Case Study

Implementing Lean Production in Copper Mining Development Projects: Case Study

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Abstract: Lean production is a management philosophy that creates competitive advantages and provides important savings opportunities for companies and organizations. However, there is limited evidence showing to what extent lean production can improve productivity and organizational performance in the mining industry. Mining is a critical industry in Chile, so to understand the impact of lean production, this research provides details regarding the implementation of lean production methodologies in three underground mining development projects belonging to a Chilean mining company. In all of the case studies reviewed, the implementation of lean methodologies generated performance improvements in related projects and construction organizations, with statistically significant improvements in workflow, actual production capacity, operational reliability, productivity, time utilization, and organizational performance. The main findings of this study suggest that the incorporation of lean methodologies has significant potential to improve the performance of mining operations, which is critical given the current and future challenges in the mining sector. **DOI: 10.1061/(ASCE)CO.1943-7862.0000917.** *© 2014 American Society of Civil Engineers.*

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Introduction

There are currently several management methodologies that facilitate efficiency in the management process in construction projects and that encompass the entire life cycle of these projects, such as critical path method (CPM), the program evaluation and review technique (PERT), integrated project delivery, management by work competencies, and total quality management (Alarcón and Mesa 2012; Buyle et al. 2013; Howell et al. 2011). Multiple strategies have been developed to address the actual environment of project management, which involves changes in contract types, modification of operational methods, new organizational structures, different options for risk management, and so forth. Projects are implemented in an environment where competition is increasingly intense and production must be managed as effectively as possible (Howell et al. 2011). Now projects have to cut costs, increase productivity, reduce waste, satisfy even the most demanding clients, increase safety, and be profitable (Do Amaral et al. 2012; Howell et al. 2011). A production management approach that has shown great potential to dramatically improve project efficiency is lean production, which has come from the manufacturing industry (Ballard 2005; Koskela 1992). This lean philosophy has successfully expanded to other industries, but mining and construction are far behind in terms of the transformation required to create lean organizations (Ballard 2005; De Valence 2005).

There is some evidence that the use of lean production methodologies in the mining industry represents an opportunity to significantly improve the performance of mining projects. However, there is limited evidence showing to what extent these methodologies can improve mining industry productivity and organizational performance (Dunstan et al. 2006; Hattingh and Keys 2010; Klippel et al. 2008a; Shukla and Trivedi 2012; Wijaya et al. 2009; Yingling et al. 2000).

Mining development projects in copper mines are currently undertaken by construction companies and involve mostly tunneling and other construction operations that are required to prepare the mine for exploitation. This paper reviews how the implementation of lean production affects an underground mining operation in Chile, assessing its impact on the projects and organizations involved. So far, there has been little scientific study of the impacts of lean implementation and transformation in the mining industry. Therefore, this research provides detailed evidence of the positive effects of lean production, including the benefits that it can provide from increased productivity and reduced waste. 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 (Howell and Ballard 1998).

Background

Lean Production

Lean production is a management philosophy that emerged from the Toyota production system, which essentially used different management philosophies and approaches from those used in the rest of the world. The lean production system radically changed paradigms regarding mass-production systems (Shah and Ward 2007; Treville and Antonakis 2006; Womack et al. 1990; Womack and Jones 1996).

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Lean production changed the understanding of organizational roles in companies, encouraging collaborative work. It also established new structures for assembly plants which promoted multifunctionality, teamwork, worker satisfaction, continuous improvement, and elimination of waste (Womack et al. 1990). Likewise, it actively incorporated the supply chain to enable continuous flow on the production line. Product development was also modified by encouraging specialized staffs to work with their coworkers in teams. Lean production specifically pays attention to the customer: flexible processes are defined that respond to demand variations, and processes are designed to focus on creating value for the customer (Shingo 1989). As a result, lean production becomes a work process alternative (or sometimes the only alternative) in slow-growth economies and under low-demand conditions (Ohno 1988). Thus, it enables efficient production of small numbers of products in multiple varieties (Shah and Ward 2007; Treville and Antonakis 2006; Womack et al. 1990).

The lean production philosophy can be summarized in five main principles: specify the value for a given product, identify the value stream for each product, allow value flow without interruptions, and allow the consumer to pull production, and pursue perfection (Womack and Jones 1996). These principles definitely provide a way to make more with less to provide customers with exactly what they want when they want it (Monden 1998).

The key measures of lean production are waste and excess—in other words, any human activity that uses resources but creates no value (Womack and Jones 1996). Waste includes errors that require fixing; manufacturing products that are not required by the client and thus create excess inventory; unnecessary processes in the production chain; unnecessary movement of employees and transport of materials; bottlenecks in prior activities that cause delays; and products and services that do not meet the client's needs (Womack and Jones 1996).

Lean Construction

Lean construction began in the late twentieth century as an outgrowth of the ongoing development of lean thinking in the manufacturing industry and the eagerness of other industries to understand and apply it (Forbes and Ahmed 2011). Lean construction refers to construction management using the lean production philosophy (Ballard 2000a; Howell and Ballard 1998; Koskela 1992; Tommelein 1998).

