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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 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, Lean Implementation, Lean Mining, Mining Industry, Operational Improvement.

1. INTRODUCTION

The process of extracting minerals and resources is referred to as mining (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, 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 (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, to cope with the complex and heterogeneous business environment (Nadeem *et al.* 2017). 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 for 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 within the context of the mining industry, along with the methodology adopted; Section 3 proposes the Lean framework for mining industry. 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.

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 mentioned in Table 1. The research excluded any articles with themes not directly related to the mining industry, e.g. Data mining, CSR, Product design, etc.

Table 1. Systematic Literature Review phases

SLR Phases	*Method*	*Tools*
1 Scope Formulation	Formulating the scope of research	
2 Locating Studies	Electronic databases	IEEE Xplore, 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 the Results	Reporting of findings	

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.

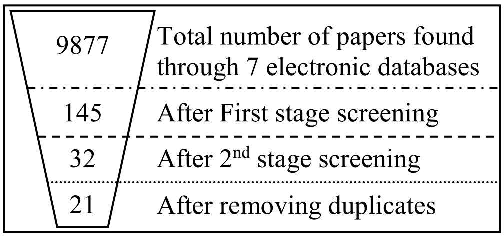

Fig. 1. Collected articles and screening

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.

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 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 this stage, 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.

For the purpose to formulate 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 businesses), Phenomena of Interest (Lean adaptation), and the Context (Lean adaptation results, outcomes, limitation, etc.), whereas addressing the questions: Who? Why? What? How? And When? This core essence of the review reflects research evidence, outcomes, implications and limitations as well as traced patterns for future research. This allows the reader to easily navigate within the research and understand complex phenomena in a conceptually easy way.

Table 2. Consolidation of Quality assessment

		Assessment Dimensions			
No	Author/s	Quality of study	Relevance to the question	Relevance to the focus	Study Asses-sment
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

2.4 Reporting and using the results

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 (Castillo *et al.* 2015) of Lean in mining sector. However, the intersection of these two sectors and possibility of adopting/ benefiting from the Lean application in the mining sector is also highlighted by scholars (Chlebus *et al.* 2015; Flynn and Vlok 2015). Thus, the scope of their interaction is realistic.

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

2.4.1 Lean's 8 wastes in the mining sector

Based on the fact that mining industry needs to focus on waste elimination, it becomes ideal to categorise wasteful activities 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, 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 (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/ incorrect processing: Performance of tasks by one employee instead of parallel operations, auxiliary equipment preparation (e.g. drill sharpening, cleaning operations), process method (e.g. dry drilling taking more time for processing compared to wet drilling) (Klippel *et al.* 2008a), incorrect processing due to equipment breakdowns or failure (Oware *et al.* 2015), 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: 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 (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), improper 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 drivers for Lean implementation in mining industry. The most significant needs of the industry are associated to the fact that natural resources are limited, of which many are non-renewable and hence circular economy elements are not applicable to the sector. Given these aspects, for businesses 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. This is significantly valid for the study of Chlebus et al. (2015) in which a Lean framework was designed to improve maintenance operations 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 in mining operations. Since these studies reported positive outcomes of the adaptation of the proposed frameworks, it is not an uncommon practice to develop Lean frameworks based on the 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. 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. 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 in this sector. Therefore, this research proposes a Lean implementation framework applicable to mining companies. The framework consists of three main phases, namely: 'Lean initiation', 'Lean implementation', and 'Lean sustainability' (See Fig. 2).

