EVALUATING THE IMPACT OF LEAN METHODOLOGIES IN COPPER MINING DEVELOPMENT PROJECTS

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ABSTRACT

The development of mines is an important stage previous to the mine exploitation, which plays a key role in the mining industry, and represents a large portion of total costs. To date, the mining industry has not appropriately adapted its processes and business models to the industry´s ever increasing production environment. In this regard, lean production emerges as a management philosophy, which creates competitive advantages and provides important savings opportunities for companies and organizations. However, there are important limitations in the practical implementation of lean production. This work explores how to bridge the gap between the theoretical use of lean production and its practical, effective application in a Chilean mining project. This paper analyzes the impact of the implementation of lean construction/production methodologies in underground mining development projects. In all of the case studies reviewed, the implementation of lean methodologies generated performance improvements in projects. The main findings suggest that the incorporation of lean methodologies is an option, which companies should consider, given the current and future challenges in the mining business. Future research will show the economic impact of adopting lean construction/production in mining companies.

KEYWORDS

lean construction, lean production, mining, construction, implementation, development.

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INTRODUCTION

Mining development projects in copper mines are currently undertaken by construction companies and involve mostly tunnel and other construction operations that are required to prepare the mine for mine exploitation. This paper reviews the impact of the implementation of lean production in an underground mining project in Chile, evaluating its impact on the project and the organizations involved. There is little scientific evidence on lean implementation and transformation in the mining industry. Therefore, this research focuses on this area, providing more detailed evidence of the impact that lean production can have in mining. Also, it reviews the benefits that lean production methodologies provide in the mining industry to increase productivity and reduce waste. Note that while this research studied production problems in the mining context, the organizations analyzed belong to the construction sector and some of the methods implemented have been developed for Lean Construction implementation.

BACKGROUND

LEAN PRODUCTION

Lean production is a management philosophy that emerged from the Toyota production system, which used different philosophies than those used in the rest of the world (Womack et al., 1990). Lean production changed the understanding of organizational roles within companies, encouraging working together as a community. It also established new structures for assembly plants, which promoted multifunctionality, teamwork, worker satisfaction, continuous improvement and elimination of waste. Likewise it actively incorporated the role of the supply chain, allowing the production line to generate continuous flow. Product development was also modified, developing specialized staffs who work as a team with the rest of their co-workers. Lean Production specifically pays attention to the customer: flexible processes are defined, which respond to demand variations; processes are designed focused on creating value for the customer. All of this allows lean production to be a work process alternative (or sometimes the only choice) in slow growth economies, enabling efficient production of small amounts of products, in multiple varieties, and in low demand conditions (Womack et al., 1990).

LEAN MINING

In the past decade, research has been done on lean principles, which are applicable to the mining industry. Studies have successfully applied specific lean tools or principles at a basic level as well as comprehensively, showing the flexibility that this methodology provides in the mining industry (Dunstan et al., 2006; Hattingh and Keys, 2010; Klippel et al., 2008a; Shukla and Trivedi, 2012; Wijaya et al., 2009; Yingling et al., 2000). It has been shown that there are inherent differences between the manufacturing industry and the mining industry. However, these differences do not prevent the application of lean production in the mining industry. In fact, lean principles and their value proposition do not belong to any particular industry, allowing their application in any industry (Dunstan et al., 2006). In general, the mining industry is compatible with lean principles, and in this way, it can access the benefits that they provide, e.g., to apply the concepts of value, value chain, flow, pull and perfection (Yingling et al., 2000). Not only lean principles have the potential to be applied but also the concept of waste can be directly applied to the mining industry (Wijaya et al., 2009). In addition, there are specific tools and areas of focus that can be directly implemented in the mining industry such as value, value stream mapping, standardization, quality from the source, total productive maintenance, multifunctional workers and continuous improvement (Yingling et al., 2000).

