# A Lean Implementation Framework for the Mining Industry

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**Abstract:** The adoption of Lean concepts beyond the manufacturing sector has been increasing recently. In this line, its scope has been expanded to the mining industry under the realisation of the need for productivity improvements and a leverage for efficient operations. Limited research exists regarding Lean implementation in the mining industry in a comprehensive and structured way. This paper therefore follows a systematic approach to review the current literature to identify Lean implementation patterns in the mining sector, its scope, challenges, and limitations. The results reveal the limited utilisation of Lean in the mining sector, and that there is a lack of coherent and conceptual models to guide the implementation of Lean in this industry. Hence, the research proposes a framework for Lean implementation in the mining industry.

*Keywords:* Lean Concept, Lean Implementation, Lean Mining, Mining Industry, Operational Improvement.

## 1. INTRODUCTION

Increased global competition and a constantly changing environment requires businesses to transform their operations in order to cope with the complex and heterogeneous business environment (Garza-Reyes 2015; Nadeem *et al.* 2017). For this purpose, businesses need to streamline their resources/processes in an effective and efficient manner to deliver quality products/services in a cost effective, and efficient manner. To assist businesses in doing so, multiple models/approaches have been developed, e.g. Six Sigma, Agile, Business Process Reengineering, etc., with their distinguishing features to help businesses of various industrial sectors, e.g. automotive, IT, Healthcare, Electronics, etc. (Flynn and Vlok 2015). This paper explores the research and implementation of the Lean manufacturing approach within the context of the mining industry.

The process of extracting minerals and resources is referred to as mining (Newman *et al.* 2010; Pooe and Mathu 2011). The mining industry has played a significant role in the global economy (King *et al.* 2017) since ancient times until now; for instance, production of a modern computer requires more than 65 various minerals (Department of Energy 2017). Presently, more than 700 mining companies are active across 100 countries (ASX 2017). Moreover, the industry is a supplier of raw materials to other sectors such as utilities, metal manufacturing, construction, electronics, etc., and attracts the attention of society and businesses in regards to the way in which it operates. A mining lifecycle consists of 5 stages (Newman *et al.* 2010), namely: prospecting, exploration, development, exploitation, and reclamation; and lasts for 10-30 years (King *et al.* 2017). Industry inputs are characterised by variable quality of deposits and their gradual depletion (Hilson and Basu 2003; Mudd 2007).

A study conducted by Damotte and Sharman (2016) highlights that global mining executives expect a growth of 63%, and 45% of the respondents were confident about the economic growth of the industry by 2018. Consequently, the industry executives regard cost and performance management as a high priority, in the past 67% of them while nowadays 77% (Damotte and Sharman 2016). Since the industry has no control over the market prices of its product (Hattingh and Keys 2010), there is a strong push to constantly seek productivity improvements and efficient operations to maximise outputs. Therefore, the application of Lean in mining operations is of high importance and relevance.

The novelty of this paper is defined by its scope of proposing a systematic framework to implement Lean principles in the mining industry. The proposed framework may be used by operations managers in the mining sector to guide their efforts towards the effective implementation of Lean. It also intends to promote further research in this area and industrial sector.

The paper is structured as follows: Section 2 presents the Systematic Literature Review (SLR) conducted on Lean and within the context of the mining industry, along with the methodology adopted and the interaction of Lean and mining industry; Section 3 proposes the Lean framework. Finally, Section 4 provides the conclusions along with the limitations and further research directions derived from this study.

## 2. SYSTEMATIC LITERATURE REVIEW

For the purpose of an in-depth analysis of peer reviewed academic publications and official reports, the SLR approach was adapted from that followed by Garza-Reyes (2015). The stages of SLR and their descriptions are presented in Table 1.

Table 1. Systematic Literature Review phases

| *SLR Phases* | *Method* | *Tools* |
|---|---|---|
| 1 Scope Formulation | Formulating the scope of research | |
| 2 Locating Studies | Electronic databases | IEEE Xpolore, Elsevier (Science Direct), Emerald, Taylor & Francis, Google Scholar, ISI Web of Science, EBSCO |
| | Search period | 2000 – 2017 |
| 3 Study Selection and Evaluations | Definition & use of inclusion/ exclusion criteria | **Inclusion:** Lean, Operations Improvement, Lean Six Sigma, Mining Industry, Mineral Industry. **Exclusion:** Data mining, CSR, Product design and development. |
| | Definition & use of search strings | Lean in mining Industry, Operations improvement in mining industry |
| 4 Analysis and Synthesis | Synthesis/ analysis for qualitative research | Thematic Synthesis |
| | Coding of data | NVivo computer software |
| 5 Reporting and Using the Results | Reporting of findings | |

### *2.1 Scope formulation*

The core essence of the research was to explore the current approaches of Lean implementation in the mining industry, and how practitioners in this industrial sector may effectively implement Lean. With this scope, the objectives of the present research were to:

- Identify current research patterns of Lean implementation in the mining industry;
- Propose a Lean implementation framework for the mining industry.

