Abstract

The future of mining will surely be subject to increased international competition. To remain successful under these conditions of heightened competition, companies may turn to rationalisation. One concept that has seen success in rationalising the industrial sector, and even the healthcare sector, is Lean Production. Based on a literature study, this paper provides an overview of Lean Production and its application to the mining industry. The paper will also attempt to provide recommendations for the implementation of the concept. It is found that parts of the concept is suitable for implementation and that other parts will require modification of the Lean Production concept or is dependent of future technology. The mining industry is, however, ready to be their “Lean journey”.

Introduction

As part of the European Union-funded I²Mine project, a handbook aimed at mine planners is to be developed. While the handbook’s main purpose is to provide mine planners with guidance in designing safe and attractive work places, the issue of organisation and management will always be encountered in exploring this topic. As such, a section of the handbook is to be dedicated to the organisation of the workplaces of the mines of the future. A management concept that is not only popular, but also has seen success in the manufacturing industry, on the one hand, and e.g. the healthcare sector, on the other hand, is Lean Production (LP) [1]. As future mining will be shaped in a context where it is necessary to produce at costs that are determined by international competition, and where long-term demand will increase [2], mining companies, too, will begin looking towards LP to rationalise and increase the productivity of their business (and, to a certain extent, already has, as this paper will illustrate).

While LP is not without critique (e.g. Carayon & Smith [3] and Sederblad (ed.) [4]), other studies have shown its potential to increase both productivity and employee well-being, given that focus is spent on the appropriate factors [5-8]. Because LP both provides the tools for mining companies to flourish, is becoming popular, and shows evidence of being able to improve work environments, using this concept for the subject of organisation and management in the handbook, can be justified. However, even though LP for mining seems to be on the agenda, there are only a few recommendations aimed specifically at LP and the mining industry.

The purpose of this paper, then, is twofold: one, to provide an overview regarding LP and its application in the mining industry; and two, to provide recommendations regarding the concept’s adaption to mining. To be able to discuss this subject, some introduction to LP, its principles and practices, and the model utilised in this paper, has to be given.
What is lean production?

There is plenty of literature describing the concept of LP, its origin, how to successfully adapt it to your business, and so on. Arguably, among the most popular of this literature are the books by Liker [9] and Womack & Jones [10].

Liker’s [9] model of LP consists of 18 principles divided into four levels, referred to as the 4P model. The model is summarised below [9]:

- Decisions should be based on a long-term philosophy, even if that would mean short-term loses.
- Create a continuous process, using pull-systems and levelled workloads, where production is set by customer demand. Create a culture that stops to fix problems and cares for quality. Standardise tasks, use visual control and adapt only reliable technology.
- Value is added to the organisation by developing employees. Leaders should adapt the philosophy of LP and teach it to others; employees should be developed to also follow the philosophy. Respect partners and suppliers; challenge them and help them improve.
- Solve the root problems and go see the problems for yourself. Make decisions slowly and by consensus; implement quickly. Strive to continuously improve.

Another model is provided by Womack & Jones [10]. The five principles of the model can be described as follows:

- value is only definable by the customer and only meaningful when expressed in terms of a product or service which meets the needs of the customer at a certain price and time.
- the value stream is the set of all required actions to produce the product and/or service;
- flow is what remains to be achieved once value has been defined and the most obvious wastes eliminated;
- pull is the concept that customer pulls the product rather than the company pushing the production (once flow has been achieved); and
- perfection is the idea of involving everyone in the value chain to perfect the creation of value [10].

The first four principles (value, value stream, flow and pull) are described as principles that “interact with each other in a virtuous circle” (p. 25) [10], with perfection encompassing it all.

As can be noted, the two models overlap and both of the above models will be of use in the reviewing texts on LP and mining. However, while each model has its own strength, and being familiar with them is important in understanding LP and its potential, they are lacking for the purpose of this paper. This is because the model utilised by each individual author (or group of authors) differ throughout the reviewed texts; not only between one of the two models, but at times no clear model is used at all. As such, the model by Lyons et al. [11] will be used when discussing the concept of LP in this paper. The model is based on the literature published on the topic of LP, i.e. the model presents LP as it is being used
and discussed, as opposed to present LP as it is prescribed. The reasoning for choosing this model is can be explained by the authors themselves:

The framework was not developed in order to make an unnecessary addition to the existing lean thinking framework-set. Rather, it provides a lean architecture that is not only suitable for this study by allowing the adoption of lean principles and practices to be readily established but also it provides a coherent, uncomplicated amalgam of those goals, principles and practices that are evident in the most authoritative lean thinking research. (p. 478) [11]

Because it is “capturing the sentiments of the published lean thinking literature” (p. 479) [11], it has the best chance of encapsulating the different aspects of LP as brought up in the reviewed texts. And, although not completely exhaustive or definitive, it is still “a representative lean model that can be utilised in a practical manner for determining the adoption of lean thinking principles and practices” (p. 480) [11].

