with the manufacturing environment. These may include the following.

- All raw material is treated, and its variable chemical and physical characteristics generally causes instability in downstream processes and/or a less predictable output than is the case in manufacturing
- Key processing variables (can be linked to geological variables) impacting operational performance are difficult to measure and control
- Operational instability (noncompliance to plan) impacts the successful implementation of the strategic and operational plans
- A balance needs to be found between capturing optimal value from the mineral resource and generating value from niche products and new markets
- Mining value chains comprise a more complex network of dependencies and interdependencies and evolve continuously.

Considering the above, it can be argued that *mining is a complex, ever-changing business environment where performance is less predictable*. As such *it is probably better served by a systemic management and improvement approach* than a mechanistic approach, as discussed in more detail in the following sections.

Feedback from the questionnaire

Feedback from 22 mines was received as summarized in Table II and presented graphically in Figures 2 and 3. Approximately half of these mines are owned by big mining companies operating in different commodities (different mining entities).

From Table II and Figures 3 and 4 the following points can be highlighted.

- All mines have opted to employ more than one management and improvement method. On average, approximately five of the listed approaches or elements of the approaches are exploited at each mine

Table II

Summary of results obtained from a survey sent to 50 operating mines

Mine/ Method	Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7	Mine 8	Mine 9	Mine 10	Mine 11	Mine 12	Mine 13	Mine 14	Mine 15	Mine 16	Mine 17	Mine 18	Mine 19	Mine 20	Mine 21	Mine 22
Lean production/Just-in-time	√	0	0	0	0	0	0	0	0	√	√	√	0	0	√	0	0	0	0	0	√	√
Business Process Management	√	√	√	√	√	√	√	√	√	√	√	0	0	√	√	√	√	√	√	√	√	√
Business Process Re-engineering	0	√	√	√	√	0	√	0	√	√	√	0	0	0	0	0	√	0	0	0	0	0
Business Restructuring	0	√	√	√	√	√	√	√	0	√	√	√	√	√	√	0	√	√	√	0	√	√
Total Quality Management	0	0	√	√	0	0	0	0	0	√	√	√	0	0	√	0	√	0	√	√	√	√
Six Sigma	√	0	0	√	0	0	0	√	0	0	0	0	0	√	0	0	0	0	0	0	0	0
Theory of Constraints	√	0	0	√	0	0	0	√	√	0	√	0	0	0	0	0	√	0	0	0	√	√
Cost saving	√	√	√	√	√	√	√	√	√	√	√	√	√	0	√	√	√	√	√	√	√	√
In-house	√	√	0	0	√	0	√	√	0	√	0	0	0	0	0	0	0	0	0	√	√	√
Ave: 4.85	6	5	5	7	5	3	5	6	4	7	7	4	2	3	5	2	6	3	4	4	7	7

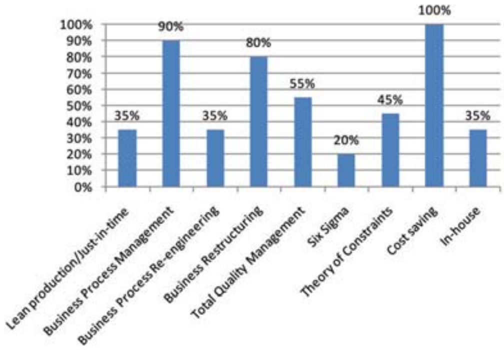

Figure 3—Percentage of mines employing the listed manufacturing management and improvement methods

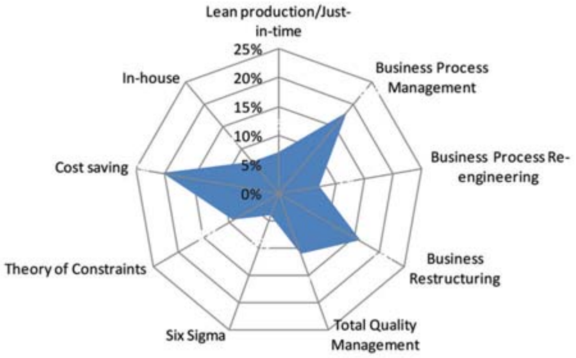

Figure 4—Normalized prevalence of manufacturing management and improvement methods in the mining environment