In the traditional view, a production system was a transformation in which processes were simple, flows were short and few, and organizations were small. However, as industry developed, the same view was applied in more complex processes, with more flows and in bigger organizations (Howell 1999). Therefore, management became more complicated, and inherent problems arose from the limitations of the traditional view (Koskela 1992). Essentially, the traditional view failed to recognize internal production flows, specifically for those activities not part of the transformation but necessary for production. These activities were delays, inspections, and movements (Koskela 1992).

The lean philosophy suggests a new vision for the production system. This vision integrates two main production components: transformations and flows, and it proposes a new definition: production is a flow of materials and information that creates a final product. In this new conceptualization, there is a transformation of materials, inspections, movements, and delays. Processing represents the transformation of material whereas inspections, movements, and delays represent flows (Howell and Ballard 1998; Koskela 1992).

With this new definition of the production system, time is added as a fundamental resource to be analyzed, where it is used in transformation activities as well as in flows (Ballard 2005; Koskela 1992). In this regard, transformation processes add value whereas flow processes do not (Ballard and Howell 1994). Therefore, the correct path is to improve the production process by eliminating flow activities and optimizing transformation (Alarcón 1994; Ballard 2000a; Ballard and Howell 1994; Forbes and Ahmed 2011; Koskela 1992).

Lean Mining

In the last decade, research has explored the application of lean principles in the mining industry. Studies have successfully applied specific lean production tools and principles at different levels of detail in the industry, showing the flexibility that lean production provides (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 mining. In fact, many say that lean production and its value proposition do not belong to a particular industry but can be applied to any industry (Dunstan et al. 2006). Therefore, not only lean principles and tools but the concept of waste can be directly applied in mining (Wijaya et al. 2009). In addition, there are specific tools and areas of focus that can be directly implemented, such as value, value stream mapping, standardization, quality from the source, total productive maintenance, multifunctional workers, and continuous improvement (Yingling et al. 2000).

Arguably, it is possible to implement a new form of management in the mining industry through the integrated use of lean production principles and tools, which are compatible with mining's traditional views, concepts, and techniques (Klippel et al. 2008b).

There are positive examples of the use of lean principles in the mining industry, and there are also important limitations that present great challenges. Specifically, there are cultural aspects that are firmly fixed in the industry, which make the implementation of company changes difficult (Freire and Alarcón 2002). Lean production methodologies not only involve tools and principles but also imply a cultural change in both 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 that should be applied and monitored continuously over time (Ade and Deshpande 2012). The lean principles that apply to the mining industry are highly interdependent. Therefore, they require strong leadership from both upper management and change agents and 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. Some of the most important organizational barriers are those represented by operators given their abilities, level of training, and culture. Specifically, the human factor can be critical in ongoing improvement because it involves training and creating the right incentives for personnel. This is essential in achieving true change (Ortiz 2010).

There are important requirements in the application of lean production in the mining industry and therefore great challenges to be resolved. There is limited evidence to show a broad acceptance of lean production in mining, and few companies have begun a systematic transformation toward lean thinking. Moreover, there is little research to show to what extent lean methodologies can improve production and organizational performance. Therefore, it is necessary to reveal and assess the impact of lean production

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initiatives on mining projects and organizations to provide knowledge that encourages the use lean thinking in future projects.

Research Methodology

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 because of a specific interest in the internal characteristics of these cases, which allows study of production management and organizational phenomena in their actual context. This is critical in case studies where the boundaries between the phenomena and the context are not apparent (Yin 1994).

Diagnosis

It is recommended that evidence and information obtained through a case study be gathered from different sources as a way to triangulate results (Yin 1994). To identify the context in which the case studies were undertaken and to diagnose project requirements, various activities were conducted, such as document review, background analysis, interviews, field visits, initial workshops, and strategic sessions. In this research, the different types of information available came from documentation, historical files, semistructured interviews, direct observation, participatory observation, and surveys.

Selection of Case Studies

Three mining development projects in Chile were selected to study the impact of a lean implementation. This allowed a comparative analysis to take place, improving the validity of the study. The main condition for selecting the projects was that they were involved in similar activities, enabling their comparison using cross-case analysis. To analyze cases under steady-state conditions, projects lasting for more than a year were selected.

Selection of Performance Indicators

The indicators were chosen in accordance with several conditions. This research considered indicators that were present before and after the lean implementation (or could be calculated and measured with common site data). Also, the indicators were used concurrently in the three projects analyzed. On the other side, the selected indicators were measured properly by the organizations involved throughout the lean implementation. These indicators also appropriately showed performance changes in projects and organizations. In the end, the selected indicators responded to a combination of requirements and were accepted by the client.

Quantitative Analysis

To properly evaluate how lean implementation impacts project performance, an analysis of project performance indicators was carried out in three ways that complemented each other: comparison of medians, analysis of boxplot diagrams, and significance tests.

A comparison of medians was performed to identify significant changes before and after the lean implementation. The median was chosen over the average to avoid possible biases due to data dispersion (Anderson et al. 2004). Boxplot diagrams were studied for all indicators to obtain a graphical comparison of the data set. The goal was to use a visual comparison of the individual indicator's behavior to determine whether there was a real difference between before and after the lean implementation.