The model describes LP as consisting of four principles which, in turn, consist of a number of practices. The principles are alignment of production with demand (e.g. pull systems, one-piece flow), elimination of waste (e.g. 5S, TPM), integration of suppliers (e.g. supplier development activities, JIT deliveries), and creative involvement of the workforce (e.g. kaizen, work organised in teams) [11]. The principles are not exclusive, however, and there is some overlap, i.e. one practice might be considered to be part of two or more principles.

The different principles and practices of LP still require further explanation. This will be briefly described in the following paragraphs. The descriptions below are based on both Liker [9] and Womack & Jones [10]. Note that this summary of the practices does not encompass all practices of LP or of the above model. The focus here is on the practices that are included in this review. The model finally utilised is presented in the ensuing section (Table 1).

The alignment of production with demand is the principle that deals directly with production. The idea is that products should be manufactured on demand instead of being “pushed” through the production, i.e. production is “pulled” based on the demand of downstream customers (both internal, e.g. other workstations, and external, e.g. people or companies buying the product). Production is stared as a signal sent from a downstream customer. Another way to express the idea is that production should be “make-to-order” as opposed to “make-to-stock”.

The principle of production alignment also requires the ability to vary production rates, i.e. production has to be flexible. The ability for machines and processes to be used for several different products (non-specialised equipment), and for changes in volume and product mix to be accounted for, also ties into the concept of flexibility. Finally, there should be a commitment to reduce cycle times and a general strive towards utilising minimum economic batch sizes.

The elimination of waste is probably the most recognisable principle of LP, and waste and its elimination are concepts central to LP. In total, there are eight different kinds of waste: (1) overproduction; (2) waiting times; (3) unnecessary transportation; (4) unnecessary processing or reworking; (5) inventories (e.g. intermediate storage); (6) useless motions; (7) scrap, repairs and inspections; and (8) unused employee creativity. To effectively and efficiently eliminate waste, commitment is required from the whole organisation. The mapping of these wastes and activities that increase the product value is referred to as value stream mapping (VSM).
Standard operations are prescribed to provide instruction on how to best perform a procedure, with as little waste as possible. It is also needed for evaluations, e.g. to determine if the task, production technology, or maybe even the whole flow, needs to be modified. To support in standardisation and in ensuring quality (the lack of which is a waste), visual control is utilised. This is usually in the form of information centres. The principle also includes the establishing of quality systems that prevent faulty products from continuing in the production process; each worker is trained to recognise and control potential defects.

Another tool included in the principle of eliminating waste is Total Productive Maintenance (TPM), which is sometimes referred to as “integrated maintenance”. The purpose of TPM is to create disruption-free production by encouraging all employees to get involved and continuously making small improvements and preventative maintenance.

To lessen the waste associated with waiting, quick changeovers (QCO) are aimed for. Single-minute change of die (SMED) is a useful tool for this purpose. The tool helps in reducing setup-times, i.e. either the time to prepare for the production of each product, or the time required to make the changes required to produce a different product, or both.

Finally, there is 5S, which is a tool with the objective of engaging every employee in all aspects of production and, with orderliness, creates an efficient and conducive workplace. 5S refers to the first letter of the words normally translated as “sort”, “straighten”, “shine”, “standardise” and “sustain”. These are the actions that are promoted in the method, with the aim of gaining an overview and to make production, flow, and any shortcomings, visible so that improvements can be made.

The integration of suppliers entails actively supporting suppliers in their efforts to become “Lean”. This means assisting in solving problems and improving performance. The goal is for deliveries to be just-in-time (JIT), i.e. deliveries should arrive exactly as they are needed in the production (JIT is also often talked about in the context of production flow, where products should arrive just in time at the next station in the flow). The suppliers, like the ordering company, will have to be flexible, with the ability to quickly respond to changing demands. Furthermore, the aim should be to develop long-term contracts and relations between the supplying and ordering company. Through these long-term contracts, both parties can develop and better align themselves to each other.