- All mines are working on cost-saving initiatives, and 80% of mines are restructuring their operations. The focus of most mines is more towards cost saving than increasing revenue
- A notable awareness in the industry exists with regards to the importance of identifying and managing different business processes – Business Process Management (BPM) and Business Process Redesign (BPR)
- Elements of several other methods such as Total Quality Management (TQM), Theory of Constraints (TOC), Lean Production, and Six Sigma (SS) are also employed by some mining operators
- 35% of mines have developed their own fit-for-use mining management and improvement methods, probably signalling a need for a more effective way of dealing with the unique challenges of the mining environment
- The top five management and improvement methods currently employed by mines to ensure sustainable operations are cost saving (20%), BPM (18%), business restructuring (16%), TQM (11%), and TOC (9%).

Applicability of the most common improvement methods in mining

The applicability of manufacturing business improvement methods in the mining industry is evaluated considering the unique challenges associated with mining and whether the methods are applied from a mechanistic or systemic perspective. For more background information on some of the improvement methods discussed here, the reader is referred to the Appendix.

Cost saving and business restructuring

Cost saving and business restructuring are currently widely employed as a means to improve business performance, as illustrated in Figures 3 and 4. When these methods are applied in a mechanistic way, all departments in the organization are often affected. One of the premises of a mechanistic approach is that money saved throughout the company will directly translate to bottom-line savings and therefore an improvement in profitability. This is mostly true in the case of simple, stable environments. In complex, ever-changing mining environments this approach can hamper the longer term performance of the organization due to:

- The constraint(s) in the mining system being adversely affected, which increases the risk of not meeting performance targets or compliance with plan and strategy
- Other dependencies and interdependencies being created that are not anticipated and therefore not managed, which further affects the organization's ability to control its processes.

When cost saving and restructuring is implemented using a systemic approach, the constraint(s) in the system and all the dependencies and interdependencies that affects its performance are considered. The impact of future changes in the internal (geological and mining conditions) and external environments that can affect the overall system stability is also considered. In this way, savings generated through cost-saving initiatives should be more sustainable than when a mechanistic approach is used.

Cost-saving and restructuring initiatives do not necessarily deal with challenges to better deal with variable raw material quality, the integration of the geology-mining-plant value chain, value captured from the mineral reserve, and value chain complexity. Instead, these approaches can have a very negative impact on the long-term profitability of the organization if the unique challenges of mining are not addressed in a systemic manner.

Business process management (BPM)

Managing an organization's key business processes as assets was proposed by Hammer (1990), and the idea later evolved to accommodate the softer' 'people' side of the organization. When BPM is applied in a mechanistic way, process silos are created in addition to the functional and discipline silos already existing in the organization, which further increases complexity as it creates more dependencies and interdependencies in the system. Furthermore, businesses very seldom appoint additional people to manage these processes. Multi-skilling and multi-tasking are required as a result, which can put the success of the approach at risk since an equal focus on all aspects of the business is required when a mechanistic approach is followed. Therefore, when BPM is applied in a mechanistic manner, the organization becomes more fragmented and more constraints can develop, which could defeat the purpose of establishing better control and management, improving compliance to plan and strategy, enhancing value capture and value generation, and addressing the complexities of the mining value chain.

When BPM is approached from a systemic perspective, the emphasis is not only on defining and managing the key business processes, but also on the management of flow through these processes, *i.e.* enhance synchronization through focusing on the system constraints and subordinating everything else to the requirements of the constraints. Through a systemic approach, an organization's business processes can be integrated with its functional requirements by defining all dependencies and interdependencies that impact the output of the system as a whole. In this way the business environment can be simplified; it presents the manager with a small number of key enablers/leverage points that are directly linked to the performance of the constraint(s).

