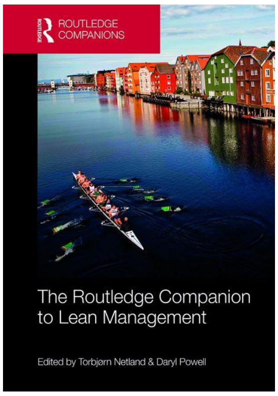

The Routledge Companion to Lean Management

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Lean Mining

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26
LEAN MINING

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Introduction

Modern-day mining is mechanized, automated, and capital intensive. Systems are expected to be robust and reliable and to perform safely at a designated level most of the time or even around the clock. However, due to unforeseen events and processes, design deficiencies, or operational and environmental stresses, system performance may not meet production requirements.

Lean mining refers to the application of the concept of lean production, to the mining industry. Mining as a process industry has specific characteristics and uncertainties. It differs from other industries where everything is human-designed and deterministic. Due to the nature of a mine, most factors are unknown until they are discovered and dealt with. This causes uncertainties from the beginning of the process (mine exploration) to the end (exploitation and reclamation). Thus, minimizing or eliminating uncertainty is a goal in the mining industry.

Mining companies are looking for ways to improve productivity; for example, adapting proven techniques used in other industries to suit the needs of mining. The concept of lean production, formulated by John Krafcik (1988), has attracted the attention of the mining industry. A company applying lean production has the goal of achieving continuous production at minimum cost (Kumar et al., 2015). Lean production focuses on managing resources to identify and eliminate any factors that do not create value for the end customer (Liker, 2009). Mann (2005) says lean principles include discipline, daily practices, and tools to establish and maintain a persistent, intensive focus on processes. In lean systems, results certainly matter, but the approach to achieving them differs sharply from conventional management methods. Lean management systems differ from conventional ones as they focus on process in addition to results (Steinberg and De Tomi, 2010).

Over the past 25 years, the lean concept has penetrated many industries and is being implemented in such diverse sectors as aircraft manufacturing, office processes, construction, and oil well drilling. Given the success of this production strategy, it is appropriate to consider its possible application to the mining industry. In fact, some mining companies have already started to do so (Wijaya et al., 2009).

The mining industry is inherently heterogeneous because of the variety of products exploited, grades, markets, and, most importantly, the size of its companies. However, it contains similarities as well. For example, the industry as a whole intensively uses capital investments, working continuously within a high degree of financial leverage. It is also a high-risk activity, since a mine plan is based on estimates. Since mines operate under conditions of permanent uncertainty, they require specialized business planning and analysis; hence the interest in lean thinking.

Other reasons for the mining industry's interest in lean production include the decreased profitability and increased cost pressure associated with uncertainty, not to mention the social and environmental demands of sustainable development (Humphreys, 2001). Arguably, the need to be compensated by reducing production costs can be achieved via lean management.

Lean principles require more than simply adopting the tool, however; the work culture must be changed to create "a true culture of continuous improvement." Furthermore, as Morgan (2005) points out, lean thinking is based on a single principle: all forms of waste should be identified and eliminated. This seems simple; however it is not always easy to recognize waste.

This chapter discusses the concept of lean thinking and management in mining. It notes possible areas of application in the mining industry and suggests reasons for using the concept in mine production processes. It concludes by presenting a number of successful lean mining case studies.

Mining Process

Mining exploitation is divided into surface and underground mining. Although we more commonly think of mining as an underground operation, high shares of raw minerals are produced by surface mining worldwide (Hartman and Mutmansky, 2002; Yamatomi and Okubo, 2015). Surface mining in the form of open pit or open cast is usually employed for deposits that are near the surface, or deposits with a low stripping ratio. Although a large capital investment is generally required, the result is a good one: high productivity, low operating cost, and good safety conditions.

The unit operations of mining can be defined as the basic steps required to produce mineral from the ore deposit. The two main components of the production cycle are rock breakage and materials handling. Each can be broken down into unit operations. Breakage comprises drilling and blasting; handling includes loading, excavation, haulage, and occasionally hoisting. A basic production cycle, therefore, consists of four unit operations: drilling, blasting, loading, and hauling.