### *2.2 Studies location, selection and evaluation*

Secondary data, published between 2000-2017, was collected using search strings that included 'Lean in mining Industry' and 'Operations improvement in mining industry'; utilising Boolean operators (i.e. and/or), from various electronic databases such as IEEE Xplore, Elsevier (Science Direct), Emerald, Taylor&Francis, Google Scholar, ISI Web of Science, and EBSCO. The research excluded any articles with themes not directly related to the mining industry, e.g. Data mining, CSR, Product design and development.

#### *2.2.1 Data screening*

The search conducted through the SLR stages shown in Table 1 resulted in 9,877 articles that later underwent 2 screening stages. First screening the title and abstract, and second full text screening (Fig 1). After the screenings, a total of 21 articles (see Table 2) fell within the scope of this research.

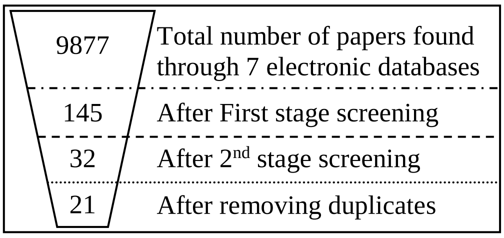


Fig. 1. Collected articles and screening

#### *2.2.2 Quality assessment*

The 21 articles were then analysed for their quality and relevance using the three dimensions classification proposed by Dresch et al. (2015), see Table 2.

Table 2. Consolidation of Quality assessment

| No | Author/s | Assessment Dimensions | | | Study Assessment |
|---|---|---|---|---|---|
| | | Quality of study | Relevance to the question | Relevance to the focus | |
| 1 | (Ade and Deshpande 2012) | Low | Low | Med | Low |
| 2 | (Boateng-Okrah and Appiah Fening 2012) | High | Low | Med | Low |
| 3 | (Castillo *et al.* 2015) | High | High | Med | Med |
| 4 | (Chlebus *et al.* 2015) | High | High | High | High |
| 5 | (Claassen 2016) | High | Low | High | Low |
| 6 | (Duin *et al.* 2008) | Low | Low | Med | Low |
| 7 | (Dunstan *et al.* 2006) | Med | High | High | Med |
| 8 | (Flynn and Vlok 2015) | Med | Med | High | Med |
| 9 | (Garza-Reyes *et al.* 2016) | High | Med | High | Med |
| 10 | (Helman 2012) | Low | Med | High | Low |
| 11 | (Indrawati and Ridwansyah 2015) | Med | Med | High | Med |
| 12 | (Klippel *et al.* 2008a) | Med | Med | High | Med |
| 13 | (Klippel *et al.* 2008b) | Low | Med | High | Low |
| 14 | (Mishra *et al.* 2013) | Med | Low | High | Low |
| 15 | (Mottola *et al.* 2011) | High | Low | High | Low |
| 16 | (Nekoufar 2011) | Med | Low | Med | Low |
| 17 | (Oware *et al.* 2015) | Med | High | High | Med |

| | | | | | |
|---|---|---|---|---|---|
| 18 | (Sanda *et al.* 2011) | High | Low | Med | Low |
| 19 | (Wijaya *et al.* 2009) | Low | Med | Med | Low |
| 20 | (Yingling *et al.* 2000) | Low | Med | High | Low |
| 21 | (Zuniga *et al.* 2015) | High | Low | Med | Low |

*2.3 Analysis and synthesis*

The quality assessment led to a further filtering of the 21 articles, by assessing them based on three dimensions, i.e. quality of the study, relevance to the research objectives, and relevance to the research focus. Only eight research papers, i.e. 3, 4, 7, 8, 9, 11, 12, and 17 from Table 2 and highlighted in grey, qualified the above quality assessment for further data extraction and thematic synthesis. The approach (see Fig. 2), adapted from Heyvaert et al. (2017), permitted a detailed assessment of each study's characteristics through line-by-line or free coding using NVivo software, and then grouping them into descriptive themes as clusters of codes. At the next stage, descriptive themes were arranged into 21 clusters to form analytical themes. At the stage of analytical themes synthesis, the review went beyond of primary data (Heyvaert et al. 2017) as analytical themes were highly integrated to the review questions. Thus, they generated additional concepts and findings of a subject of the review. This method was appropriate for deployment within this study as eventually primary data of the review should be integrated to the conceptual framework of the research.