BPR, and later BPM, was not developed in the mining environment. At a high level the methodology does assist mining operators to identify and manage the key business processes. The stability and profitability of mining systems are, however, dependent on establishing the ability to successfully integrate the geological, mining, metallurgical, and service environments in a systemic flow-based manner, which is not a key focus of BPR and BPM.

TQM and related methods

TQM (Porter and Parker, 1993) evolved from methods such as Total Quality Control (Feigenbaum, 1991), Quality Management (Juran, 1999), and statistical process control. Other management and improvement methods with roots in TQM include Continuous Improvement (Rijnders and Boer, 2004) and Six Sigma (Eckes, 2001).

These methods are essentially based on a mechanistic approach towards organizational management and improvement that supports:

- An equal focus on each part of the organization. The performance of each process, department, individual, piece of equipment and cost centre must be optimized
- The use of endless performance, quality and governance rules, protocols, and standards in an attempt to ensure compliance in every aspect of the business.

From a systemic point of view, time and resources can be wasted when this approach is followed as it has the potential to:

- Direct money, time, and energy towards non-constraints in the value chain (excluding legislative requirements), which will not yield the expected improvement
- Further fragment the organization and increase the need to implement more control systems, at huge cost, on non-constraints and variables that do not enhance geology-mining-plant integration and performance optimization
- Balance capacities in the mining value chain over time, which makes it increasingly difficult to prioritize the allocation of resources
- Create more dependencies and interdependencies in already complex systems if the up-and downstream impacts of changes are not fully understood
- Create bulky and expensive business structures by focusing on all parts/aspects of the organization.

TQM and related methods are tried and tested in the manufacturing environment, but have the potential to adversely affect the performance of mining systems over the long term when the above-mentioned points are considered.

TOC and related methods

Systemic flow-based management and improvement principles are included in TOC (Goldratt and Cox, 1986), Lean Production (Krafcik, 1988), Just-in-Time (JIT) (Ohno, 1988a), and Toyota Production Systems (TPS) (Ohno, 1988b). Lean Production is a westernized view of TPS developed by Toyoda and Ohno in the post-WWII Japanese automotive industry. These methods (excluding TOC) were exclusively developed in and for the motor vehicle manufacturing environment. As such, these methods essentially do not accommodate the unique mining challenges listed earlier, and the following shortcomings should be highlighted:

- JIT, TPS, and to some extent Lean Production promote the concept of flow perfection, which is achievable within a simple, stable environment where no or very little variability in raw material quality occurs
- All these methods are supported by the ability to rigorously control all processes and equipment, which in turn ensures that buffer sizes (work in process) are minimized, waste is eliminated, and the constraint stays in one place so that its performance can be optimized
- These methods support organizations where operations successfully follow the strategy and where there is a strong focus on value generation (compared to a mineral reserve value capturing potential focus).

Mining can, however, significantly benefit from the following concepts promoted by these methods:

- As systemic flow-based methods, they promote the establishment and management of the system constraint(s) and all dependencies and interdependencies affecting its performance
- *Complex systems can be simplified* by identifying and managing the key throughput drivers of the production value chain, as opposed to a focus on every aspect of the business
- Performance is optimized through the creation of a stable and predictable operational environment
- There is an emphasis on *synchronization*, which significantly enhances the value chain and overall business performance.