Finally, there is the principle of the creative involvement of the workforce. In many respects, this principle concerns avoiding the eighth waste, unused employee creativity; however, it also deals with developing and training the workforce, as well as improving their working environment. The principle aims for work to be organised in multi-functional teams, i.e. there is no specialists; instead, each member of the team should be capable of doing the tasks of the other team members. This not only makes the teams less sensitive to disruptions, but also allows workers to rotate between different tasks.

Problem solving should also be team-based. The problem solving ties into the concept of kaizen, or continuous improvements, which is the idea that organisations should continuously strive to improve on ever last detail, i.e. develop existing, stable and standardised processes in small steps. However, these improvements have to be worker-driven; it is the workers who possess the knowledge of the manufacturing process and its short-comings.
Literature study

The majority of the papers on the topic of LP and mining were gathered through the use of the databases Scopus, Web of Science, and ProQuest, as well as Google Scholar and the database search engine of Luleå University of Technology (LTU), Primo, was utilised. The results from the queries yielded a significant amount of irrelevant results. However, by reading the abstract and titles of the identified papers it was possible to distinguish the relevant papers from the irrelevant ones.

Following the identification of the initial papers, the references of these papers were reviewed in order to find additional articles. The references of any new articles were also reviewed, and so on. And, lastly, some reports on LP and mining were acquired with the help of the faculty of the division of Human Work Science at LTU.

In total, 17 texts on this subject was found and considered for this paper. Three of these did not cover the subject in a sufficient enough manner and has therefore been excluded from this paper.

Analysis of results

For analysing the identified texts, the model by Lyons et al. [11] was initially used. Each text was analysed and themes corresponding the practices in the model were identified. As not every practice could be identified as a theme, and some identified themes did not directly fit into the model, the model was modified. The final model utilised for this study is presented in Table 1.

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Table 1: The model, based on Lyons et al. [11], used for analysing the identified texts. The principles (in bold) are listed with the practices listed below

The most notable addition to the model is contractors. The importance of the topic of contractors is twofold as mining companies are already dependent on contractors in their operations [12] and contractors are worse off in e.g. work environmental issues [13, 14]. This being the only included “practice” in the principle of supplier integration will be made clear below. Further additions to the model will be noted where needed and relevant.
An overview of lean production in mining

The review of the application LP to mining, or Lean Mining (LM) as it will be referred to occasionally from this point forward, will be based on the model presented in Table 1, but in a different order; the principles will be presented in the order of most frequently mentions throughout the texts. Where possible, this review will be broken down to “practice level”.

Waste elimination

The principle relating to waste elimination is the most widely covered topic in the reviewed texts, with all texts discussing parts of the principle in some manner. Waste elimination is probably the principle closest associated with LP, which might help explain its popularity in the texts. This is, furthermore, the topic in which most tools of LP are included. Also, note the addition of “value” to the original model [11].

Value

As waste can be considered anything that does not add value to the final product, it makes sense to first account for the views on value throughout the reviewed texts. Three papers cover the topic in a large enough extent to merit inclusion here [15-17] and the importance of correctly defining value is highlighted by all three. In one case, the topic of value is expanded beyond simply being defined as value for direct customers. Wijaya et al. [16] argue that mining companies have several indirect customers. These are stakeholders such as society, government and media. The values and opinions of these stakeholders should influence the mining company’s definition of value [16]. An example of this would be taking into consideration society’s “green” values by ensuring the ore is produced with as little environmental impact as possible.

Standardisation

Amongst the texts, standardisation represents the most popular of practices of waste elimination. The opinions regarding the applicability of this practice to mining vary between authors. Most authors argue that standardised work is desirable [15, 16, 18, 19], but it is also described as more difficult to apply, compared to traditional manufacturing [15, 16, 20, 21]. Furthermore, it is stated that standards intended for mining activities would have to be more flexible than “traditional” standards [15, 19].

Although an agreement, for the most part, exists regarding standardisation in mining, there is one case of descriptions of the standard differing in a significant manner. Haugen [20, 21] describe standards and instructions as being perceived as being inhibiting for initiative and improvement, in part because conditions in mining vary considerably; while Hattingh & Keys [19] argue that standardisation is the foundation for change and improvements, since if methods and plans constantly change, a high level of variation is a certainty (a similar argument is put forth by Yingling et al. [15] and would be in line with Liker [9]).