Finally, significance tests were undertaken to determine whether the variation before and after the lean implementation was statistically significant, including a nonparametric Wilcoxon-Mann-Whitney test with a confidence level of 95% [For small sample sizes, below 30, violations of parametric assumptions are most critical, so nonparametric tests are more appropriate (Martin 2001; Anderson et al. 2004)]. This test evaluated whether the two independent groups were extracted from the same population. If it detected that the data were not extracted from the same population, it could be assumed that there was significant change after completing the implementation (Siegel and Castellan 1995).

Qualitative Analysis

To understand the impact of lean production implementation on organizational performance, a survey was developed and administered to the organizations involved (contractors) and semistructured interviews were conducted with change agents (external consultants) who led the implementation.

The survey's main goal was to identify the lean implementation's impacts on the work teams' ability to manage the project. This referred to companies involved in project execution right at the end of the implementation. The population surveyed included all who had a more overall view regarding the impact of the implementation, so the representative sample was made up of 18 professionals who were in the position of area supervisor. The parameters used in the survey are listed in Table 1.

The semistructured interviews were conducted with the aim to better understand the lean impacts on organizational behavior and to offer an external view of the change experienced by the organizations. Interviews were conducted with the change agents (external consultants) who led the implementation, and they gave their perception of how the organizations had changed. In this research, the semistructured interviews were carried out with nine people who worked with the contractors. In fact, they were conducted with experts from local companies. Even with the subjective character of the interviews (and the potential biases involved), these interviews, with open and closed questions, provided qualitative anecdotal information.

Unlike a quantitative investigation, where the goal is to obtain large and representative samples to generalize results, this research used a qualitative methodology, where sample size was not as relevant. Given the character of this study, the goal was to obtain a better understanding of certain processes and prevalent practices (Onwuegbuzie and Leech 2007). Because of the exploratory nature of the research, what was sought was perceptions of performance improvements in the organizations. Generalization of these findings was severely limited by the nature of the qualitative analysis; future research is required to allow generalization.

Case Studies

Three case studies were selected to analyze underground mining development projects in Chile. The selected case studies allowed

Table 1. Survey Parameters

Parameter	Value
Population size (N)	19
Expected percentage (p)	0.5
Confidence level (Z)	95%
Estimation error (e)	10%
Required sample size (n)	16
Actual sample size	18

a comparative analysis, improving the validity of the study. The case studies represented the development of three projects executed by three construction companies. The projects were developed in the same underground mine and were supervised by the same mining company or legal representative.

In the three case studies, similar work was carried out, including projects for horizontal developments, vertical developments, draw points, ore passes, set-up of ore chutes, and set-up of vent fans. The horizontal developments are horizontal and continuous mining excavations, described by height, width, and sections. Vertical developments are similar, but their execution is vertical. Draw points are areas at the production level where the fragmented material, which comes from the caving level, is collected. Ore passes are areas where the unloading of fragmented materials in the unloading shafts takes place; the passes have a unique configuration for filtering and adapting to the required grading. The set-up of ore chutes involves conditioning and installation of the chutes, which operate as flow regulators when materials are lowered from one level to another by gravity. The set-up of vent fans involves the conditioning and installation of the fans, which allow air to be forced from the inside of the mine (Portal Minero 2006).

The projects included work at most of the levels in the mine: caving level, production level, hauling level, and ventilation sublevel. The caving level is where the caving of the mineral column takes place. The production level comprises the galleries from which the fractured mineral is captured. The hauling level is where the minerals are loaded on a train for transport. The ventilation sublevel is a network of galleries below the production level that renew the air (Portal Minero 2006).

The contracts indicated that all of these projects had similar deadlines and costs. The average schedule was approximately five years with an estimated cost of US$130 million. The contracts did not have modifications in their terms or costs; however, they overlapped in their implementation periods. For example, two of them (Project N1 and Project N2) had been in operation for over a year before lean production was implemented. However, Project N3 had modified its contract, so it had recently begun its first months of implementation. The projects reviewed included a staff of approximately 500 people per project.