Conclusions and recommendations

Some mining operators and firms consulting in the mining industry are again turning to management and improvement methods developed in and for the manufacturing sector in an attempt to improve performance. A questionnaire sent to 50 operating mines to establish how widely manufacturing methods are applied in the industry, which element(s) of the profit equation currently receives the most attention, and which methods are favoured, indicated the following:

- All respondents opted to employ more than one management and improvement method. On average, approximately five of the listed approaches/elements of the approaches are exploited by each mine
- All respondents are working on cost-saving initiatives, and 80% of mines are restructuring their operations. The focus of most mines is more towards saving cosst than increasing revenue
- There is a notable awareness in the industry with regard to the importance of identifying and managing different business processes (Business Process Management (BPM) and Business Process Redesign (BPR))
- Elements of several other methods such as Total Quality Management (TQM), Theory of Constraints (TOC), Lean Production, and Six Sigma (SS) are also employed by some mining operators
- 35% of mines have developed their own fit-for-use mining management and improvement methods, probably indicating a need for a more effective way of dealing with the unique challenges of the mining environment
- The top five management and improvement methods currently employed by mines to ensure sustainable operations are cost saving (20%), Business Process Management (18%), business restructuring (16%), TQM (11%), and TOC (9%).

A high-level mechanistic *vs* systemic evaluation of the suitability of these methods to bring about positive change in the mining industry indicated that:

- A systemic approach that better suits the management and improvement of complex, ever-changing mining environments should be adopted when applying manufacturing management and improvement methods in the mining environment
- Cost saving and restructuring initiatives should consider the requirements of the constraint(s) in the mining system in order to avoid increasing the risk of not meeting performance targets
- Most manufacturing management and improvement methods were exclusively developed in the manufacturing environment and as such do not adequately address mining's specific requirements such as treating raw material with variable physical and chemical properties, measuring (online) and controlling physical material properties, improving compliance to plan, focusing on value capture compared to value generation, and managing and improving more complex networks of dependencies and interdependencies
- TQM, CI, Six Sigma, and BPM present means to focus resources on every aspect of the business. This, however, has the potential to destabilize organizations in the long-term as it establishes a balanced capacity environment, which in turn has a detrimental impact on the prioritization and allocation of resources. Bulky and expensive structures are required to support a focus on every part of the organization
- JIT, TPS, and Lean Production were developed in and for the motor vehicle industry, and do not support optimal synchronization of the geology-mining-plant system. These methods, however, emphasize the importance of simplifying and stabilizing value chains through creating a focus on flow through the system as a whole. Mining can significantly benefit from the implementation of this approach
- The mining industry can also benefit from the implementation of TOC principles. This method, however, lacks industry presence, possibly due to its inability to deal effectively with the mining-specific challenges indicated earlier.

In conclusion, it can be argued that a successful mining management and improvement method should include a focus on the *integration of the geology-mining-plant and other essential systems in a systemic flow manner that enhances overall system stability and predictability*.

It is therefore recommended that mine owners and managers cultivate a systemic thinking capability and business schools are encouraged to expand their programmes to incorporate systemic thinking elements (Atwater, *et al.*, 2008) in order to optimize mining systems in a sustainable manner.

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Appendix

High-level background to improvement and optimization methodologies

The best known value chain improvement and optimization methodologies were developed in and for the manufacturing environment. These include Quality Control (QC) (Juran, 1999), Total Quality Control (TQC) (Feigenbaum, 1991), Total Quality Management (TQM) (Feigenbaum, 1991), Just-in-Time (JIT) (Ohno, 1988a), Toyota Production System (TPS) (Ohno, 1988b), Lean Production (Womack *et al.*, 1990), Theory of Constraints (TOC) (Goldratt and Cox, 1986), Six Sigma (Eckes, 2001), Continuous Improvement (CI) (Rijnders and Boer, 2004), Business Process Re-engineering (BPR) (Champy, 1995), and Business Process Management (BPM) (Vom Brocke, and Rosemann, 2010). Lately, the application of combinations of these methodologies is also gaining ground. These include Lean-Six Sigma (Muir, 2006), TOC-Lean-Six Sigma (Nave, 2002) and Lean-Six Sigma-BPM (BPTrends, 2014).