It is possible to implement a new form of management for the mining industry through the integrated use of lean production concepts. They are compatible with mining´s traditional concepts and techniques (Klippel et al., 2008b). There are positive examples in terms of the use of lean principles in the mining industry, and there are also important limitations, which present great challenges. Specifically there are cultural aspects that are firmly implanted in the industry, which make the implementation of company changes difficult (Freire and Alarcón, 2002). The application of lean production methodologies does not only involve the application of the tools, but it also implies a cultural change of the company and industry. This is a slow process that must have the correct follow-up and control (Wijaya et al., 2009). In fact, it is an iterative process, which should be continually applied: this should be done continuously over time (Ade and Deshpande, 2012). The lean principles, which apply to the mining industry, are highly interdependent. Therefore, they require strong leadership from upper management and change agents as well as a high level of investment in the training of personnel (Yingling et al., 2000). In fact, the technical work should be accompanied by organizational interventions, which present an important challenge when processes are transformed and improved. One of the most important organizational barriers faced are those expressed by operators, given their abilities, level of training and culture. Specifically the human factor can be a key factor in on-going improvement as it involves training and creating incentives for personnel, and this is essential in achieving true change (Ortiz, 2010).

There are important limitations in the application of lean production into the mining industry, and therefore, great challenges to be resolved. There is limited evidence to show the broad acceptance of lean production in mining, and few companies have begun a systematic transformation toward lean thinking. Therefore, it is necessary to bridge the gap between the theoretical application of lean thinking and its practical application. For this reason, there is an opportunity to study the impact generated from the implementation of lean methodologies in projects of mining development, providing knowledge, which will encourage the use of this type of thinking in future projects.

RESEARCH METHODOLOGY

In order to analyze the impact of the implementation of lean methodologies in mining development projects, the case study methodology was used (Yin, 1994). This was chosen due to the specific interest in the internal characteristics of these cases, which allow us to study production and management phenomena in their actual context. This is critical in case studies where the limits between the phenomena and the context are not apparent. This research had the primary focus to provide an answer to the following theoretical propositions:

- The implementation of lean production methodologies over the execution of mining development projects allows performance improvements as measured with process indicators, and those results are statistically significant.
- The implementation of lean production methodologies over the execution of mining development projects creates improvements in organizational behavior.

Due to space limitations, only the evidence collected for the first proposition is reported in this paper.

CASE STUDIES

Three case studies were selected, which analyzed underground mining development projects in Chile. The selected case studies allowed a comparative analysis to be undertaken, improving the validity of the study. The case studies represent the development of three different projects executed by three different construction companies. The projects were developed within the same underground mine, and were supervised by the same mining company or legal representative.

In the three case studies, similar work was implemented, including projects for: horizontal developments, vertical developments, draw points, ore passes, set-up of ore chutes and vent fans set-ups. The horizontal developments are horizontal and continuous civil or mining excavations, known by their height, width and sections. The definition of vertical developments is similar to horizontal ones, but their execution is vertical. The draw points are areas at the production level where the fragmented material is collected, which comes from the caving level. The ore passes are areas where the unloading of fragmented materials in the unloading shafts takes place, which has a unique configuration to filter and adapt to the required grading. The set-up of ore chutes involves the conditioning and installation of the ore chutes, which operate as flow regulators when materials are lowered from one level to another by gravity. The vent fans set-up involves the conditioning and installation of those fans, which allow ventilation of air to be forced from the inside of the mine.

The contracts indicate that all of these projects have similar deadlines and costs. The average schedule was approximately 5 years, with an estimated cost of US$130,000,000. The contracts have not had modifications in their terms nor costs: however, the contracts overlap in their implementation periods. For example, one project analyzed had just recently begun its implementation (Project N°3). Finally, it is worthy to note that the projects reviewed included an approximate staff of 500 people per project.