Fig. 2. Thematic synthesis stages (adapted from Heyvaert et al. 2017)

For the purpose of formulating analytical themes in a structural interrelated manner and aligned with the research objectives, an extended version of the 'PICO' model (Boland *et al.* 2017) was adapted, PICO being; Population (mining industry, mining sector businesses), Phenomena of Interest (Lean adaptation), and the Context (Lean adaptation results, outcomes, limitation, etc. in the mining sector), whereas addressing the questions: Who? Why? What? How? And When?. This was the core essence of the review as it reflected research evidence, outcomes, implications and limitations as well as traced patterns for future research. This would allow the readers to more easily navigate within the research and understand complex phenomena in a conceptually easy way.

*2.4 Reporting and using the results*

The detail review of the eight selected papers indicated that differences between the automotive and mining industries may pose pitfalls (Dunstan *et al.* 2006), difficulties (Flynn and Vlok 2015), challenges and limitations for the adaptation (Gustavo *et al.* 2015) of Lean in mining sector. However, the intersection of these two sectors and possibility of adopting and benefiting from the Lean application in the mining sector is also highlighted by some scholars (Dunstan *et al.* 2006; Chlebus *et al.* 2015; Flynn and Vlok 2015). Therefore, the scope of their interaction seems realistic.

The mining and automotive sectors intersect, as the first typically comprises individual and stand-alone business units that seek business improvement methods to pursue a reduction of operating costs, increase productivity and efficiency (Klippel *et al.* 2008a; Chlebus *et al.* 2015), achieve process optimisation (Castillo *et al.* 2015), meeting targets and plans (Dunstan *et al.* 2006), improve internal communications (Castillo *et al.* 2015), and customers satisfaction (Garza-Reyes *et al.* 2016). Fig. 3 illustrates the overlapping elements of the automotive and mining industries. Thus, the analysis of the eight papers indicates the fact that mining companies aiming to initiate the deployment of Lean methods should focus on the ultimate goals of its principles, i.e. waste elimination.

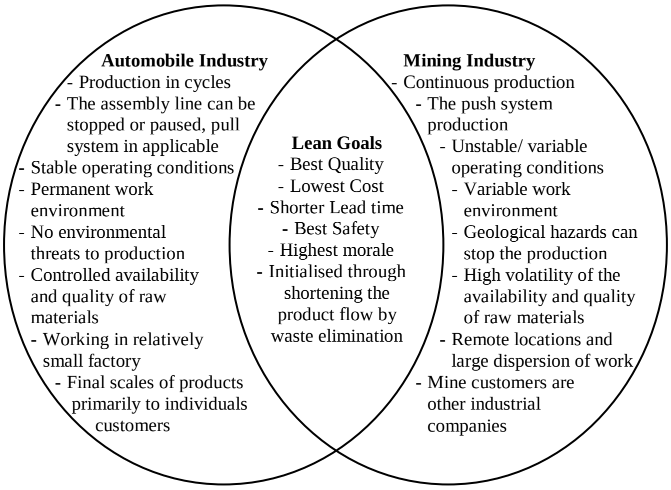


Fig. 3: Lean goals in the automotive and mining industries

*2.4.1 Lean's 8 wastes in the mining sector*

Based on the intersecting features of the automotive and mining sectors illustrated by Fig.3, it becomes ideal to categorise wasteful activities occurring in the mining industry and their classification as per Lean's eight wastes. Table 3 summarises these wastes

Table 3: Lean's 8 wastes in Mining Industry

| **Waste and its occurrence form** |
|---|
| **Overproduction:** (Flynn and Vlok 2015), due to mining capacity to outstrip ore processing (Dunstan *et al.* 2006), continuous production with push system (Dunstan *et al.* 2006; Chlebus *et al.* 2015) |
| **Waiting:** Inappropriate conditions/working environment, e.g. lack of ventilation for dust and gases removal (Klippel *et al.* 2008a), due to unavailability of machines and spare parts (Dunstan *et al.* 2006; Chlebus *et al.* 2015), equipment breakdowns and plant downtime (Dunstan *et al.* 2006; Oware *et al.* 2015), maintenance downtime and unscheduled shutdowns (Indrawati and Ridwansyah 2015), equipment failures (Dunstan *et al.* 2006). |