Traditionally, the various production operations have been separate, but the current trend is to eliminate and/or combine functions. Accordingly, a number of specialized machines have been designed. In modern surface mining, to remove consolidated rock, rotary or percussion drills are used to create blast holes of 3 to 15 in. (75 to 380 mm) in diameter; explosive charges are inserted into these holes and detonated to reduce the ore to a size suitable for excavation. Shovels, draglines, or wheel loaders are then used to load the ore fragments on to trucks or other haulage units. Some common unit operations in surface mining are shown in Figure 26.1.

Lean Principles' Requirements in Mining

Mine production systems are associated with a wide range of uncertainties. These uncertainties often result in unplanned non-value-adding activities, leading to a waste of resources. Implementing lean manufacturing principles in the mining processes may help eliminate waste, but the high degree of uncertainty makes it difficult to do so. Mining is dynamic in nature and somewhat unpredictable compared with manufacturing processes. Therefore it requires unique solutions.

To reduce the waste of resources and efforts, we need to predict the process behavior as accurately as possible to meet just-in-time (JIT) delivery with agreed-upon quality. At the same

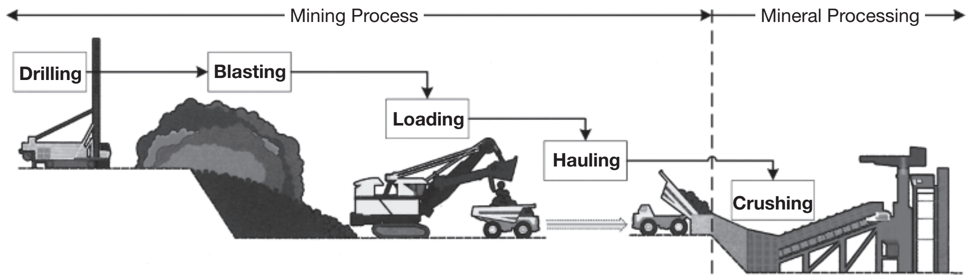

Figure 26.1 Typical unit operations in a surface mining process

Source: Adapted from Boliden AB (2012).

time, measures must be taken to remove uncertainty. To achieve a lean approach in mining, the entire mining chain needs to be considered, from mine exploration to mine planning, drilling, blasting, loading and transporting, ore dressing processes, reclamation, etc. Lean mining is not only dependent on mine production systems consisting of equipment and machines. It also depends on the quality and reliability of information flow in real time, generating action plans to achieve production goals and reduce waste. As in the manufacturing sector, reliability and maintenance preparedness have a major influence on the degree of waste generated. For example, if an ore body is not correctly delineated/characterized, if drilling operations are not performed correctly, or if the wrong charging process or the wrong loading process is used, resources are likely to be wasted.

The application of lean production to mining has two main objectives:

1 *Increasing productivity by eliminating waste and reducing cost*: Mine production processes are designed to meet customer needs and cost objectives. Lean mining recognizes that the marketplace, not the producer, sets the price of raw minerals, and better profitability can only be attained through cost reduction. Customer-oriented production is considered appropriate to meet profitability objectives, and the company continually seeks to reduce the production cost.
2 *Increasing safety*: Decreasing the cost of production should not result in a reduction in safety. Cost reduction generally affects safety issues in production. However, in lean mining we attempt to maintain costs, profit, and risk in an overall balance and at an acceptable level.

Mine exploitation is a cyclical series of activities, with one activity dependent on the next. Failure in one activity leads to many delays in the whole process. All activities are naturally subject to uncertainty (market, geological, operational, human, society, natural and rare events) (see Figure 26.2). On the operational level, uncertainty stems from the complex interaction between the ore body, the machinery, and the environmental parameters. This complexity results in the propagation of uncertainty which can be impossible to understand, realize, or control. Simply stated, the main concern in lean mining is the elimination of uncertainty.

Sources of Waste in Mine Operation

As mentioned earlier, waste elimination is one of the core issues tackled by the lean production concept. To implement lean thinking in mining, we must first define the sources of waste accurately.