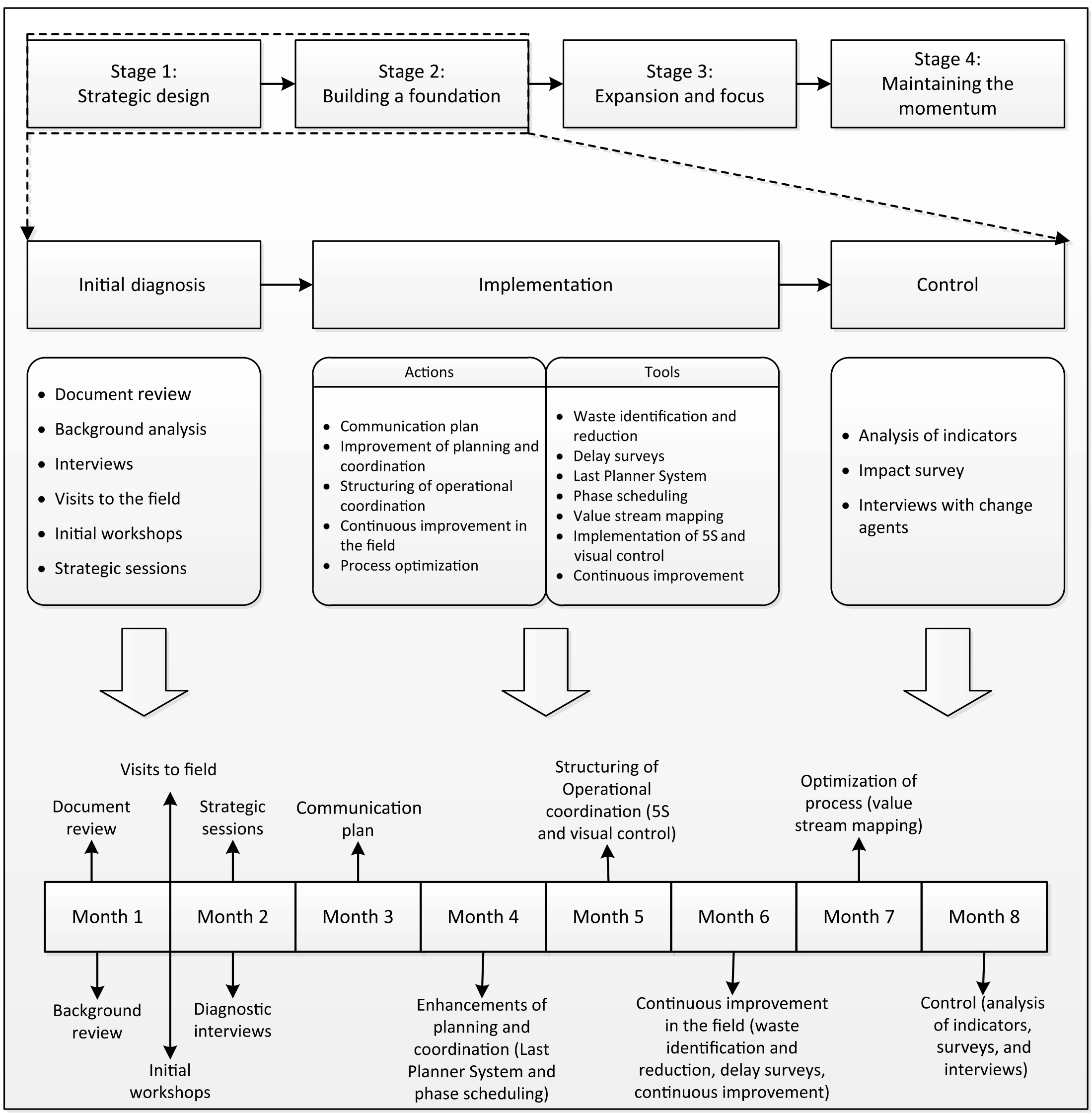

Fig. 1. Improvement program and research

Improvement Program

This research was part of a long-term improvement program that included lean transformation of all areas in the organization (operations, supply chain, maintenance). The improvement program was created by the Production Management Center of Pontificia Universidad Católica de Chile (GEPUC) to mitigate and solve production problems that the mining company had with its contractors which were mainly due to low productivity. The overall objective was the implementation of lean thinking through methodologies and tools that would promote continuous improvement and the elimination of waste in the processes, thus increasing productivity with the appropriate involvement of the contractors. However, during the study and corresponding impact analysis of the lean implementation, only the first part of the program of long-term improvement was considered (i.e., two out of four stages). The research time frame allowed only analysis of the first two stages. The first part included intervention in three pilot cases and an 8-month implementation period. Fig. 1 shows how the improvement program was structured.

Diagnosis

Several problem areas were identified in the diagnosis stage and were sorted into categories to improve understanding of them. The main problem areas identified were use of time, planning, results and indicators, management systems, and use and availability of resources. Given the problem areas identified, the main opportunities for improvement were based on the following objectives: improve planning and coordination; improve communication between parties and manage knowledge and use of process information; reduce operational waste; consolidate work teams; and improve alignment of parties.

Components

To mitigate and solve the problems identified, five components were considered that defined the direction of the lean implementation: communication plan; improvement of planning and coordination; structuring of operational coordination; continuous on-site improvement; and process optimization.

The aim of the communication plan was to achieve dissemination and understanding of the program, motivating the necessary leadership to achieve success. Improvement of planning and coordination focused on the fulfillment of monthly production to reduce performance variability and improve coordination and communication between teams. The structuring of operational coordination focused on the standardization of work practices and the maximization of time allocated to effective work, improving productivity through coordination. This also supported transparency and provided visual support for planning and coordination. Continuous on-site improvement had the objective of identifying and reducing process waste through empowerment and participation of workers in continuous improvement. The goal, identified by the client, was to increase the percentage of productive time. Process optimization focused on reducing waste in key execution processes, allowing greater generation of value for the client and increased productivity.

The tools and methodologies used to carry out the aforementioned actions were identification and reduction of waste (Koskela 1992), delay surveys (Alarcón 1994), 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). The appendix includes a brief description of these tools and methodologies.

Because of the duration of the implementation, not all of the tools were applied at the beginning of the project. The first two months focused on the initial diagnosis, the identification of actions to take, and the launch of the program. Then, in the following months, lean tools were implemented as they were needed by the projects. Fig. 1 shows how these tools were implemented.