| |
|---|
| **Unnecessary transport and conveyance:** Inefficient layout for transportation (Garza-Reyes *et al.* 2016), stockpile material transportation (Indrawati and Ridwansyah 2015), inefficient movement of extracted ore until it reaches final destination (Dunstan *et al.* 2006), long distances (Flynn and Vlok 2015). |
| **Over processing or incorrect processing:** Performance of tasks by one employee instead of parallel operation for higher value adding time, auxiliary equipment preparation (e.g. drill sharpening, cleaning operations), process method (e.g. dry drilling taking more time for processing compared with wet drilling) (Klippel *et al.* 2008a), incorrect processing due to equipment breakdowns (Oware *et al.* 2015) or equipment failures (Dunstan *et al.* 2006), inefficient use of materials (Indrawati and Ridwansyah 2015), over processing to better grade ore than the customer willing to pay (Dunstan *et al.* 2006). |
| **Excess inventory:** High inventory of spare parts (Chlebus *et al.* 2015; Flynn and Vlok 2015), inefficient inventory management (stockpiles/ shortages) (Dunstan *et al.* 2006) |
| **Un-necessary Movement:** Interruptions due to inefficient location of instruments (Dunstan *et al.* 2006; Klippel *et al.* 2008a), transport material unavailability, non-compliance of workers (Indrawati and Ridwansyah 2015), walking of operators (Dunstan *et al.* 2006; Flynn and Vlok 2015). |
| **Defects:** Rework/repair (Dunstan *et al.* 2006; Oware *et al.* 2015), quality of raw materials (Indrawati and Ridwansyah 2015), equipment failures (e.g. fluid leaks) (Dunstan *et al.* 2006), physical material waste (Flynn and Vlok 2015) |
| **People:** Unskilled labour (Indrawati and Ridwansyah 2015; Oware *et al.* 2015), inefficient shift schedule (Indrawati and Ridwansyah 2015), absenteeism (Dunstan *et al.* 2006), incorrect assignment of people to tasks (Klippel *et al.* 2008a), lack of proper communication (Castillo *et al.* 2015; Flynn and Vlok 2015) |

### *2.4.2 Current Lean approaches in the mining industry*

The classification of wasteful activities in the mining sector, as per Lean (summarised in Table 3) further affirms that a systematic approach to waste elimination and promoting a continuous improvement culture are the key traits and main drivers for Lean implementation in mining industry. The most significant needs of the industry are those which are associated to the fact that natural resources are limited. Additionally, many of the natural resources are non-renewable and hence circular economy elements are not applicable to the sector. Given these aspects, for businesses operating in the mining sector it is crucial to deploy an optimum strategy for operations in order to generate greater economic benefits.

Typically, Lean experts (academics/consultants) first build a theoretical foundation for a possibility of adapting Lean in order to provide practical solutions to specific industry needs. Then, based on these specific needs of the industry business units and on broad academic knowledge, they propose a possible adaptation of the approaches for Lean implementation. This is significantly valid for the study of Chlebus et al. (2015) in which a Lean framework was designed to improve maintenance operation practices of a mining company in Poland.

Similarly, Lean maintenance operations improvement approaches have been tested in a Ghanaian mining company (Oware *et al.* 2015). Thus, the studies under review have shown the development of various theoretical frameworks for practical utilisation of Lean principles and tools in mining operations. Since these studies reported positive outcomes of the adaptation of the proposed frameworks and Lean methodologies, it is not an uncommon practice to approach the development of Lean frameworks based on the Lean literature and theory.

On the other hand, the frameworks are sometimes highly authentic and closely aligned to organisation's specific issues, which make them difficult to be generalised. More importantly, a few academics in the studies under review paid close attention to critical-to-satisfaction factors of their clients. These factors reflect a need for the voice of the customer (Garza-Reyes *et al.* 2016) to be captured as organisational inputs and interpreted for business improvement outputs by Lean practices. A study by Castillo *et al*. (2015) clearly shows that parameters for the study were elaborated in accordance to the goal, identified by the mining organisation-client. Thus, these practices demonstrate the customer-oriented focus of Lean experts on creating Lean adaptation frameworks for mining organisations. Consequently, this customer-oriented focus of Lean experts developing Lean frameworks for the mining industry entails to a diversity of Lean implementation frameworks. Thus, this research does not specify various characteristics of each framework proposed by the different studies under review, but has highlighted common practices reported to solve mining industry issues.

## 3. LEAN FRAMEWORK FOR THE MINING INDUSTRY

Despite the fact that the mining industry can benefit from Lean principles, the industry still lacks a coherent and general framework to initiate Lean for organisations operating in this sector. Therefore, this research proposes a Lean implementation framework applicable to mining companies. A visual representation of the proposed framework is illustrated in Fig. 4. The proposed framework is consistent with the major Lean implementation trends and practices in mining organisations, therefore it is of direct practical relevance to them.