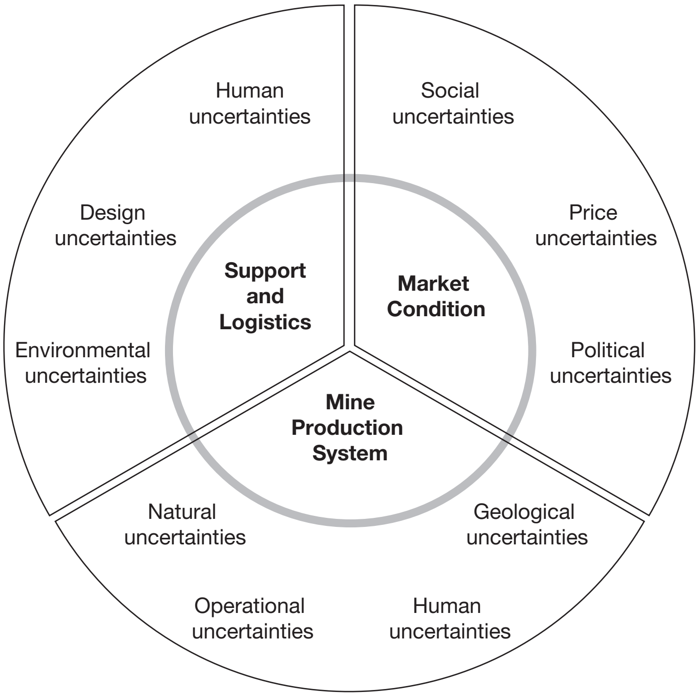

Figure 26.2 Actors involved in mining and their associated uncertainties

Based on the literature and the experience of the authors, we identify the main sources of waste in the mine production process as the following:

1 *Waiting*: Machines may have to wait to receive service/feed from each other in a production chain. For example, a shovel may wait for a truck or a load-haul-dump (LHD) machine might wait for a scaling machine.
2 *Overproduction*: This can be internal or external. Internal overproduction could represent producing more ore than the hauling or processing capacity in the mine. For instance, the mining capacity may outstrip the plant's ability to process ore, or the drum shearer might cut too much coal and overload the armored face conveyor (AFC). External overproduction could be producing more ore than market demand requires.
3 *Repair or rework*: Machinery might have to wait for repairs if there are large numbers of machines in a fleet, or they may take a long time to repair because of unskilled crews, complex machinery, or disorganized workshops. Finally, the support and logistics may be inefficient.
4 *Motion*: In large-scale operations, this represents operators' transportation to working faces or the transportation time of machines to the workshop.
5 *Over processing*: Ore may be processed to a better grade than the customer is willing to pay for (Dunstan et al., 2006).
6 *Inventory*: Too much inventory (capital blocking) or too little inventory (risk of shortage when it's needed) of material may be kept on site.
7 *Transportation*: Non-continuous transportation and low-capacity machinery.

To sum up, there is a wide range of waste in the mining industry, making it difficult to handle and having a destructive effect on mine production.

Flow, Stability, and Flexibility of Operation

Basically, the concept of flow in lean thinking may be expressed in terms of two ideals: 1) continuous flow, whereby products should flow continuously through value-added operations without delay, and 2) leveled production, whereby every product is produced in direct proportion to the demand for that product. In lean mining, continuous production is important to respond directly to demand, but leveled production is not applicable.

A high degree of stability is a prerequisite of flow because it minimizes operational disruptions, which are difficult to tolerate in continuous flow systems. In lean production systems, stability is achieved through such practices as consistent work and quality.

A key performance measure for achieving continuous and stable production is the availability of the production fleet during scheduled operational time. Here, the reliability and maintainability of the machinery play a key role. An optimal maintenance strategy, efficient spare part planning, effective logistics/support, and skilled personnel are crucial if lean mine production is to be achieved.

As mentioned, mine operation is cyclical, with specific machines set up in specific places at specific times. This procedure seriously reduces the utility of the mine fleet. A reduction of set-up time would significantly reduce idle time and increase productivity. A good strategy is to develop systems that increase the cycle duration and minimize the frequency of set-ups.

Flexibility is another feature of lean production. In mining, it can be attained through the use of flexible equipment (i.e. used for more than one task) and multi-workface (i.e. work in more than one location at one time). From a flexibility and production reliability point of view, several working faces with the same or different capacities would assure continuous and reliable throughput.

