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Lean Methodologies and Productivity in Mining Development – A Case in a Public Company.

Metodologías Lean y Productividad en el Desarrollo Minero: Estudio de caso en una Empresa Pública.

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Abstract

Codelco is a Chilean public company that is the largest copper producer in the world and it has developed multiple initiatives to implement Lean Management in its operations. This article evaluates the impacts of the implementation of Lean production methods on an underground mining development project. The effects of Lean methods, such as The Last Planner® System (LPS), on an appropriate case study and the analysis of these results produced statistical research findings and qualitative observations that suggest a broader implementation of Lean in the mining industry. Among these observations are: a) improvement of the mean for all indicators studied; b) reduction in the variance of some indicators, suggesting more stable processes; c) correlation between the percent plan complete (PPC) from the LPS and its coefficient of variation (CV); d) reduction in the time wasted in delays; and, e) improvement in key organizational attributes. Additionally, all variables associated with positive performance improved during the research, suggesting that the implementation of Lean methodologies improved overall performance throughout the organization.

Keywords: *Lean management; Last Planner® System; Production Planning and Control.*

Resumen

Codelco, el mayor productor de cobre del mundo, es una empresa pública chilena que ha desarrollado múltiples iniciativas para implementar Lean Management en sus operaciones. Este artículo evalúa los impactos de la implementación de los métodos de producción Lean en un proyecto de desarrollo minero subterráneo. Los efectos de los métodos Lean, como The Last Planner® System (LPS), en un estudio de caso y el análisis de sus resultados produjo hallazgos estadísticos y observaciones cualitativas que sugieren ampliar la implementación de Lean en la industria minera. Entre estas observaciones se encuentran: a) mejora de la media para todos los indicadores estudiados; b) reducción de la varianza de algunos indicadores, lo que sugiere procesos más estables; c) correlación entre el porcentaje de ejecución del plan (PPC) de la LPS y su coeficiente de variación (CV); d) reducción del tiempo perdido en retrasos; y, e) mejora de atributos organizacionales clave. De forma adicional, todas las variables asociadas con el desempeño positivo mejoraron durante la investigación, lo que sugiere que la implementación de metodologías Lean, en general, mejoró el desempeño de la organización.

Palabras clave: Gestión Lean; Sistema Último Planificador®; Planificación y Control de la Producción.

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1. Introduction: Preliminary Remarks and Literature Review

This paper describes how the Last Planner® System, a production planning and control system developed by Glenn Ballard and Gregory Howell (Ballard and Howell, 1994) has been a key methodology to introduce Lean Management practices in mining projects in Chile. Glenn Ballard had an active participation in initial efforts to introduce these practices, through visits and conferences which open the way to implementation efforts in this case study.

In Chile, mining has the highest relative productivity rate of any industry, reaching 68% of the productivity of the Australian mining industry. Other sectors are significantly less competitive, such as the construction industry, which has 38% relative productivity compared with the same industry in the United States (McKinsey and Company, 2013). Differences in productivity measures indicate disparity in Gross Domestic Product, a critical statistic and particularly relevant for the economic growth of developing countries.

According to McKinsey reports on Labour Productivity, improving low operational efficiency in the Chilean mining and construction industries has the potential to increase relative productivity by 27% and 32%, respectively (McKinsey and Company, 2013). To do so requires the correction of many detrimental management trends: low adoption of advanced management methods, low level of standardization of planning processes, fragmentation of the phases of the projects, lack of training for workers, and sub-optimal organization of work.

Lean Management, a management philosophy based on the Toyota Production System (TPS), provides a promising alternative to the operational management methods currently in use by adopting a philosophy that seeks to achieve operational excellence by eliminating waste, adding value and continuous improvement. Lean aims to deliver to the costumer what is needed in the appropriate amount and at the appropriate time, based on just-in-time delivery (Shah and Ward, 2007); (Womack and Jones, 1996); (Womack et al., 1990).

The sustaining principles of the Lean philosophy are to reduce variability and increase the share of value-adding activities (Koskela, 1992). This is achieved by generating more value with less resources, creating a stable workflow, using pull production systems and continuously seeking perfection (Liker, 2004); (Womack and Jones, 1996). Lean has been initially applied in manufacturing and healthcare (Cooney, 2002), (Ballard, 2005); (Ballard and Howell, 1994); (Ballard, 2000); (Koskela, 1992) however, there are other industries that have adopted it slowly and belatedly, among which are the construction and mining industries (Ballard, 2005); (Castillo et al., 2015); (De Valence, 2005).