IMPROVEMENT PROGRAM

This research was part of a long term improvement program that included lean transformation of all the areas within the organization (operations, supply chain, maintenance). However, during the study, only the first part of the program of long term improvement was considered, i.e. 2 out of 4 stages were studied. The first part included the intervention in three pilot cases, and an 8-months implementation period. Figure 1 shows more detail regarding how the improvement program was structured.

In this research the different types of information available came from documentation, historical files, interviews, direct observation, participatory observation and surveys. The main problems identified were: use of time, planning, results and indicators, management systems, use and availability of resources. Given the problems identified, the main opportunities for improvement are based on the following objectives: improve the processes of planning and coordination; improve the communication between parties, manage knowledge and use of process information, reduce operational waste; achieve consolidation of the work teams; and improve alignment of the parties. In order to address and solve the problems identified, five components were taken, which defined the direction of the lean implementation: communication plan, improvement of planning and communication, structuring the operational coordination, continuous improvement on-site and optimization of processes.

The tools and methodologies used to satisfy the above mentioned actions were: identification and reduction of waste (Koskela, 1992), delay surveys (Alarcón, 1997), Last Planner System (Ballard, 2000a), phase scheduling (Ballard, 2000b), value stream mapping (Rother and Shook, 1999), implementation of 5S (Ohno, 1988), visual control (Dos Santos et al., 1998), and continuous improvement (Ballard and Howell, 1994). Figure 1 shows more detail of how these tools were implemented.