Case Studies

While lean production seems to be a new concept in mining, it has been indirectly used since 1975 when continuous mining was introduced into many mining methods, including longwall, and room and pillar. In addition, in the past 20 years, an impressive level of automation has been achieved. This has the potential to improve both safety and productivity. A holistic and lean view of the mine value chain and business has emerged more recently and continues to be developed. Applications of lean production in mining include long conveyor belts and *continuous material handling systems and machinery* such as huge bucket wheel excavators (Figure 26.3). These solutions avoid many problems associated with transportation (e.g. dump trucks) and discontinuity of operation.

Case Study 1: VALE Mining Company

VALE mining company has implemented the concept of lean in its iron ore mining and processing in Carajas mine in Brazil. To ensure the stable flow of goods along the mine production chain, VALE has designed its process with a *high degree of automation* (Steinberg and De Tomi, 2010). In addition, a high level of availability has been achieved for its mining machines by applying proper maintenance. Automation, along with continuous material handling, has resulted in good and reliable production.

(a) Continuous material handling system (conveyors) from underground to train loading station, Tabas Coal Complex, Iran (Photo: Authors)

(b) Continuous excavating and transporting of overburden and lignite by giant bucket wheel excavator in open pit mines in Hambach, Germany (Photo: Thyssenkrupp AG)

Figure 26.3 Continuous material handling systems

Table 26.1 Annual achievements of lean production in Carbon Bake Furnace

Criteria	*Parameters and measures (2004–2006)*	
Health and safety	Incidents (154 ↘ 67)	First aid (24 ↘ 0)
People commitment	Turnover (15.5% ↘ 9%)	Absenteeism (3.4% ↘ 1.8%)
Environment and communities	Odors (14 ↘ 2)	
Operational excellence	Carbon dust (20% ↘ 6%)	Net carbon ratio (0.431 ↘ 0.41)
Financial strength	Recycled >200 t coke valued at $386,867. New in-house coke screen saves $130,000. $2 million annual savings. $1.9 million gained by avoiding additional fan capacity. Delays of $1.2 million furnace rebuild.	

Source: Dunstan et al. (2006).

Case Study 2: Rio Tinto Mining Company

Rio Tinto is one of the best-known international mining companies. It has selected lean thinking to extend business improvements into the workplace. Its objective is to achieve *daily incremental improvements* at an operational level, engaging everyone in the process (Dunstan et al., 2006). Aware of the successful application of the lean concept in other aluminum business activities, Rio Tinto Aluminum (RTA) tried to implement it in its own aluminum mining, refining, and melting processes. Rio Tinto has also applied lean mining in its other mines, especially in coal mining in Northparkes Mines and Hunter Valley Mine in New South Wales, Australia. However, the best results have been achieved in Rio Tinto's Carbon Bake Furnace; the results are presented in Table 26.1. As shown in this table, for the five criteria (health and safety, people commitment, environment and communities, operational excellence, and financial strength), Rio Tinto has achieved considerable improvement (more than 200 percent in some cases).

Case Study 3: National Iranian Steel Company

National Iranian Steel Company is the owner of several coal and iron ore mines in Iran and has started to implement the lean concept in its mines. As a prerequisite, it sought *ISO certificates* for its mines. Tabas coal mine, a fully mechanized longwall mine, was the first Iranian mine to run the ISO-9001 and ISO-14001 standards in its operation and managerial systems. ISO-9001 describes how an organization should focus on customer needs and review internal working methods to reduce costs and increase efficiency and profitability. ISO-14001 is an internationally accepted standard, providing the basis for establishing environmental management in all types of organizations in all kinds of industries. The main goal of these standards is to minimize the waste in the whole production process. This, of course, is the main goal in lean production. As in the VALE experience, the implementation of ISO standards and lean thinking in the Tabas coal mine has resulted in daily improvements at an operational level, with everyone engaged in the process.

We should point out that these applications are not consistent with a holistic view of mining. Rather, the lean idea has been applied in certain individual operations in the mining process. The results are positive but cannot be considered holistic, largely because of the partial application of lean thinking.