The Last Planner® System, a commitment-based planning and production process control system that emerged from Lean principles and has been applied primarily to construction projects, relies on front line managers making and securing promises to each other and to the project to complete their work reliably (Ballard and Howell, 1994); (Ballard, 2000), (Viana et al 2017), (Zegarra and Alarcón 2017). In this sense, the "last planner" is the person in control of managing the people who are performing work assignments and is responsible for the work's execution and control. In addition, the "last planner" is responsible for the capacity of the production units and performance (Campero and Alarcón, 2008). The study of the application of the Last Planner System in mining development projects has been limited (Leal, 2010), although there are evidences that is applicable (Castillo et al., 2015); (Leal, 2010).

While some literature exists on the applicability of Lean principles to the mining industry (Hattingh and Keys, 2010); (Wijaya et al., 2009); (Yingling et al., 2000) and implementations in mining operations and projects (Ade and Deshpande, 2012); (Castillo et al., 2015); (Dunstan et al., 2006); (Klippel and Antunes, 2008[a], (Klippel and Antunes, 2008b), there are few reported cases of implementation in mining development projects (Castillo et al., 2015); (Dunstan et al., 2006). Additionally, only one paper, from (Castillo et al., 2015), discusses a sample size that allows the use of significance tests to prove improvements due to Lean implementation. It is important to note that the cases reported of Lean implementation in mining development projects present only small sample sizes, which makes it difficult to use large batch statistical analysis tools. Nevertheless, Lean has been identified as having high potential for successful implementation and improvement of the mining industry (Loow, 2015).

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2. Research Methodology

An underground mining development project was selected for an empirical study to investigate the potential impacts of Lean implementation in the mining industry. Using case study methodology enabled the authors to: study the traits of a particular case (Arzaluz, 2005); (Simons, 2011); (Yin, 2003); utilize multiple sources of evidence, such as documents, reports, interviews and surveys (Arzaluz, 2005); (Goode and Hatt, 2008; (Yin, 2003); and use both quantitative and qualitative data (Yin, 2003). This type of research strategy provides in-depth study of a phenomenon by considering the particularities of a single case (Arzaluz, 2005); (Simons, 2011); (Yin, 2003) from a contemporary, rather than a historical, perspective (Schell, 1992); (Yin, 2003). The data collected over the course of the study enabled the use of both inferential statistical analysis and correlational analysis for the purpose of testing the following hypotheses:

1. *The implementation of Lean principles in the execution phase of mining development projects improves the mean of project indicators associated with progress, program compliance, and performance in a statistically significant way.*
2. *The implementation of Lean principles in the execution phase of mining development projects reduces the variability of project indicators associated with progress, program compliance and performance in a statistically significant way.*
3. *The correlation between the Percent Plan Complete (PPC) from the LPS and its coefficient of variation (CV) found in industrial and multistory building projects is extensive to mining development projects.*
4. *The implementation of Lean principles in the execution phase of mining development projects reduces the amount of time wasted in delays.*
5. *The implementation of Lean principles in the execution phase of mining development projects produces an improvement in key organizational attributes.*

2.1 Research and Implementation Plan

Lean principles and methodologies were applied on a horizontal mine development project that was being delivered by an international construction company which carried out tunneling work at the production, caving, intermediate transport, ventilation and crushing levels. The scope of the work was the development of horizontal underground tunneling on a structural project for a mine extension.

As part of a long-term cultural transformation based on Lean Management, the mining company embraced a pilot project designed to practice Lean initiatives on their structural large-scale mining extension projects. The company hired the Dirección de Investigaciones Científicas y Tecnológicas de la Pontificia Universidad Católica d

e Chile (DICTUC) to implement Lean methodologies and provide training in order to improve productivity on the project.

The implementation lasted for twelve months and it was divided in three stages: (1) Diagnosis and design of implementation strategy, (2) Implementation, and (3) Control, as illustrated in (Figure 1). During the first stage the performance of the project was evaluated and the implementation strategy was established. In the second stage the proposed initiatives and strategies of Lean methods and training were applied for a period of six months. Finally, in the third stage, the impacts of the implementation were observed, evaluated and reported.