One paper [18] provides an example of standardised work from an actual implementation. However, this implementation was done to a supporting function and not a main mining activity. In this case, standardised work was introduced to a truck service bay. Results are reported to have been reduced time required for service and some cost reductions [18]. Another paper [16] provides a theoretical example of the possibility to standardise one activity of the mining cycle: rock bolting. The number of bolts used and the pattern utilised
is based on worse rock conditions. This would increase material used and time taken, but would reduce variation in process time and improve quality [16].

5S and visual control

5S and visual control are both practices that represent a common starting point when it comes to implementing LP [16]. It would also seem that they are not limited to the unique characteristics of mining in the same way other practices might be. They also seem to be mostly discussed together: in all but one paper, 5S is discussed together with visual control [16, 18, 22, 23] (the exception being Helman [22]). These practices’ applicability to mining is demonstrated by two practical examples [18, 23]. In both these cases, the practices seem to have had a positive effect.

In some cases, the implementation of 5S and/or visual control is recommended for supporting functions if their adaption to main mining activities cannot be realised [18, 22] (Dunstan et al. [18] also showcase the possibility of doing so, but provides no recommendation). Such supporting functions would be e.g. repair bays, storage, and tool chambers. The reason for applying these practices to these areas might be explained by the fact that they usually resemble more “traditional” workplaces.

TPM

The practice of TPM is described as being needed for stability in the mine production process [15]. TPM could increase the reliability of machinery (increased mean time between failures), which would decrease variation in the production process [22, 21]. The importance of TPM is also due the long distances usually involved in mining; if a machine has to be taken away from the face and to a repair shop, a significant amount of time may be lost [16].

Two papers describe TPM as already practiced and even accepted to a certain extent (e.g. in the form of preventive maintenance or simple non-routine maintenance) [15, 16]. This could, on the one hand, be used to argue for the practice’s importance to mining, or, on the other hand, be taken to mean that an implementation would be of little difficulty. It is also argued that the practice is ready to implemented “as is”, because of this [22].

However, while TPM can be considered important to mining, Wijaya et al. [16] note that it is also important that the operators (i.e. those who are supposed to perform the maintenance) receive the proper training. Otherwise, TPM might have the opposite of the desired effect: more uncertainty and variations as faulty repair and maintenance increase machine breakdown frequencies

SMED/QCO

The topic of SMED/QCO is only covered by two authors [15, 16]. The conclusion of another paper [24] does, however, affect the discussion. The discussion by Yingling et al. [15] relates mostly to flexibility. The general recommendation is that reduced setup-times should always be aimed for. However, the differences between mining and manufacturing would require a different approach to the subject, as illustrated by the following quote:

In contrast to manufacturing operations, mining operations tend to be cyclic, with most setups occurring between successive cycles. A wise strategy often is to devise systems that increase the cycle duration and thereby minimise the frequency that setups are needed. (p. 227-228) [15]
Wijaya et al. [16] argue that the implementation possibility largely relates to scheduled maintenance. Here, the maintenance is, presumably, considered the setup-time (as it happens at regular intervals and represents time that is required before machine can be used again). As such, the focus is prescribed to be to increase the “maintainability” of the equipment, make maintenance easier, and “design-out” maintenance completely, where possible [16]. All of these suggestions would reduce the setup-time.

In discussing QCO/SMED, the “matching” of some of LP’s concepts to mining, as done by Maier et al. [24], should be noted. In their description, driving times would be considered changeover times. With this definition, reducing changeover times would entail minimising driving distances. This could be done by e.g. making sure machines are assigned to faces that are closest to the machine; or that the planned order in which the faces are to be worked, ensures that an optimal path is utilised.

**Quality**

Quality is usually described as something that is hard to control in the mining industry [15], and there is some evidence that it is an issue frequently disregarded in favour of keeping production up [20, 21]. Quality is, to a large extent, dependent on ore selection as well as ore body and rock characteristics [15]. As such, the operators themselves have little influence over the quality of the product. Despite limited control, mining techniques that minimise e.g. ore dilution would be beneficiary [15]. Such a view on improving quality would be in line with the matching by Maier et al. [24], who translate “good part success chance” to mineral content. From this is seems quality in mining should be considered the percentage of ore in e.g. each truck load.

The discussion on quality also involves standards. Here, it is argued that without standardisation, quality has to be controlled or inspected, where with standards it would be a question of quality assurance (i.e. as long as the work is done in accordance with the standards, good quality can be expected) [16].