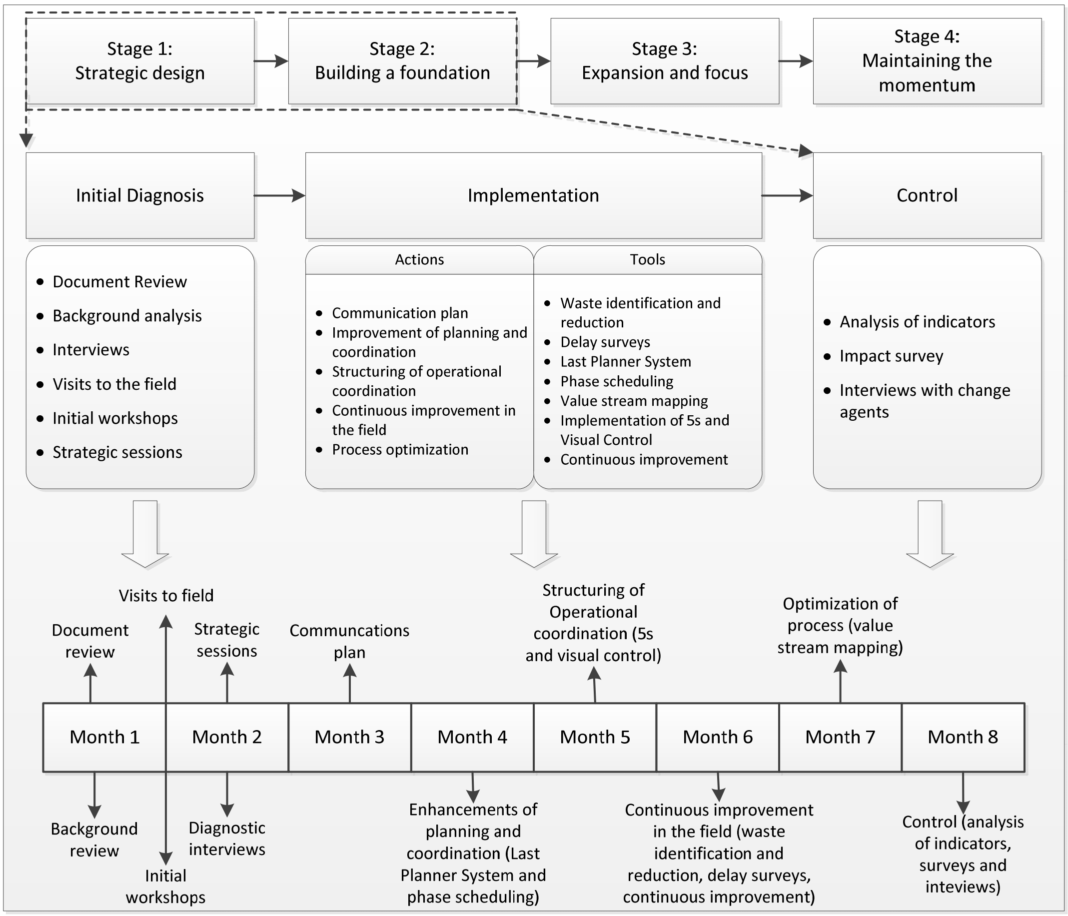

Figure 1: Outline of the improvement program and research.

PERFORMANCE VARIABLES

In order to quantify the lean implementation impacts in the case studies and provide answers to the theoretical proposals, it was necessary to determine production performance variables aligned with the actions and methodologies proposed. Table 1 shows the variables that were used in this research.

Table 1: Description of the production variables related to the research.

Approach	Variable	Conceptual definition	Operational definition
Project	Interferences	Time that workers lose when they face restrictions to do their work	Man hours lost to interferences per month (MH)
	Physical progress	Amount of the project that is done in a set period, in relation to the total project	Percentage of physical progress by month (%)
	Reliability of the plan	Relationship that exists between what was done versus what was planned.	Percentage of completion of the plan by month (%)
	Productivity	Relationship between production and resources used.	Revenue by employee per month ($/EM)
	Time efficiency	Ability to use time in activities that add value	Proportion of time spent on value adds (%)
Organization	Team work	Collaborative performance of a group of people to reach a common goal	Results of a survey to construction companies, project management section.
	Participation	Positive intervention of workers in their daily activities	
	Communication	Capacity of workers to share ideas and opinions	
	Commitment	Contribution to the capability to achieve the various common objectives	
	Learning	Acquisition of knowledge and time spent on it	
	Alignment of objectives	Alignment of objectives between the various business units	Results of interviews with change agents, section enterprise vision.
	Customer Focus	Importance of customer needs in the work being done	
	Organizational needs	Prioritization of organizational needs above individual interests	
	Construction techniques	Specific techniques used to do the work	Results of interviews with change agents, section technical competencies.
	Project management	The way projects are managed	
	Lean tools and methodologies	Understanding and use of lean methodologies in projects.	
	Self-management	Ability of workers to actively make decisions	Results of interviews with change agents, section social competencies.
	Relationship management	Ability to motivate workers to achieve performance improvements	
	Values	Shared principles between the individuals doing the work	

Analysis of Project Performance

In order to correctly evaluate how lean implementation impacts project performance, an analysis of the project performance indicators was done in three ways, which complemented each other: a comparison of medians, an analysis of boxplot diagrams and significance tests.

A comparison of medians was done to identify significant changes before and after the lean implementation. Therefore, it was possible to obtain objective information on the change produced by the implementation. The median was chosen over the average to avoid possible biases due to data dispersion. In addition, when asymmetrical distributions are studied, the median is the closest to the central point (Anderson et al., 2004).

Box-plot diagrams were studied for all of the indicators to graphically obtain a comparison of the data set. The goal was to determine whether there is a real difference between before and after the implementation by a visual comparison of the indicators behavior.

Finally, significance tests were analyzed in order to determine whether the variation before and after the lean implementation was statistically significant. This included a non–parametric test of Wilcoxon-Mann-Whitney with a confidence level of 95%. This test evaluated whether the two independent groups were extracted from the same population. Therefore, if it was detected that the data was not extracted from the same population, it can be assumed that there was significant change after completing the implementation (Siegel and Castellan, 1995).

Performance analysis of organizations

In order to understand the impact that the lean production implementation produced in organizational performance, a survey applied to the organizations involved (contractors) and semi-structured interviews with change agents who lead the implementation were developed. The survey´s main goal was to identify the lean implementation impacts over the work team's ability to manage the project. This referred to companies involved in the project execution, right at the end of the implementation. For space reasons, the results of this part of the research are not discussed in this paper and are reported in (Castillo, 2013).