Quality Control, Total Quality Control, Total Quality Management, and Continuous Improvement

The concept of quality has evolved significantly over time. Initially it meant inspection of finished goods to ensure adherence to specifications. From the 1920s onwards, it underwent significant change with inputs from quality experts such as Shewhart, Deming, Juran, Feigenbaum, Ishikawa, Taguchi, and Crosby as shown in Table AI.

A study of improvement methodologies suggests that many of these have roots in quality control and quality management. The contributions (Table AI) of the early quality experts are specifically noteworthy. They not only shaped the western world's thinking around quality, quality control, and quality management but also had a significant impact on the understanding of quality and the application of quality control in Japan after World War II. Quality gurus such as Taguchi and Ishikawa were influenced by Deming and Juran, who visited Japan in the 1950s, and Toyoda and Ohno who visited Ford in 1950. It could be argued that this early work and interaction between west and east (Toyota was an early adopter) laid the foundation for the development of what are known today as TQM, CI, JIT, Toyota Production System, Lean Production, and Six Sigma.

During the twentieth century, quality control and management evolved into what is known today as TQM. TQM, according to Feigenbaum (1991), is the consequent further development of Statistical Process Control (from Shewhart and other quality concepts) and Total Quality Control. It uses quantitative methods, people across all the processes in an organization (multidisciplinary approach), and guiding principles (Deming and Co.) to lay the foundation of a continuously improving organization that exceeds customer's expectations. TQM has customer service at its core and forms the basis of the service–cost–revenue 'triple crown' improvement drive upon which other methodologies such as Lean Production, Six Sigma, and BPM were built, as illustrated in Figure A1.

Table AI

Contributions made to quality control and quality management by the best known quality experts

Period	Quality expert	Contribution
From 1920s	W.A. Shewhart	• Understanding process variability • Concept of statistical control charts
From 1940s	W.E. Deming	• Management of quality (management responsibility) • 14 points to assist with quality management
From 1950s	J.M. Juran	• Concept of fitness for use • Concept of cost of quality
	G. Taguchi	• Product design quality • Taguchi loss function
From 1960s	A.V. Feigenbaum	• Concept of total quality control • Concept of total quality management
	K. Ishikawa	• Cause and effect diagrams • Concept of internal customer
From 1970s	P.B. Crosby	• Phrase: quality is free • Concept of zero defects

Just-in-Time, Toyota Production System, and Lean Production

The Toyota Production System was described by Ohno (1988b) as a system that supports the maximum production of goods in a continuous flow. Ohno (1988b) also pointed out that JIT and smart automation (autonomation or Jidoka) form the two main pillars of TPS. JIT enhances flow and pull perfection where the right parts reach a designated point in an assembly line at the time they are needed and only in the quantities needed (abolishes inventory, eliminates waste, synergizes entire process, and provides support at all levels). Jidoka, on the other hand, represents the ability of machinery and processes to stop when products or intermediate products are not within specification.

The term Lean Production was coined by J. Krafcik (1988) and was based on lean principles employed by Toyota and other Japanese manufacturing companies at the time. Krafcik's research was continued by the International Motor Vehicle Program at MIT, which produced the best-seller book *The Machine that Changed the World* by Womack *et al.* (1990). Lean Production is therefore a western interpretation of Toyota's manufacturing methodologies. Lean Production not only provides a set of tools to assist the identification and