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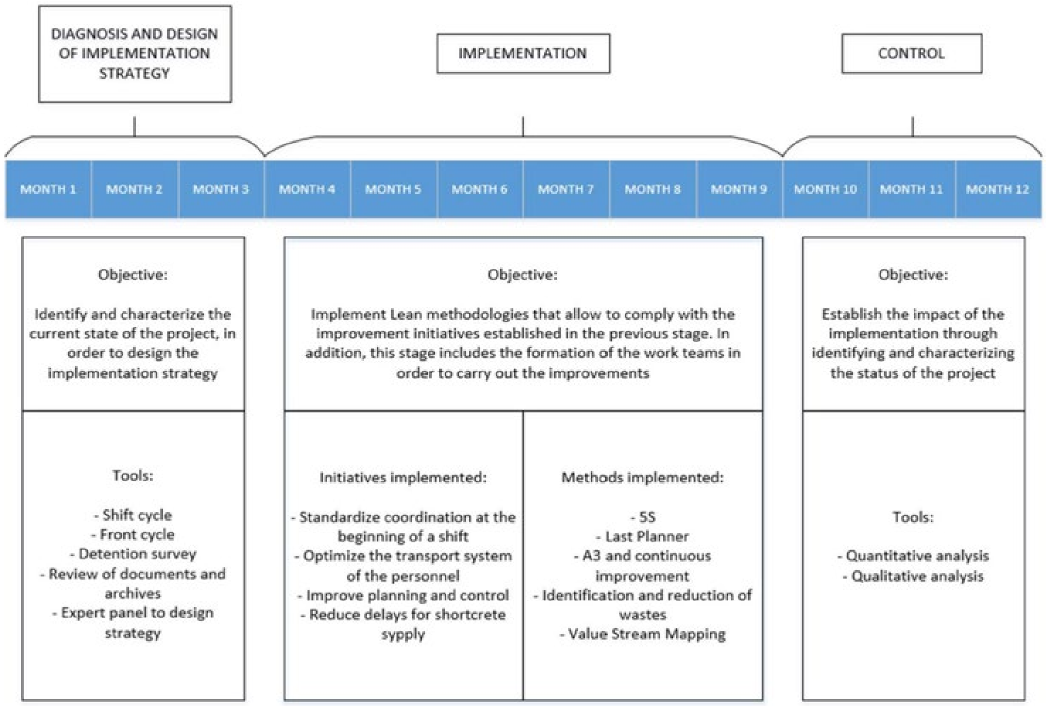

Figure 1. *Research and implementation plan*

An advisory board of international researchers, senior consultants of two international Lean consulting companies and executives of the mining company was assembled. Based on diagnostic results, key performance indicators (KPI's) with baseline measurements, benchmarking related to similar experiences in mining, meetings and interviews with key stakeholders, and experience in implementing Lean initiatives, the board developed an implementation strategy identifying three major focuses of attention:

1. ***Increase the time available at the front***: *It was found that workers were delayed from working at the beginning of their shift by an inordinate amount of pre-work meetings. Standardization of work during these meetings reduced the time devoted to them without negative impact and increased the time workers were available at the front.*
2. ***Delays reduction***: *Eliminating identified delays due to disruptions in the development of work at the front. These were recorded through delay surveys.*
3. ***Work dynamics and continuous improvement***: *An implementation team was assembled for each of the four initiatives (Figure 1). These teams were made up of members from the owner, contractor and consultant; and they were trained on Lean Management principles and performed their work using A3, a Lean methodology based on a continuous improvement cycle or Plan-Do-Check-Act (PDCA). Visual management was also encouraged and used throughout the implementation.*

To implement this strategy, four initiatives were carried out (Figure 1):

- ***Initiative 1: Standardize coordination at the beginning of a shift***:
  The objective of this initiative was to standardize the coordination at the beginning of a shift. Specifically, crew's handovers meetings and security talks were structured to reduce their average length and variability.
- ***Initiative 2: Optimize the transport system for personnel***.
  The objective of this initiative was to improve the transport system for personnel, by defining the stops for minibuses, clearly defining destinations, and arrival and departure times, to help reduce waiting times for transportation.
- ***Initiative 3: Improve planning and control***.
  The objective of this initiative was to improve planning and control, by providing the crew with structured planning and shift transfer meetings. For achieving this, the Last Planner System was implemented. Based on the "Diagnosis" stage, this initiative was designed to address the top three reasons for delays, "Waiting for availability of front", "Waiting for information" and "Waiting for equipment availability" (Table 6).

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- ***Initiative 4: Reduce delays for shotcrete supply.***
  The objective of this initiative was to reduce the delays related with shotcrete supply. According to the "Diagnosis" stage, "waiting for materials" was the fourth most important delay. Specifically, shotcrete was the material that crews were waiting longer to get (Table 6).