Table 2. Production Variables Related to the Research

Approach	Variable	Conceptual definition	Operational definition
Project	Interferences	Time workers lose when they are prevented from doing their work	Staff-hours lost to interferences per month (SH)
	Physical progress	Amount of the project done in a set period in relation to the total project	Percentage of physical progress by month
	Plan reliability	Relationship between what was done and what was planned	Percentage of plan completion by month
	Productivity	Relationship between production and resources used	Revenue by employee per month ($/EM)
	Time efficiency	Ability to spend time on activities that add value	Proportion of time spent on value adds (%)
Organization	Teamwork	Group collaboration to reach a common goal	Results of survey administered to construction companies, project management section
	Participation	Positive intervention of workers in their daily activities	
	Communication	Workers' ability to share ideas and opinions	
	Commitment	Contribution to achievement of various common objectives	
	Learning	Acquisition of knowledge and time spent on it	
	Alignment of objectives	Alignment of objectives among business units	Results of interviews with change agents, enterprise vision section
	Customer focus	Importance of customer needs in work being done	
	Organizational needs	Priority of organizational needs above individual interests	
	Construction techniques	Specific techniques used to do work	Results of interviews with change agents, technical competencies section
	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, social competencies section
	Relationship management	Ability to motivate workers to achieve performance improvements	
	Values	Shared principles among workers	

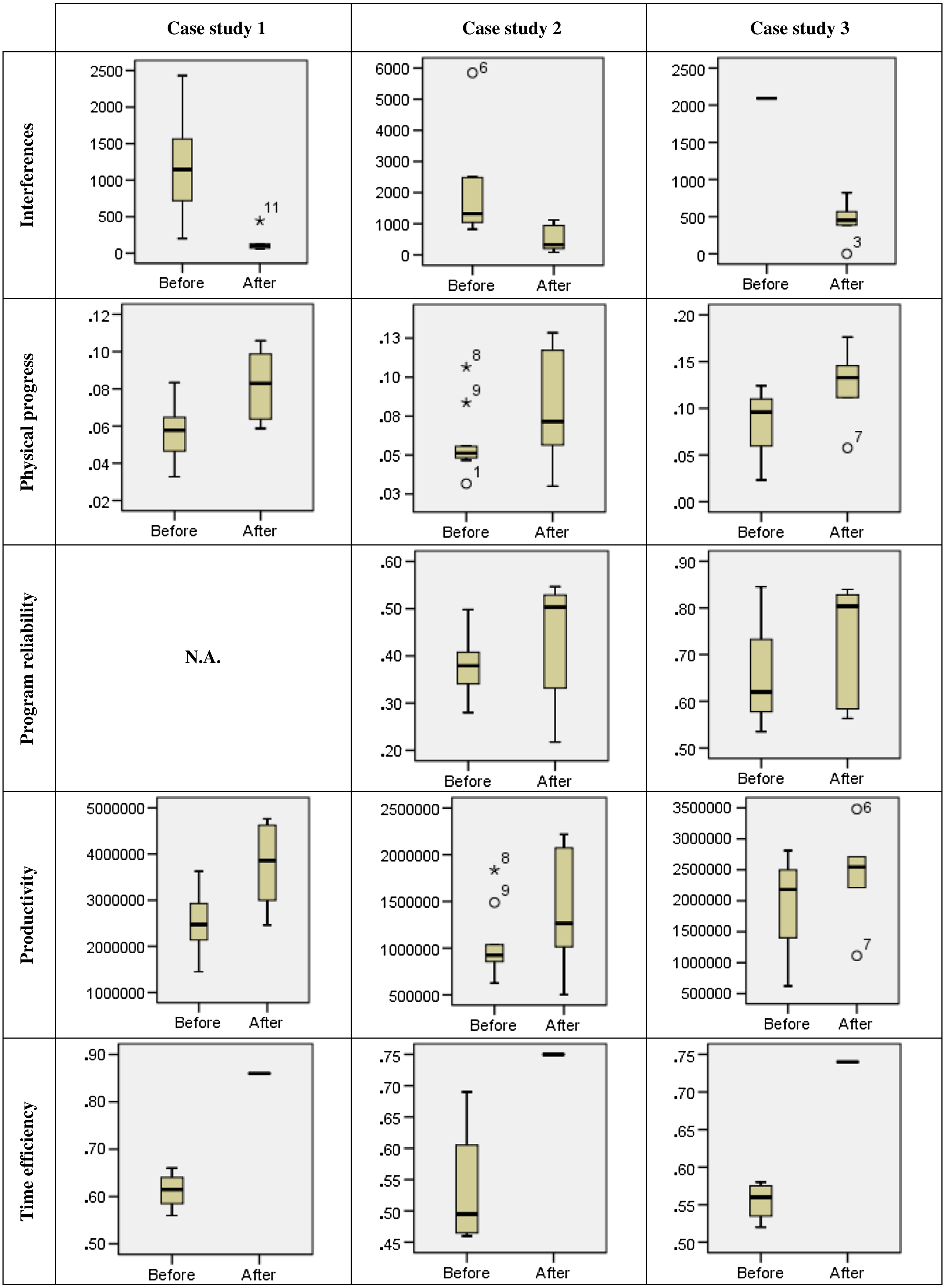

Fig. 2. Boxplot diagram of performance indicators in the case studies

Table 3. Analysis of Lean Implementation's Impact on Project Performance

Case study	Analysis	Interferences	Physical progress	Program reliability	Productivity	Time efficiency
1	Variation (%)	91	44	N/A	56	40
	Test of hypothesis	Yes	Yes	N/A	Yes	N/A
	Boxplot	Yes	Yes	N/A	Yes	Yes
2	Variation (%)	75	40	38	37	52
	Test of hypothesis	Yes	No (0.181)	Yes	No (0.224)	N/A
	Boxplot	Yes	Yes	Yes	Yes	Yes
3	Variation (%)	78	38	30	17	32
	Test of hypothesis	N/A	N/A	N/A	N/A	N/A
	Boxplot	Yes	Yes	Partial improvement	Partial improvement	Yes

Performance Variables

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 that aligned with the actions and methodologies proposed. Table 2 lists the variables that were used in this research.