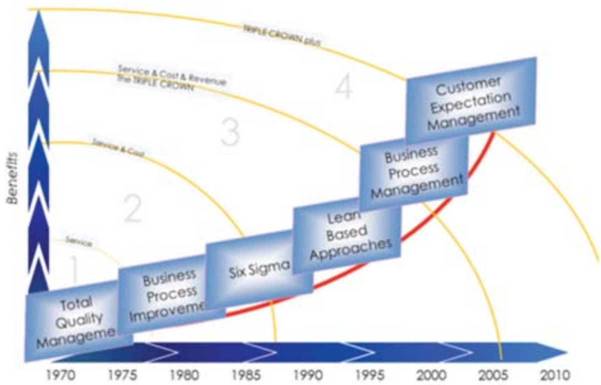

Figure A1—Development of business improvement methodologies to support service, cost, and revenue needs of organizations (BPTrends, 2014)

elimination of waste, it also enables the improvement of flow (smoothness of work) in a production system. Its focus, therefore, is on optimal planning, preparation, and design (muri), elimination of variation in quality and volume at scheduling and operational levels (mura), the elimination of waste (muda), and Lean Leadership (Lean Sensei). Lean Leadership is required to make work simple enough for everyone to understand, do, and manage and to foster lean thinking in the organization.

Theory of Constraints

The concept of focusing on a limiting factor to improve the output of a system was first developed by Carl Sprengel in 1828 and later popularized by Justus von Liebig (Liebig's Law, 2014). It propagated the principle that plant growth is controlled by the scarcest resource and not the total amount of resources available. This concept surfaced again in the 1960s and 1970s in the financial environment when Wolfgang Mewes (2014) propagated Management by Constraints (solving complex market constraints). It was also used in a scheduling software product called OPT (optimized production technology) in the late 1970s (Jacobs, 1983). E. Goldratt's book *The Goal* (Goldratt and Cox, 1986), however, created enough momentum for this concept (termed Theory of Constraints) to become one of the most widely applied business improvement methodologies (it was not tailored for a specific industry) in the world today.

Goldratt postulated that every organization has at least one constraint that limits its performance. Performance is often expressed as the rate at which money or goal units are generated, which emphasizes the unique flow-based nature of this methodology. Five focusing steps were presented to identify the constraint and optimize flow through the system as a whole, now and in the future. These include the subordination of non-constraints to the needs of the constraint, which is coordinated through the drum-buffer-rope technique. The TOC emphasizes the importance of *firstly* stabilizing the system, and then enhancing capacity if needed and where needed most (at the constraint(s)).

Six Sigma

Six Sigma is commonly used in the field of process capability studies, and it indicates the ability of a manufacturing process to produce a high proportion of output within specification. Six Sigma strives to produce products/outputs to a quality standard of less than 3.4 defects per million attempts (99.99966% within specification) by focusing on the elimination of variability throughout the organization or core business/manufacturing process.

The methodology was developed at Motorola in 1986 and gained momentum when GE's Jack Welch made it part of his business strategy in 1995. The methodology focuses strongly on statistical control and decision-making through the use of quality management tools. It also employs champions (black belts) that facilitate improvement initiatives across all business functions.

Business Process Re-engineering and Business Process Management

Business Process Re-engineering was introduced to the private sector by Michael Hammer (Hammer, 1990) when he stated that companies should reconsider their processes in order to maximize customer value while minimizing the consumption of resources required for delivering the product or service. A similar idea was propagated by Davenport and Short (1990) more or less at the same time that Hammer made his statement.

BPR strives to review key processes (the way work is done) in order for the organization to become a world-class competitor. It results in a radical re-design of an organization's resources and order-of-magnitude improvements are claimed once it is successfully implemented. Benefits come from managing processes as assets (end-to-end process view) in the organization and using IT to make non-value-adding work obsolete. This radical IT-driven re-thinking and re-design of an organization was criticized for its ambitious (change too radical) and often inhumane (lay-offs resulted from implementation) approach. One can also argue that BPR does not provide an effective way to focus the organization's efforts on the improvement of the constraint(s) and therefore flow through the processes.

BPM (also called management by business processes) also requires a re-thinking and re-design of all business processes before it can be successfully applied. Essentially it propagates the same concepts as BPR, but it leans strongly on TQM and CI methods and approaches.

High-level comparison between improvement and optimization methodologies

Table AII highlights some key differences and similarities between the above-mentioned improvement methods in terms of general focus, outcomes, and means of achieving these outcomes.