2.2 Selection of Indicators

The indicators analyzed were selected based on the existing literature, expert opinion, and recording capabilities. It was also important that the indicators be trackable during the diagnosis and control stages and that they directly related to measurements of productivity. The quantitative data was obtained from field samples and reports from the contractor, as illustrated in (Table 1).

In the case of the indicators "workable time", "daily physical progress" and "program completion", they were chosen because they are recognized as being directly related to project performance (Cámara Chilena de la Construcción, 2015); (Castillo et al., 2015); (Green, 2013); (Leal, 2010). In the case of the Last Planner System, "PPC" was chosen because to measure plan reliability (Ballard, 2000). This research also aims to demonstrate that there is a correlation between the "percent plan complete" (PPC) and its CV, as found in the literature for industrial and multistory building construction projects (Alarcón et al., 2008); (Bernardes and Formoso, 2002).

Table 1. *Indicators studied*

Hypothesis	Indicator	Definition	Operational measurement
1. Mean improvement of indicators **2. Variability reduction of indicators**	Workable time	Time of the day that the worker is in front and that could potentially be used in productive work	Time the worker is on the front, considering a 12-hour day
	Daily physical progress	Number of advanced linear meters daily	Number of advanced meters per day
		Number of daily blasts	Number of daily blasts
	Program completion	Relationship between the executed and the programmed	Monthly percentage of program compliance
3. Correlation between PPC from LPS and its Coefficient of Variation	PPC	Relationship between activities completed and planned	Daily PPC: Activities Completed / Planned Activities
4. Reduction of delays	Delay	Time workers lose when they are prevented from doing their work	Man-hours lost to detention/delays (MH)
5. Organizational improvement	Teamwork Leadership Communication Commitment Relationship owner-contractor Motivation		Results of the surveys of the construction company

The reduction of delays was measured by using delay surveys. This is a tool to identify the sources of delays that occur during the workday of a work crew. The reason why the work was stopped is recorded, the time of detention, the number of persons affected, in order to calculate the effect of detention on working time, and then take action to eliminate or mitigate these detentions (Alarcón, 1997). In the case of the organizational attributes selected, they were chosen based on literature review (Castillo et al., 2015); (Leal, 2010).

2.3 Quantitative Analysis

Two types of method for quantitative analysis were used: statistical significance and statistical correlation. In this case, statistical analysis is related to the hypothesis test; the process of hypothesis testing attempts to corroborate whether an assertion about some population property can be sustained in the light of the available sample information (Pardo and San Martín, 1998) and then compares the null hypothesis and the alternative hypothesis (Molina and Rodrigo, 2014).

For this particular investigation, parametric statistical significance tests were used. Within the parametric tests, the following are used: (1) test T for equality of means, to determine if two samples have equal mean, and (2) Levene's test to assess the equality of variances for a variable calculation of two or more groups. The parameters to determine the sample size required are shown in (Table 2).

Table 2. *Determination of simple size for correlation test*

Parameter	Value
r	-0.6
Confidence level	0.95
Statistical power	0.8
Losses	0%
Sample size required (unilateral sig.)	16

Statistical correlation is defined as the degree of association, similarity, or joint variation between two or more variables of a population. In this research, the statistical correlation used was linear correlation, enabling a study of the relationship between two quantitative variables. In particular, Pearson's correlation coefficient was used to quantify the degree of correlation between the variables. The absolute value of the Pearson correlation coefficient indicates the strength of the correlation, while the sign indicates the direction of the correlation.

2.4 Qualitative Analysis

The parameters of the qualitative analysis are shown in (Table 3).

Table 3. *Determination of sample size for qualitative analysis*

Parameter	Value
Population size (N)	20
Expected proportion (p)	0.5
Confidence (Z)	95%
Estimation error (e)	1%
Sample size required (n)	17
Real simple size to use	20

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A survey was given to the four improvement teams that were assembled to evaluate the impact of the implementation of Lean methodologies on the performance of the organization. Some questions related with the overall perception of project performance and key organizational attributes, for example teamwork, leadership and commitment, were based on a Likert scale to collect the perceptions about the impact of the implementation of Lean methodologies in key aspects of the organization. Others were open questions to collect opinions on the main barriers and difficulties of implementation and to provide feedback for future implementations.

3. Implementation Results

3.1 Project Performance

Each indicator in the "Diagnosis" and "Control" stages was characterized by mean, standard deviation, CV, and sample size. (Table 4) summarizes the statistics of the indicators.