With quality being hard to influence in main mining activities, quality in supporting or auxiliary functions is instead discussed [15, 16, 20, 21]. In this, internal quality (defined here as problems that result in e.g. uneven ramp or unstable pillars) [20, 21] and safety is considered [15, 16]. For safety, focusing on quality could result in e.g. rock bolts being ensured to be installed correctly, or faces only worked under safe conditions [15]. In ensuring internal quality, rework (a waste) can be avoided [20, 21].

**VSM**

The topic of VSM will be kept relatively brief as it seems the practice’s application to mining would be straightforward. The mining process would be mapped, and waste identified, just like it would in other industrial sectors. It is noted, however, that it is important that the “process mapping … cross inter-organisational boundaries since the greatest wastes often occur at those boundaries” (p. 219) [15]. It is also prescribed as the logical first step in applying LP to mining in one paper [17]. The idea of VSM’s applicability to mining is further reinforced by two case studies which shows not only the ability to use VSM in mining, but also the benefits in doing so [23, 25, 26].

**Workforce involvement**

The general involvement of the workforce is also an easily recognisable part of LP. All texts cover this principle in some way, but to a lesser extent than the principle of
elimination of waste. It is also worth to note that the principle of workforce involvement does not seem to be limited by the characteristics of mining.

Apart from the themes brought up below, some authors mentions or at least implies the general involvement of the workforce [19, 25-27], even if they do not expand on this topic. These efforts range from involving the workforce in decisions affecting their work environment or in problem solving related to their work [19, 25, 26], to their involvement being vital to the success of the implementation [27].

**Team-based organisation of work**

Like in the traditional application of LP, work in LM is recommended to be organised in teams as well [15]. The practice in mining should not differ from its realisation in traditional applications areas. One case study shows the potential of organising work in teams [25, 26]. It should be noted, however, that the cases described in the study are work places of low mechanisation: power-tools are used, but bigger, more advanced machines are not [25, 26]. Adding to this, the aim does not seem to have been to organise work in team. Rather, this was the most suitable solution to the encountered problem.

There is other evidence exists to showcase the potential of utilising team-based organisation in mining: tunnelling and development activities can be found to be organised in small teams with a supporting team leader [20, 21]. Furthermore, historical accounts also serve to illustrate the adaption potential; previously, mines were split into production levels with small, three to four man teams with dedicated production equipment being assigned to them. This team was responsible for all production activities on that level, including maintenance [20, 21].

**Cross/multi-skilling**

The topic of cross/multi-skilled workers is a central theme in LP and is also considered for LM [15, 20-22, 25, 26]. Usually it is discussed alongside team-based work organisation (all papers mentioning the one topic, also mentions the other), but no practice is dependent on the other. Mining still involves a lot of work with machines designed for one person, and even if work is not organised for teams, cross/multi-skilling is still of use [15]. The underlying idea is best described by Yingling et al. [15]:

> Lean production systems seek a flexible workforce where each individual can man numerous operations … Here, one individual works multiple machines each production cycle in contrast to traditional practice to assign one individual per machine. (p. 227)

To some extent, this appears to already be the case. Experiences from one author shows that operators are multi-skilled (including having knowledge about maintenance), sometimes to the extent that it is not possible to trace which operator performed a certain task at a given time [20, 21]. Furthermore, because of this skillset, the operators might rotate to get variation in their work and reduce stress, and there are times when an operator does not know what task he or she is to perform during the shift, before the shift starts [20, 21]. The case study by Klippel et al. [25, 26] also shows there might be advantages to workers being cross/multi-skilled. In this case, having three workers being able to do all the activities of the mining cycle resulted in increased productivity.

**Kaizen/continuous improvements**

Kaizen/continuous improvements are also mentioned by several authors [15, 17, 22, 23]. For the most part, the implementation should not differ from any other industry. In fact, no
article brings up any argument for why kaizen/continuous improvements would not be applicable to mining. On the contrary, there are examples of the practice not only being applied but also improving work performance [23] (the exact details of the utilisation of the practice is not clear, however).

One issue regarding kaizen/continuous improvements is brought up by Yingling et al. [15]: succeeding in the practice of kaizen/continuous improvements requires a change in value. The values that would have to be changed to be successful in this practice, are perhaps more prominent in mining [28, 29].