Implementation Results

Impacts of Lean Implementation on Production Performance

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

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

Fig. 2 is a summary of data for all performance indicators, considering all of the case studies, using boxplot graphs. The goal was to provide an overall view of the dispersion of the data obtained. The figure shows the maximum and minimum values; the center box represents 50% of the data, and the centerline represents the median (points out of the diagram were considered outliers). Therefore, the median shows improved performance in all three case studies because the value improves for every indicator. The boxes, which represent a range and a central trend, also show improvements in performance. It can be concluded that there was a trend toward improved performance in the production indicators when comparing data distribution before and after lean implementation.

Table 3 summarizes the analysis done with the indicators selected to synthesize the impact that lean implementation had on project performance. The table shows the variation percentage for the various indicators after lean implementation, the result of both the nonparametric tests and the review of the boxplot graphs.

In the case of the variation percentage, a positive variation shows that the indicator improved its performance. In contrast, a negative variation shows that the indicator had poorer performance. In the results from statistical analysis of the Wilcoxon-Mann-Whitney nonparametric hypothesis test, "Yes" is obtained when the null hypothesis is rejected; thus, the statistical evidence indicates that there was a change between before and after lean implementation. On the other hand, "No" indicates that, given the level of significance (0.05 for this analysis), there is no 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, given the possibility that the data characteristics are unable to carry out the hypothesis test, the response is "N/A" In the case of the results from the boxplot diagram analyses, "Yes" indicates a significant difference between before and after; "Partial improvement," smaller differences; and "No," no considerable differences.

Finally, Fig. 3 shows the overall impact of lean implementation.

Given the information presented in Table 3, it can be stated that all of the indicators showed 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 nonparametric test in case study 2. However the

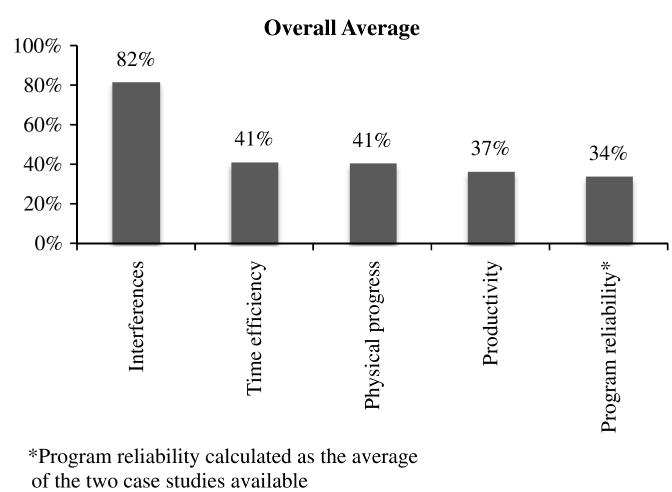

Fig. 3. Summary of improvements in project performance; program reliability is calculated as the average of the two case studies available

significance required was not very high (18%), so it can be assumed that there was a positive response of the indicator and the difference was 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 2 was not analyzed given a lack of plan definition. 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 nonparametric test in case study 2. However, the required importance was not high (22%), so it can be argued that there was a positive response to that indicator and that the gap was mainly due to 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 nonparametric test because of the small amount of data. Still, it did respond positively to all of the other analyses.

In summary, it can be observed that there was a positive impact on production performance in the analyzed projects as a result of lean implementation, with statistically significant variations in the indicators studied. Fig. 3 shows the average of the improvement rates.

Impact of Lean Implementation on an Organization's Performance

A survey of the organizations involved (contractors) and semistructured interviews with change agents who led the implementation (external consultants) were carried out to understand the impact