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Table AII

High-level comparison between some well-known business improvement methodologies

Method/criteria	TQC/TQM	TPS/Lean/JIT	BPM	BPR	TOC	Six Sigma
Definition	Business management philosophy and guiding principles that lays the foundation for sustainable business	Business management philosophies centered around the optimisation of flow (JIT) and reduction of waste (TPS, Lean) in a production system based on customer's needs	Holistic business management philosophy aligning all aspects of an organization with the needs of customers.	Fundamental re-thinking and design of an organisations resources to align with strategic business processes	Holistic business management philosophy whereby at least one constraint is managed to increase the business' throughput and reduce costs	Business management strategy seeking to identify and remove causes of defects/errors and minimise variability in manufacturing and business processes
Focus	Ensure quality in every part of the organisation; its practises, processes and product(s)	Smoothed flow (flow and pull perfection) and expend resources to create optimal value	Understanding, managing and improving business processes	Redesign the way work is done (functional to process driven) and reduce costs	Identification, exploitation and elevation of constraints in a value chain/business process and subordination of all non-constraints to the constraint	Reduction in variation and optimal design
	Reduction in variation		People and/or technology orientated			
Desired outcomes	Highest customer satisfaction; focus on what adds value to the customer	Higher production levels, lower cost, higher levels of productivity, improved product quality, higher customer satisfaction, increased profitability	Business effectiveness and efficiency, higher customer satisfaction, improved product quality, improved product delivery speed	Dramatic improvement in cost, quality, service and speed. Maximise customer value while minimising the consumption of/need for resources	Increase the rate at which money (make money now and in the future) is generated, lower operating expenses and manage inventory	3.4 defects per million (less variability means stable processes, an increase in output and improvement in quality)
	Cost effective operations					
	Continuous organisational improvement					
Means of achieving outcomes	Identify and meet customers' needs	Simplify work; focus on value-adding activities	End-to-end alignment of business processes, people and technology to improve flexibility, stimulate innovation and technological developments	Re-engineering of core business processes as a whole (sub-process optimisation give limited benefits)	Increase flow through the constraint(s):	Measure, analyse, improve/re-design and control process characteristics (DMAIC and DMADV)
	Establish a never-ending improvement culture	Smart automation (autonomation)		Use IT as an enabler and not just for support	Use pull system (customer requirements)	Quality management tools (statistical and process)
	Empower employees to identify and correct quality issues	Optimal planning, preparation and design (muri)			Buffer management	Stable and predictable processes
	Effective use of quality tools – reduction in variation improve quality (statistical quality control)	Eliminate variation in quality and volume at scheduling and operational level (mura)			Optimal scheduling of CCR	Strong, passionate leadership and support
	Design products to meet customer's expectations	Eliminate wastes (muda)			Subordinate all activities to the needs of the CCR	Champions to lead and implement change
	Effective process management: quality is build into processes	Lean leadership (Lean Sensei)				
	Address quality at the source					
	Quality concepts transferred to the suppliers					
Contribution	Shewhart – process variability, statistical control charts	Respect for people, value stream mapping, one-piece flow, pull, takt-time (time between production unit output, synchronized by customer demand) and heijunka (technique to achieve even output flow)	Processes as assets enabled/supported by technology	Radical improvement through business process redesign	Mechanism of focussing on constraints	Quantification of variation and financial outcome
	Deming – management responsible for quality			Consider business processes as a starting point for business analysis and redesign		Organisation structure change to incorporate "Champions" to lead Six Sigma implementation
	Juran, cost of quality and fit for purpose (fitness for use) concepts					Project orientated approach
	Feigenbaum – concept of total quality control					
	Crosby – concept of zero defects and quality is free					
	Ishikawa – cause and effect diagrams and concept of internal customer					
	Taguchi – Taguchi loss function and focus on design quality					

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