**Competence/training**

The topic of competence/training represents the most discussed practice in the principle of workforce involvement, being covered by a majority of the authors [15-18, 20-22]. There is a general agreement that the competence and training of operators is of import. However, the extent to which the workforce is proposed to be trained varies between the authors.

In the more far reaching descriptions, each and every employee is suggested to become somewhat of an industrial engineer; an operator would have to know the basics of time studies and ergonomics as well as being able to utilise basic analysis principles [15]. Furthermore, and perhaps most important, the workforce will have to be encouraged to learn and would also have to receive the correct training [15].

Other views on training are also present throughout the literature. There is one case where LP is being regarded as way for retaining skill in an industry with high labour turnover [18]. In this case, LP is considered a tool for acquiring and relearning basic skills in a fast and structured way. However, this would be contrary to the argument conveyed by Yingling et al.[15] who argue for LP as a tool for retaining staff. The issue of high labour turnover is also raised by Wijaya et al. [16], but their standpoint is on emphasising training for new workers.

The intended recipient of the training efforts also differs between different authors. In a simplified manner, the differences can be summarised as training being for the operators or mine face workers [15, 18, 22], or the whole organisation [17, 18]. The motivation and purpose of focusing on the entire organisation is to engage all in the elimination or reduction of waste [17] and to ensure participation and understanding of LP/LM on all levels of the company [18]. When it comes to focusing training efforts on operators, one motivation is that these employees are the ones that need to be cross/multi-skilled to allow for flexibility and stability [15].

The discussion on competence/training can also be extended to include other practices. This is perhaps most evident in the subject of TPM. Even though only brought to attention in one paper [16], such an initiative would also have to include training that is fit for purpose. Failing in providing proper training could make worse the problems TPM, in this case, was set out to solve (e.g. variations in the production process caused by machine breakdowns) [16].

One author make a case for operator training being able to replace work standardisation [20, 21]. The argument here is that, with operators being sufficiently trained, standards become redundant as the operator would know the best course of action in most situation that the operator might be presented with (it would certainly be true that proper training would be able to cover more situations than standards would be able to do).

Finally, there is the question of how the workforce should be trained. Only two papers discuss the issue [18, 22]. In the one case, a vertical slice of the organisation attended
training workshops [18], while in the other, a case is made for the workforce training itself; the most competent worker would share their knowledge to others [22] (note that this might also be considered a part of kaizen).

**Demand-based production**

The principle of aligning production with demand represents the principle of LP that is argued to be the hardest to adapt to mining. The general theme is that it would be desirable to practice demand-based production, or even needed, but also that, today, it is not possible in any greater extent. Instead, the recommendations and discussions in the texts are usually concerned with the principle’s application to the supporting functions or auxiliary activities of mining.

Because of the similarities regarding the discussion of the practices of demand-based production, breaking the section into subheadings would be redundant. What is important, instead, is to try to crystallise what makes the practices of demand-based production unsuitable for or inapplicable to mining. There seems to be an agreement between the authors in this. For one, the tradition, common to mining, of constantly pushing production, at any cost, might be hard to abandon [15, 20, 21]. Furthermore, it is still, to a significant extent, believed that expensive machines have to be manned at all times to justify the investment [20, 21]. The long distances and tendency for large batch operations are also argued to be a hindrance for the principle [16]. The variations that exist in the production process of mining would make any implementation harder as well [20, 21]. Finally, it is argued that the tools available for fulfilling demand-based production are not suitable for mining and would require modification [15]. It might also be worth noting that no case study has shown the applicability of the demand-based production practices to mining.

The discussion is not ended here, though. As mentioned, the principle still has relevance to parts of mining, unrelated to the main mining activities. Two papers argue for the implementation of the principle to supporting or auxiliary functions [15]. Such supporting or auxiliary function could be e.g. repair or service bays, machine shop, or warehouses. Here, practices such as JIT deliveries and kanban (to indicate when supplies have to be ordered and to lessen inventories) could be used [22]. Even transports, using the principle’s practices, could be arranged in such a way that they arrive in a uniform and highly predictable manner [15].

**Supplier integration**

Even though, or perhaps because, supplier integration in the mining industry would differ little from its traditional application, it is a sparsely discussed subject. The idea seems to be encouraged [15], and Steinberg & De Tomi [17] advocate involving the whole value chain (including suppliers) to eliminate waste. On the other hand, supplier interaction happens at a higher level than many other practices of LP. This would mean that the type of company would be of little importance and that mining companies are just as suitable for this principle as any other business. This could serve as one explanation for the lack of coverage throughout the texts.