3.1 Lean initiation

The literature revealed that Lean adaptation in the mining industry is generally initiated by a number of primary activities, mostly carried as a multilevel analysis of current state of operations. The authors grouped these into a sequence of activities:

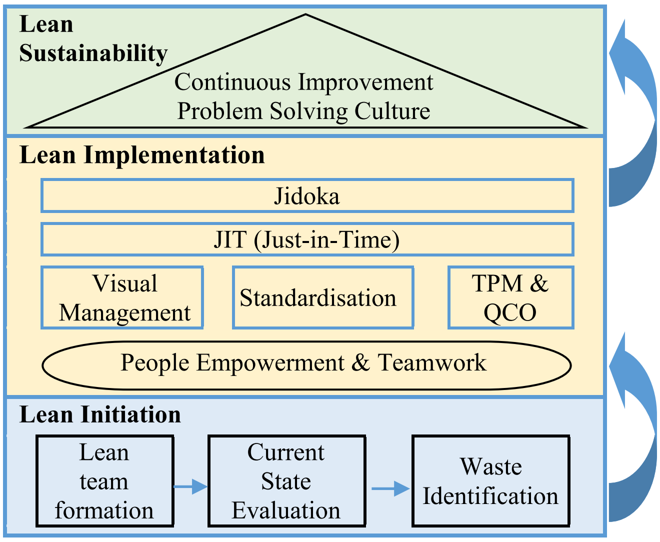

Fig. 2. Lean Framework for Mining Industry

3.1.1 *Lean team formation*

Generally, Lean teams consists of company employees and Lean experts (academics/consultants) (Garza-Reyes *et al.* 2016). It is crucial to involve people from the mining company itself as they are familiar with existing operations and company procedures, instead of only external consultants who might lack detailed knowledge. Moreover, involving employees to basic decision-making processes strengthens the process of building a Lean culture (Dunstan *et al.* 2006). Therefore, employees that have sufficient knowledge/ experience should be assigned under the leadership of Lean experts (Garza-Reyes *et al.* 2016) and if needed the team should be trained in Lean principles (Klippel *et al.* 2008a).

3.1.2 *Current state evaluation*

The aim of this step is to collect information about value adding (VA) and non-value adding (NVA) activities by adopting the Lean principle of value stream identification (Womack and Jones 2003). Tools such as value stream mapping (VSM), visual control techniques (Castillo *et al.* 2015) as well as collecting secondary data such as master schedule (Dunstan *et al.* 2006), record of demand and production, delay surveys, last planner system (Castillo *et al.* 2015), etc. can be used. VSM will help to streamline stockpile levels for continuous material flow as well as the information through earlier mentioned secondary resources will provide a snapshot of the current state to identify areas for improvement.

3.1.3 *Waste identification*

At this stage the team needs to analyse the VA and NVA activities from the data collected in the previous stage. It is necessary to specify value to fully utilise Lean (Womack and Jones, 2003). However, the process of value specification in mining operations is neither simple nor straight forward as it cannot be predetermined from the beginning of production processes due to the fact that production is mostly carried out in a natural environment. Therefore, the possibility to predetermine the quality of raw materials being extracted is minimal. Value in mining industry can be specified through process and operations management. Within this scope, NVAs can be defined as any interruption with negative impact on operation/ processes, wasteful activities. The Lean team must focus on delineation of VAs and NVAs in the operations/process and subsequently identify waste. Some examples of waste occurrence in the mining industry are described in Table 3.

Lean tools such as kaizen and brainstorming sessions (Dunstan *et al.* 2006; Klippel *et al.* 2008a), root cause analysis (Chlebus *et al.* 2015), cause-and-effect analysis (Garza-Reyes *et al.* 2016), Failure Mode Effect Analysis (FMEA) (Indrawati and Ridwansyah 2015), and others, can be deployed to facilitate the findings.

3.2 *Lean implementation*

Once the waste has been identified, the next phase is to begin implementing Lean and streamlining the processes/ operations. In the mining industry, it would be best to choose specific areas for pilot projects rather than ubiquitous implementations over all identified areas for improvements.

In this phase, the central strategy is to build a Lean culture through trainings to empower people and communication programmes to enhance team work. Organisations will need to ensure commitment to the Lean culture (Bevilacqua *et al.* 2017) and regular practice of people empowerment for sustainable outputs (Boscari *et al.* 2016).

There are “no one size fit all strategies” and with diverse range of elements under Lean thinking, the research proposes Lean elements that are the most feasible for the mining industry.