Case Study 4: A Swedish Mining Company

The final case study is a Swedish open pit mine. It presents the results of a lean mining research project (2010–2014) in the Division of Operation and Maintenance Engineering at Luleå University of Technology, in combination with other research findings in Sweden (Yngstrom, 2012; Loow and Johansson, 2015). The mine in the case study is one of Europe's largest open pit mines. It produces copper, along with some gold and silver as by-products. The mine began production in 1968 with two million tons of annual ore production. Since then, production has gradually increased to 18 million tons per year. At the end of its current expansion projects, it could potentially produce 39 million tons.

Mining is an outdoor, large-scale, and harsh industry. The case study shows the difficulties involved in implementing the lean concept throughout the entire mining production process. It takes years to be successful. If lean thinking is partially implemented at the outset, this could lead to subsequent expansion throughout the whole system.

Defining subgoals and establishing a step-by-step procedure is an essential start to applying the lean concept in mining. The case study mine defines the following as its subgoals:

1 improving the reliability of production machinery,
2 creating a continuous mining process, and
3 improving the working environment to enhance quality.

The field analysis of the case study mine and the assessment of current operational conditions considering the basic principles of lean production show some weaknesses that need to be eliminated from the mining processes, as well as some strengths which should be extended. These are presented in Table 26.2.

When we take a close look at the weaknesses and strengths, we realize the case study mine could take a number of practical and managerial actions to improve the production system from a lean point of view. Suggested improvements include:

1 establishing better data collection and flow,
2 improving fleet availability,

Table 26.2 Strengths and weaknesses of mine production process from a lean concept point of view

Weaknesses	*Strengths*
• Insufficient data available • Low machinery availability • Lack of standardized work • High level of uncertainty • Low integrity of production components • Inefficient use of batch	• Value added in all process steps • Partly standardized information flow • Flexible production resources • Several working places and high-capacity machinery

Source: Adapted from Yngstrom (2012).

3 implementing advanced maintenance programs (e.g. eMaintenance),
4 implementing comprehensive decision support systems for different organizational levels,
5 implementing automated systems and machinery,
6 developing visual controls and mobile apps for continuous production monitoring, and
7 developing new standards and getting more standardized work orders in daily operation.

In addition, two lean metrics should be used to follow up the mine's lean initiative: total lead time and machine availability. Individual cycle times are important components of total lead time. The total lead time of ore production (time length of the exploitation process from drilling to delivery to crusher) is 33.6 days in the current state. According to the future-state map, the lead time could be lowered to 17.16 days by enhancing the fleet availability from the present average value of 78 percent to 90 percent (Yngstrom, 2012). This could be achieved by implementing the lean-based improvement techniques mentioned above, especially maintenance-related solutions and automation.

Findings from the case study suggest the lack of stability and standardization in the production process are the main challenges to lean mining. If standard approaches are developed in mining, companies will be able to adjust their specific cases to fit the benchmarks. Lean production will lead the way to a substantial improvement in efficiency.

Conclusions

The lean thinking approach involves the creation of continuous production flows based on customer demand. The use of lean thinking can increase a company's ability to satisfy its customer needs in delivery time, price, and quality, thus ensuring a higher level of profitability. These concepts apply in all types of industries, including mining.

With the emergence of less costly technologies, it is possible to enhance the accuracy of mining processes (e.g. correct delineation of ore body, elimination of hole-deviation, etc.) and reduce waste from the mining value chain. These new technologies facilitate real-time condition monitoring, eliminating unplanned stoppages and system idle time as a major cause of the loss of production capacity.

There are still many challenges to the full implementation of the lean concept in the mining industry:

1 Lean thinking must be culturally accepted by miners and mine managers. A prevailing mindset says "mines are different from Toyota." This may be true, but we should focus on the similarities and implement as many features of lean thinking as possible.

2 Due to the high degree of heterogeneity in mining and the many variations in logistic and support systems, it is challenging to establish a single standard process for all kinds of underground and surface mining methods. It may be best to partially apply the lean concept in the beginning and then gradually extend it.
3 Mining is associated with a wide range of uncertainties, making it a complex process to analyze and improve. Therefore, lean implementation should be considered at all levels of operation and in all aspects of mine design.
4 Companies using lean mining methods have been met with only partial success. That said, they have noted a considerable improvement in health and safety, environment, and operational excellence.

Acknowledgment

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