Apart from this, the topic of contractors is covered by three papers [16, 18, 23]. The potential problems regarding the prominence of contractors are only raised in one paper [16], however. Wijaya et al. [16] note that engagement from contractors in practices such as 5S and continuous improvements might be hard, as the contractors do not necessarily share the same values and investment as ordinary employees.
On the other hand, both Dunstan et al. [18] and Castillo et al. [23] show the potential of introducing LP despite the problems described above. Dunstan et al. [18] describe one successful case where contractors were involved, while the study by Castillo et al. [23] describes LP as being used to combat problems that were associated with contractors, also successfully. However, Castillo et al. [23] note that these effects were short-term and, as such, it is hard to comment on the longevity of these effects (this also applies the results reported by Dunstan et al. [18]).

The road to lean mining

What remains, then, is to provide a possible route forward. Based on the reviewed texts it is not possible to draw a complete map of the road ahead, but it is possible to find some direction. Keep in mind, however, that this “map” is a suggestion. What works and does not work will differ between companies and their particular situation.

As most proponents of LP would insist, the first step in the “Lean journey” is correctly defining value [9, 10]; correct, in that it should be value in the eyes of the customer. However, this definition of value should be extended to include all relevant stakeholders and their values and opinions [16]. Value should be defined in such a way that the societal value of e.g. low environmental impact is considered; or in such a way that the final customer’s requirement that the work required to produce a certain product is done under fair conditions, is reflected in the values. Making this definition would be the first step, and all subsequent actions and decisions would have to be in line with this definition of value. Having value be defined this way, an improvement only improving the environment might perhaps be considered valuable where it might otherwise have been considered waste.

Waste elimination

With value defined, practices related to the principle of waste elimination should be adapted and practiced. Starting in this principle makes sense as these practices are more general and are hindered to a lesser extent by the unique characteristics of mining, compared to the practices of other principles. Furthermore, practices such as visual control and 5S are included in the principle of waste elimination. This is advantageous in two respects: first, they are the first practices usually adopted by companies beginning their “Lean journeys” [16], providing some evidence of the practices’ suitability as starting point; and, second, the effects of these practices are visual, which may serve as a motivator and help in engaging the workforce. These practices could be applied to the whole mining operation [18] or, if options are more limited, in supporting function such as machine workshops and warehouses [18, 22]. Developmental works also represent a suitable area of implementation [23].

Standards should be developed to allow for continuous improvements [15, 19]. However, it is important that these standards are flexible [15]. This is a somewhat contradictory statement, though. As such, it might be better to talk about “action plans”, an instruction on what should be done in a given situation but that does not specify how. Furthermore, it is important that these standards are developed with the involvement of the workers and operators themselves [27]; without their involvement these standards might not just be rejected, but valuable information may also be lost. Even more so, the operators will have to be given proper training to be able to, themselves, identify areas of improvements and be aware of the effects their proposed changes might impose on e.g. their working environment [15]. This is also something that could be introduced to the entire mining
value chain; all employees of the company should receive training in the principles of LP [17, 18]. Standards or “action plans” can be considered to be of greater importance in the actual production process, as this could decrease variations. Since the variation in the mining process represents a barrier to fully realising LM (or at least LP) this could considered a prioritised area. An example of standard operations in the production process would be the procedure of rock-bolting the roof: with the help of the operators, a technique (how many bolts, in what order, etc.) that guarantees safety, a good working environment, and efficiency can be found [16].

Continuing: TPM needs to be fully adopted to improve machine availability and, by doing so, further decrease the variations of the production process [20, 21]. As there is some evidence of it already being practiced (or at the very least, similar concepts are being practiced) [15, 16], the implementation should be relatively “quick-fix” in nature. However, it is important that the operators, who are doing this maintenance, get the training they need to successfully perform the maintenance. Otherwise, with faulty maintenance being performed, additional variation might be introduced to the production process instead of reducing them [16]. The practice of TPM would mainly apply to the activities related to the production processes, but could also be of relevance for supporting functions such as transportation [22].

**Supplier integration**

The principle of supplier integration can be of benefit to the mining industry. Apart from “traditional” suppliers, contractors should also be included here. For the “traditional” suppliers, this principle does not differ much from any other industrial sector and should be implemented in the same way as done there. Introducing the principle to contractors, however, should have a priority, as not only are some mining companies dependant on contractors [12], contractors’ working environment and accident rate is worse than those of regular employees [13, 14].