3.2.1 *Visual management*

Visual management is one of the most useful tool to manage mining operations in remote locations with wide spread dispersion of work in open natural environments. It provides transparency for planning and control (Castillo *et al.* 2015). Tools such as shadow boards with equipment locations, Kamishibai boards indicating work progress, single point lesson sheets, 5S (sort, set, shine, standardise, and sustain) (Dunstan *et al.* 2006) can be adopted at this stage. It is important to clarify that the role of VSM is not limited to provide the snapshot of the company but can also assist in visual management. Therefore, updating VSM regularly is necessary. A combination of VSM and RFID would further enhance the organisation’s ability to manage the actual flow of real data (e.g. monitoring inventory, etc.).

3.2.2 *Standardisation*

The following most feasible tool for the mining industry is standardisation. It clarifies the procedures and therefore enhances team work and improves communication. It also plays a great role to promote a continuous improvement culture as it involves challenging current practices through kaizen meetings and problem-solving sessions. This should result in the development of baseline procedures to be used by everyone, which makes the standard immediately measureable, followed by creativity to improve it (Dunstan *et* *al.* 2006). Moreover, since mining operations are in hazardous open work environments, standardisation is even more necessary to follow set procedures.

3.2.3 TPM/ QCO

Equipment plays a crucial role in mining operations and failure rate of mining equipment is mainly due to external variable physical conditions (Chlebus *et al.* 2015). Total Productive Maintenance (TPM) and Quick Changeover (QCO) approaches should be deployed to improve maintenance services and operations. Chlebus *et al.* (2015) suggests a three dimensional approach of: standard development, autonomous (routine) and planned maintenance, and improvement of work environment. Developing standards to record equipment failure is vital for Lean practices (Oware *et al.* 2015) and allows to monitor/measure performance, and to plan for spare parts and maintenance scheduling; an often neglected area (Chlebus *et al.* 2015). Autonomous checks and planned maintenance will facilitate employees to switch from 'fire-fighting' to a preventive maintenance culture. The "go-and-see" approach can be adopted to inspect machine performance, tag any equipment needing attention (Dunstan *et al.* 2006), etc. Improvements of work environment in order to adapt TPM should aim to enhance organisational workplace conditions. Tools such as 5S can be used (Dunstan *et al.* 2006). Similarly "Method of painting" can be used to delineate workplace areas for transportation paths (Chlebus *et al.* 2015).

The application of Quick changeover is equally important as any failure or shutdown can be quickly managed by the adaptation of QCO and would result in reduced downtime and efficient use of resources while stabilising the operations.

3.2.4 Just-in-time

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 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/encourage a solid Lean culture throughout the supply chain by encouraging suppliers, and also by using other Lean tools such as kanban, etc. within the operations of the organisation.

3.2.5 Jidoka

Jidoka faces a 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 Lean implementation phase suggests the adoption of 5 Lean tools for the mining industry (see Fig. 2). However, it should not be considered as a limitation. In this regard, the framework is flexible to add/remove tools as per convenience of the users as well as the need/context of the problem.

3.3 Lean sustainability

Although Lean adaptation in the mining industry is recent, its positive impact has been observed in the form of production capacity, workflow improvements, time utilisation (Castillo *et al.* 2015), reducing production costs, overall safety improvements (Chlebus *et al.* 2015), resource utilisation, cycle completion times, employee availability (Dunstan *et al.* 2006), process capability index and shipping time improvements, cost savings (Garza-Reyes *et al.* 2016), etc.

It is noteworthy that cultural changes in organisations are foundational to continuous improvement. Nevertheless, all these positive outcomes have been observed by organisations within a short period of time. Thus, Lean sustainability in the mining industry has not been reported yet and leaves a research gap to be explored in future. The Lean team(s) are strongly recommended to build a continuous improvement culture to bring Lean sustainability.

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 a specifically adapted frameworks for 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. Due to the time constraints the proposed framework has not been tested. However, this does not undermine its practical relevance, given the fact that a thorough study has been conducted prior to its development, and in a similar way other frameworks have been developed based upon literature reviews. Testing of this framework, followed by any amendments would greatly benefit both further research and its practice in the mining sector.

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