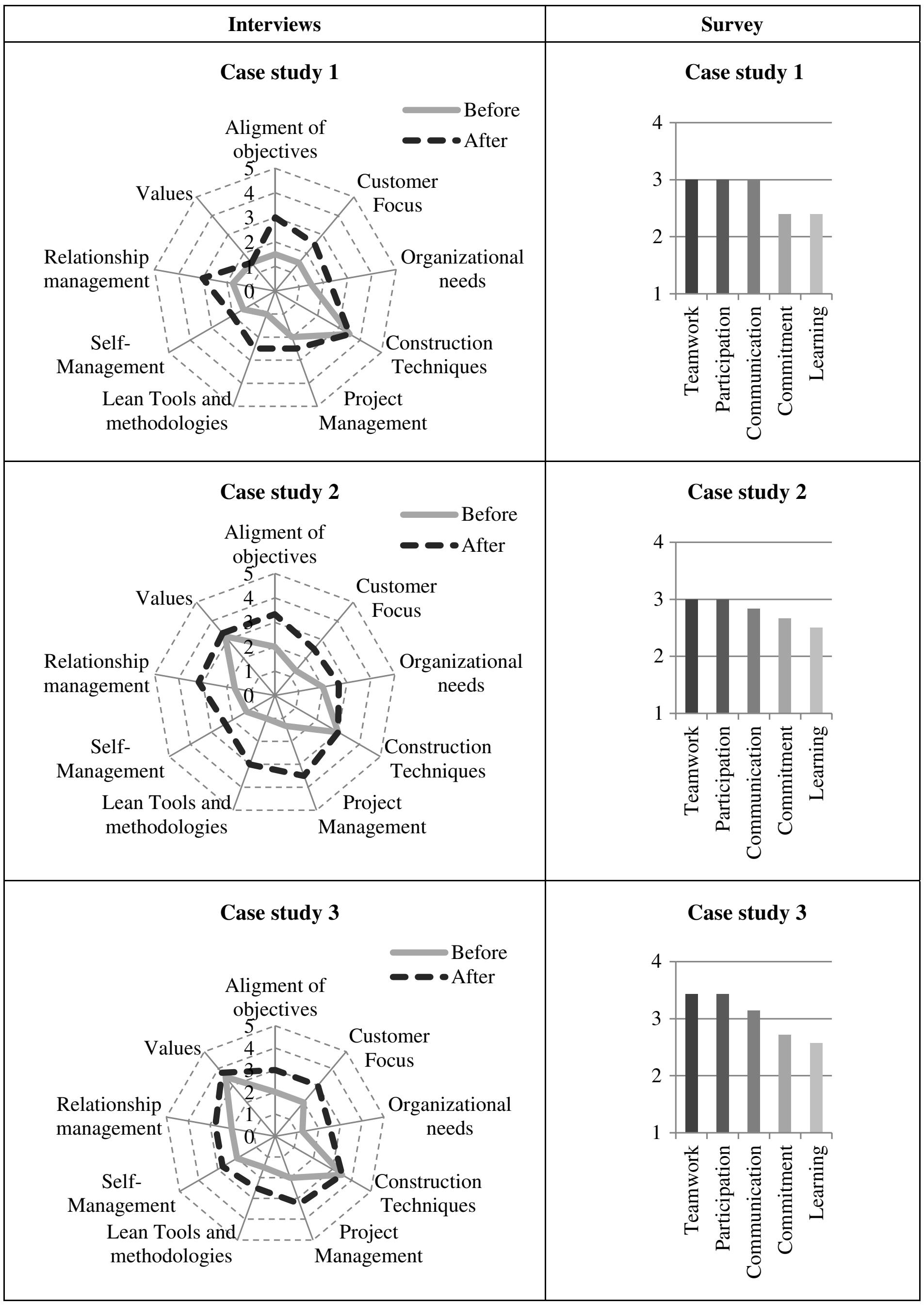

Fig. 4. Impact of lean implementation on the organization and on project management in the case studies

Table 4. Summary of the Analysis of Lean Implementation's Impact on Organizational Performance

Source	Variables	Case study 1	Case study 2	Case study 3
Surveys	Teamwork	Positive	Positive	Highly positive
	Communication	Positive	Positive	Highly positive
	Participation	Positive	Positive	Highly positive
	Commitment	Positive	Positive	Positive
	Learning	Positive	Positive	Positive
Interviews	Alignment of objectives	Positive	Positive	Positive
	Customer focus	Positive	Positive	Positive
	Organizational needs	Slightly positive	Slightly positive	Positive
	Construction techniques	Zero	Zero	Zero
	Project management	Slightly positive	Very positive	Positive
	Lean tools and methodologies	Positive	Very positive	Positive
	Self-management	Slightly positive	Positive	Slightly positive
	Relationship management	Positive	Positive	Slightly positive
	Values	Zero	Slightly positive	Slightly positive

on an organization that applies lean methodologies to project implementation.

In the survey, five variables were quantified: teamwork, participation, communication, commitment, and learning. In this case, the rating system used was as follows: 1 = no impact; 2 = a slightly positive impact; 3 = a positive impact; and 4 = a highly positive impact.

In the interviews, three areas of competence were studied simultaneously: enterprise vision, technical competencies, and social competencies (Pavez and Alarcón 2008), which were defined through the variables in Table 1. The goal was to describe the organizations involved in project management and evaluate the lean implementation impacts on organizational performance. The evaluation employed a scale of 1 to 5, with 1 being the most negative and 5 being the most positive.

Fig. 4 shows the lean implementation impacts on the organization and on project management for the three cases studies analyzed. It details the results achieved with the survey and the interviews. In the surveys, it can be seen that the three case studies demonstrated a positive impact on all variables analyzed. In addition, case study 3 had a very positive impact for the variables teamwork, communication, and participation. In the case of the interviews, the results were the most varied. The greatest impact was in enterprise vision, mainly in the variables alignment of objectives and customer focus, because these tools promote customer satisfaction and collaborative work. However, lean implementation still positively impacted the rest of the competency areas but with varied results for each one. In social competencies, this was because it directly affected organizational culture, where changes are more difficult to detect.