RESULTS OF THE IMPLEMENTATION

Impacts of Lean Implementation on Project Performance

In order to study how the implementation of lean production impacts project execution, five indicators were analyzed: interferences, physical progress, reliability of the plan, and time efficiency.

In the case of interferences, the main focus was to evaluate how the implementation impacted work flows, through the analysis of the reported hours of interferences. The main focus of the physical progress indicator was to analyze how the lean implementation impacted production capacity, which was quantified as monthly work completed. This was calculated as a percentage of physical progress done monthly versus the total included in this analysis. The objective of the plan reliability indicator was to evaluate how successful companies were in completing their agreed plan. By doing so, a comparison between the actual monthly progress versus the planned monthly progress was done. The goal of the productivity analysis was to examine how the lean implementation impacted production efficiencies. The productivity indicator was based on the company´s monthly revenue, so as to establish a common indicator, which was applicable for each company and project (all of the case studies). To achieve this, the measurement is monthly revenue over the monthly staff level. The main goal of the time efficiency indicator was to study the impact that the lean implementation had on time utilization. This indicator was developed considering the proportion of time, which is used in activities that add value. This proportion is defined as the ratio of time used for value added activities versus the total time available for the project.

Table 3 shows a summary of the analysis done with the indicators selected in order to synthesize the impact that the lean implementation had on project performance. It shows the variation percentage of the various indicators after the lean implementation, the result of the non-parametric tests and the result of the review of the box-plot graphs.

Table 3: Summary of lean implementation´s impact on project performance

		Indicators				
		Interferences	**Physical progress**	**Program reliability**	**Productivity**	**Time efficiency**
Case N°1	**Variation**	91%	44%	N.A.	56%	40%
	Test of hypothesis	Yes	Yes	N.A.	Yes	N.A.
	Box-plot	Yes	Yes	N.A.	Yes	Yes
Case N°2	**Variation**	75%	40%	38%	37%	52%
	Test of hypothesis	Yes	No (0.181)	Yes	No (0.224)	N.A.
	Box-plot	Yes	Yes	Yes	Yes	Yes
Case N°3	**Variation**	78%	38%	30%	17%	32%
	Test of hypothesis	N.A.	N.A.	N.A.	N.A.	N.A.
	Box-plot	Yes	Yes	Partial improvement	Partial improvement	Yes

In the case of the variation percentage, when there is a positive variation, the indicator improved its performance. In contrast, when there is a negative variation, the indicator had poorer performance. In the results obtained with the statistical analysis of the Wilcoxon-Mann-Whitney non-parametric hypothesis test, “yes” is obtained when the null hypothesis is rejected, when statistical evidence indicates that there is a change between before and after lean implementation. On the other hand, when "no" is obtained, it indicates that given the level of significance (0.05 for this analysis), there was not statistical evidence showing a change; that is why it indicates the significance level at which the null hypothesis would be rejected and the change would be accepted. In addition, there is the possibility that the data characteristics are not able to carry out the hypothesis test, and then the response would be "N.A." In the case of the results of the box-plot diagram analyses, "Yes" is indicated when there is a significant difference between before and after; "Partial improvement" when there were smaller differences; and "No" when there were not any considerable differences.

Given the information presented in Table 3, it can be stated that all of the indicators presented performance improvements. Specifically, the interferences indicator presented the best performance, showing that it responded very positively to all of the analyses. The physical progress indicator responded positively to all of the analyses, except the non-parametric test in Case Study N°2. However the significance required was not very high (18%), so it can be assumed that there is a positive response of the indicator and the difference is mainly related to the data dispersion in a short evaluation period. The reliability indicator also responded positively to all of the analyses. However, Case Study N°1 was not analyzed given a lack of definition of the plan. Therefore, the result of this case study can be ignored and it can be stated that the reliability indicator also responded correctly. The productivity indicator responded positively to all of the analyses, except the non-parametric test in Case Study N°2. However the required importance was not high (22%), so it can be argued that there is a positive response to that indicator and the gap is mainly due to the data dispersion in a short evaluation period. Finally, the efficiency indicator showed a positive response in all of the case studies. However, this was not analyzed by the non-parametric test due to little amount of data. However, it did respond positively to all of the other analyses.