The framework consists of three main 'blocks' corresponding to three Lean implementation phases as follows:

- Lean initiation
- Lean implementation
- Lean sustainability

The initiation phase comprises of the following sequence of operations: (1) the formation of a cross-functional Lean team, (2) the evaluation of the current state of a company's operations, and (3) the identification of wasteful operations. An output of this phase should give a clear direction as to where to focus Lean efforts and where to deploy Lean tools.

The implementation phase has the waste identified in the previous phase as an input. At this stage, the initial steps to build a Lean culture should be taken through training in order to empower people and communication programmes in order to enhance teamwork. Organisations will need to ensure commitment to the Lean culture and regular practice of the people empowerment. Next, standardisation for baseline procedures and activities is necessary and should be done regularly by challenging current practices through kaizen meetings and problem-solving sessions. This will promote the establishment of a continuous improvement culture.

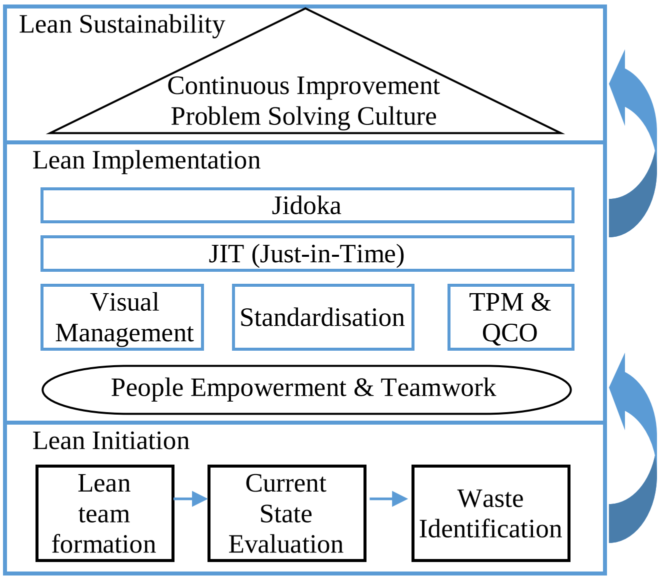


Fig. 4. Lean Framework for Mining Industry

As technology plays a crucial role in mining organisations, Total Productive Maintenance (TPM) and Quick Changeover (QCO) approaches should be deployed to improve maintenance services and operations. In addition, an application of these tools should switch employees' culture from 'fire-fighting' to a preventive maintenance culture. TPM and QCO should be followed by Just-in-Time (JIT) and Jidoka. In the studies reviewed, these two methods have somehow been neglected by Lean adopters in the mining industry. The most likely cause for this could be the fact that JIT's utilisation requires a highly integrated supply chain. However, supply chain integration in the mining industry is a complex process, subsequently making the implementation of JIT an also complex task. In addition, prior to JIT implementation, it is strongly suggested to establish a solid Lean culture by using other Lean tools first. This would contribute to a smooth and successful implementation of JIT.

Jidoka faces similar scenario as with the utilisation of JIT. Its feasibility has not been discussed within the studies reviewed. Nevertheless, it has a potential application in the mining industry, provided that technological advancements are brought to the industry by innovative solutions.

The current proposed model only suggests the adoption of 5 Lean tools for the mining industry (see Fig. 4). However, this should not be considered as a limiting factor. In this regard, the framework is flexible in adding or removing tools for the convenience of the users. The implementers are strongly recommended to build a continuous improvement culture to bring Lean sustainability in their mining organisations.

## 4. CONCLUSIONS

Lean manufacturing has been greatly appraised and adopted in a wide range of different businesses and industries. With its scope not being limited to the automotive industry only and the potential to be contextualised in other sectors, it can greatly benefit the mining sector. However, this industry lacks of specifically adapted frameworks to facilitate its implementation in this sector. This research is an igniting step and has developed a framework after systematically reviewing the research in the given area. The framework is girded in a detailed analysis of current practices and models. Testing of this framework, followed by any amendments/ modifications would greatly benefit both further research and its practice in the mining sector.

Due to the time constraints the proposed framework has not been tested in a real-life situation. However, this does not undermine its practical relevance, given the fact that a thorough study has been done before its development, and in a similar way other frameworks have been developed based upon literature reviews. For the purpose to establish a continuous improvement culture, further research is highly recommended and can be done by practicing problem-solving sessions in a regular manner at practitioners level and academic research.

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