To recap the impact that lean implementation had on organizational performance, Table 4 summarizes the results obtained for the different variables analyzed. In the table, the impact on the organizations was analyzed using the following ratings: zero, slightly positive, positive, and very positive.

For the surveys, the rating was directly obtained from the survey responses. However, for the interviews the rating was indirectly calculated according to variations in the evaluation. Thus, the ratings were defined as follows: zero when there was no variation; slightly positive when the variation was between zero and less than one; positive when the variation was between one and less than two; and highly positive when the variation was greater than two.

Table 4 shows that the three case studies presented a generally positive impact after lean implementation. It can be seen that there was relative consensus in the surveys regarding lean implementation, in that all variables analyzed showed at least a positive change. However, in the case of the interviews, there was more variation in the results. There was a positive impact and less variation in enterprise vision. In technical competencies, there was a positive impact in general but the results were more varied according to the variables and the case study analyzed. Finally, in social competencies, there was generally a slightly positive impact.

Finally, it can be stated that lean implementation had a positive impact on the performance of the organizations, according to the perception of both the team that developed the implementation and the teams that were analyzed in the case studies.

Conclusions and Future Research

To expand understanding of the use of lean production in mining, this research studied a lean implementation and evaluated its impact in mining development projects undertaken by construction companies. The study focused on impacts in project development and organizational performance. To quantify the impacts, 5 indicators were selected for project performance and 14 variables were determined for organizational performance. For the three cases studies analyzed, after lean implementation a positive change was observed in project performance and organizational performance.

The research showed that lean production can improve project performance. The quantitative analysis of its implementation in the mining development projects indicated statistically significant improvements in project performance as measured by the projects' process indicators. There were improvements in workflow, actual production capacity, operational reliability, productivity, and time utilization.

The research also showed, through a qualitative analysis, that lean production in mining development projects had a positive impact on organizational performance. It promoted teamwork while strengthening communication, participation, and commitment. In addition, it strengthened the alignment of objectives between the different work areas, fostering greater value generation and customer focus. A positive attitude toward continuous improvement, visible through a strong desire to learn, was also detected.

Analyzing the implementation's timeline and its impacts, it can be concluded that significant results can be obtained in short periods of time. However, it cannot be assured that these impacts will be sustained over time and it cannot be said that the lean implementation in the case studies reached a steady state. Impacts were observed during an implementation period shorter than six months; if the implementation period were extended, increased impacts could be expected. However, this is an assumption that should be tested in further research to come up with stronger and more sustainable conclusions. While it is a challenge to consolidate the results obtained, a significant opportunity emerges to take advantage of the implementation experience and expand it to all production areas.

On the other hand, different limitations and improvement opportunities relating to lean implementation were detected. The organizations recognized the difficulty of balancing daily work with the effort 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 and to be informed of the continuous evolution of performance. It is acknowledged that the ability to generalize the qualitative analysis in this research is very limited. However, it provides a subjective dimension to the analyses undertaken and complements the quantitative analysis. Further research should improve the design and increase the sample size of qualitative analyses. In terms of quantitative analysis, future research might focus on complementing it. The economic impact of lean implementation could be investigated by looking at the costs incurred and quantifying the economic impact of the improvements. There would also be an opportunity to develop complementary indicators and control tools for the implementation to quantify the direct relationship between changes in the indicators and implementation. progress.

Appendix. Tools

Delay Surveys

A delay survey (Alarcón 1994) is a tool to estimate the magnitude of delays occurring on a project by cause. At the end of each day, foremen or first-line supervisors estimate the total time lost for each of their crews by cause. The survey also enables systematic understanding of the general perception of the project team, focusing on the most important processes and creating a culture of continuous improvement.

Last Planner System

The Last Planner System (LPS) (Ballard 2000a) is a production planning and control system based on lean production principles and is focused on increasing workflow reliability under highly uncertain project conditions, increasing the reliability of planning and thereby improving performance. LPS acts at different levels of the planning system. Therefore, it is essential that those involved in the planning process make and maintain reliability commitments.

Phase Scheduling

Phase scheduling (Ballard 2000b) is a mechanism in LPS for encouraging more participation, stability, coordination, and integration of planning activities. Its main objective is to promote reliable commitments, reduce uncertainty, and increase certainty in the performance of activities.

Value Stream Mapping

Value stream mapping (Rother and Shook 1999) is a lean tool that helps to visualize and understand the flow of material and information in product creation through the value chain to reduce activities that do not add value. The tool follows the path of production from the supplier to the customer and can graphically represent the steps and processes involved in the flow of material and information.

5S and Visual Control

5S (Ohno 1988) and visual control (Dos Santos et al. 1998) are management tools that allow workers to be informed about what they need to do during the day, the situation they are in, and the situation they should be in. It also makes the work area clean, orderly, without distractions, and safe.

Continuous Improvement

Continuous improvement (Ballard and Howell 1994) is an iterative process that allows sustainable change in an environment to take place. This should foster continuous improvement and progress under normal working conditions. The stages in achieving continuous improvement in an organization are to select a process that can be improved; plan a change identifying expected results; implement the change; describe and measure what actually happens (check results); and evaluate the results to standardize or improve further changes.

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