Figure 2 shows the overall impact, representing the calculations of the average improvements for these indicators. In summary, it can be observed that there was a positive impact in project performance as a result of the lean implementation, with statistically significant variations in the indicators that were studied.

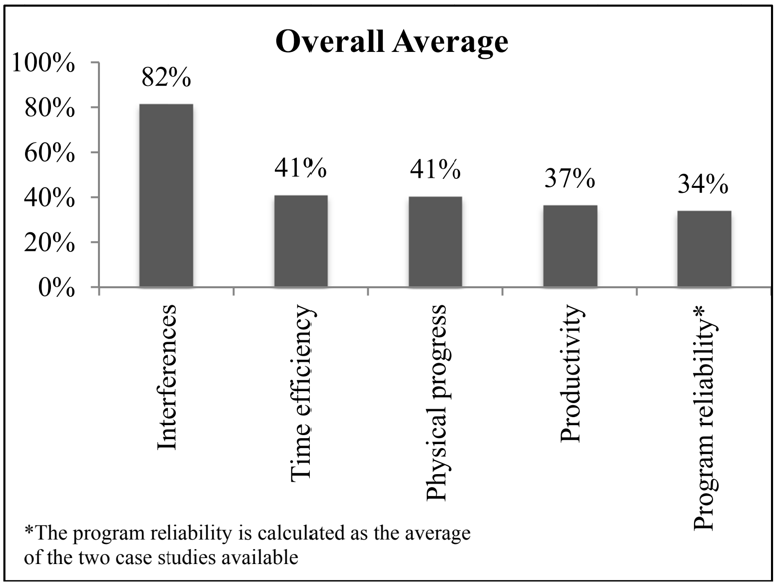

Figure 2: Summary of improvements in project performance.

CONCLUSIONS AND FUTURE RESEARCH

In order to expand the understanding of the use of the lean methodology applied to mining; this research has developed a lean production implementation and has evaluated the impact of it in mining exploitation projects undertaken by construction companies. The study focused on impacts in the following areas: project development and organizational performance. So as to quantify the impact, five indicators were selected regarding project performance and 14 variables were determined to be related to organizational performance. For the three cases studies analyzed, after implementing the lean methodologies, a positive change was observed in project performance and in the organizations.

The research showed the capacity that lean production has to improve project performance. The implementation of lean production, applied during the mining development projects, presented statistically significant improvements in the performance of the projects as measured by their process indicators. There were improvements in work flow, actual production capacity, operational reliability, productivity and time utilization.

When analyzing the implementation timeline and the impacts achieved, it can be concluded that in short periods of time, important results can be obtained. The impacts were obtained in an implementation period shorter than six months, so it could be expected increased leverage if the implementation period were extended. In fact, while it is a challenge to consolidate the results obtained, an even greater opportunity exists to take advantage of the changes and expand them to all the production areas.

On the other hand, different limitations and improvement opportunities regarding the implementation were detected. The organizations recognized the difficulty of balancing daily work with the efforts required to learn and implement new methodologies. A need to have a concrete work plan was identified, with updates including quantitative information to provide follow-up activities as well as to be informed of the continuous evolution of performance.

Future research might focus on complementing the analysis of this research. For instance, the economic impact of the lean implementation could be investigated, analyzing the costs incurred and quantifying the economic impact of the improvements. There is also an opportunity to develop complementary indicators and control tools for the implementation to quantify the direct relationship between the change in the indicators and the progress of the implementation.

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