In applying the principle of supplier integration, contractor companies are to be challenged and assisted in their own Lean journeys and work in providing a good working environment. Those who are successful in this should be rewarded with long-term contracts. Furthermore, when establishing supplier relationships, it is also important to look beyond monetary factors. Areas such as safety records should also carry heavy weight when choosing the most appropriate contractor.

As an alternative to this, the utilisation of contractors could be discouraged as a line in becoming more aligned with the philosophy of LP. In this, mining companies should maintain and possess necessary knowledge and a sufficient workforce, and this workforce should be developed and essentially offered permanent work security [15].

Not explicitly a part of the principle, but still relatable to it and important, is the involvement of equipment manufacturers. When procuring new equipment, on-going communication with the manufacturer is required. The aim here could be likened to that of mistake proofing; equipment should be designed in such a way that mistakes are impossible to make [21]. The exact details of this “mistake proofing”, i.e. which mistakes are to be designed out, will, of course, vary for each machine. As examples, though, it worth looking into the ability for machines to disallow to high loads (as this can introduce unnecessary wear to the machine), or speed limiters that prevent the operator from driving at a speed deemed unsafe. This would apply for most a mine’s operations and activities.
Demand-based production

In providing a road map for leaner mining, the principle of aligning production with customer demand could constitute unknown or unmapped terrain. While the reader perhaps could be provided with some recommendations regarding this principle and its application to the production process, there is almost an unanimous agreement among the authors (who cover the issue) that the biggest potential for the principle today is in supporting functions. In its application in supporting mining functions, tools such as kanban can be applied to make sure supplies and material are delivered when needed, reducing inventories and creating a flow [15, 16, 22]. Furthermore, the arrivals of transports to the mine site should be uniform, helping in keeping production levels balanced [15].

For the production process itself, and the establishing of a continuous flow, Haugen [20, 21] provides recommendations. Her recommendation is that of substituting fragmentation technique of drill and blast for mechanical fragmentation. Furthermore, the machines capable of this would have to break the rock at the face and transport the ore to a transportation system (e.g. truck or conveyor). Haugen [20, 21] also argue for this type of machine being able to install rock support as well. In this, several machines would be substituted for one.

Workforce involvement

The final principle to be covered is that of involvement of the workforce. This is a principle that is not, to any larger extent, hindered by the mining industry’s characteristics. For the most part, this principle, as described in the “Lean literature” (e.g. Liker [9] and Womack & Jones [10]), can be implemented as prescribed. There are, however, some exceptions that require some further clarification.

The practice of operators working in teams and being cross/multi-skilled should be practiced to an even larger extent. Having operators able to operate all machines in the mining cycle will further increase both flexibility and stability. This also ties in with work being performed in teams. Although mining has, historically, to a certain extent, been performed in teams, this practice seems to have decreased following increased mechanisation. And the mechanisation might, indeed, make organising work itself in teams hard. Instead, work tasks should be assigned to teams, who, themselves, plan their work. In the future, as remote control will come to be more dominant, and work being performed with several operators in one control room, teamwork might once again be possible.

Regarding the topic of training, operators have to be offered training (e.g. to become cross/multi-skilled) and continuously have their competences developed. A solution also has to be reached regarding contractors and their training/competence. The goal of having cross/multi-skilled operators could be hindered by this practice. If the reliance on contractors remains, developing their skills should be an integral part of the supplier integration principle.

Concluding remarks

LP is a mind-set based management model and, as such, much of the work in realising LM will have to happen in the minds of employees. Values and philosophy will have to be aligned that those of LP. This, in itself, might constitute a significant part of the implementation efforts.

Following the realisation of the “soft” part of the concept, the principle of waste elimination seems most suitable for implementation. These practices and tools will have to be adapted
and practiced throughout the company. There is evidence of this being possible and advantageous. Also, integrating suppliers should be beneficial, especially if this solves the issue of contractors (either through integration or substitution). As the practice of supplier integration would differ little from other application areas of LP, it should be ready for implementation to mining. Demand-based production will have to be focused on supporting functions as a start. As work towards actualising continuous mechanical metal miners continues, the principle can start being implemented to the production process as well. And finally, the involvement of the workforce should encompass the entire implementation effort.

All in all, it seems that the mining industry is ready to at least begin its journey towards LM. Even though some problems remain to be solved, they should not be considered severe enough to discourage starting LM efforts.

References