Table 4. *Implementation results*

	Descriptive statistics	Workable time	Daily physical progress (meters)	Daily physical progress (blasts)	Program completion
Diagnosis	Mean	5.75 hours	12.7 meters	4.8 blasts	60.9%
	Standard deviation	1.43 hours	6.32 meters	1.84 blasts	4.9%
	CV	25%	50%	38%	8.1%
	Sample size	98	92	90	3
Control	Mean	6.67 hours	20.5 meters	6.7 blasts	81.4%
	Standard deviation	0.98 hours	5.49 meters	1.76 blasts	7.9%
	CV	15%	27%	26%	9.7%
	Sample size	41	88	88	3
Percent variation of mean (diagnosis vs. control)	Mean	+16%	+61%	+40%	+34%
	Standard deviation	-31%	-13%	-4%	+61%
	CV	-40%	-46%	-32%	+30%

The histograms and box plot graphs of each indicator during both the "Diagnosis" and "Control" phases are displayed in (Figure 2).

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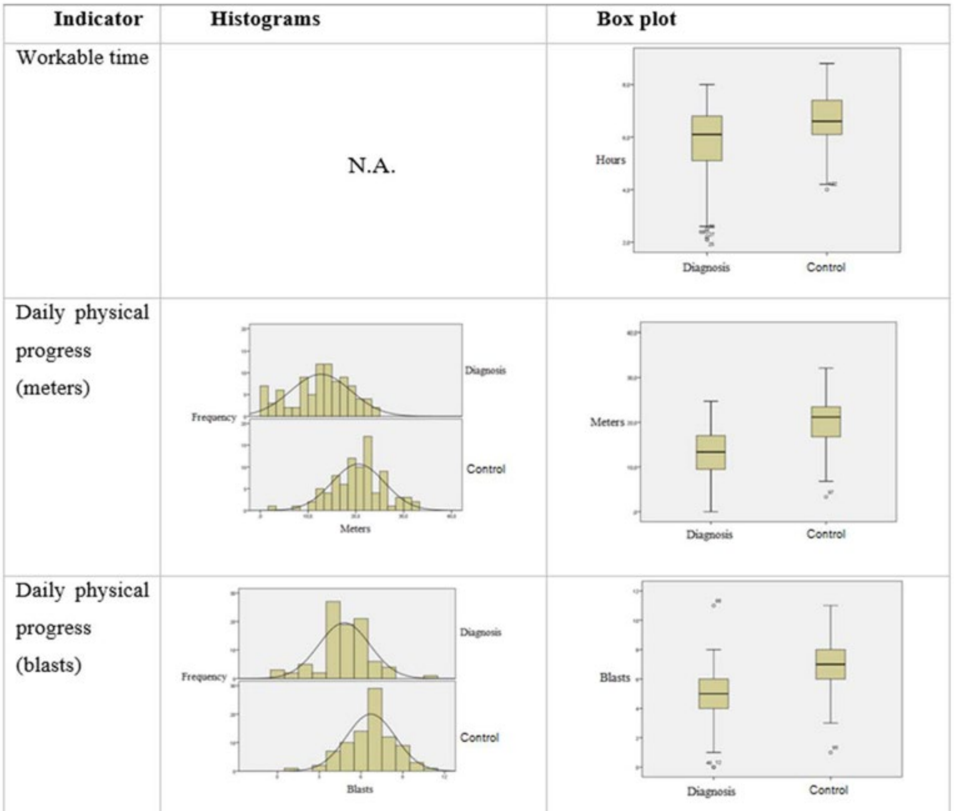

Figure 2. *Implementation results*

(Table 5) summarizes the inferential statistical tests performed. "Yes" indicates a statistically significant difference in the value of the indicator when comparing the "Diagnosis" and "Control". "No" indicates that there is no such statistical significance, and "N.A." means that it was not possible to perform the tests due to small sample sizes.

Table 5. *Statistical results*

	Workable time	Daily physical progress (meters)	Daily physical progress (blasts)	Program completion
Equality of means test	Yes	Yes	Yes	N.A.
Equality of variance test	Yes	No (0.172)	No (0.909)	N.A.

Considering a level of significance of 0.05, there is an improvement of the mean across all indicators and an improvement of variance in the indicator of "workable time." Most indicators also showed a reduction in their CV, demonstrating that the indicators, and by extension the underlying processes, became more stable.

Delays

Diagnosis

During the "Diagnosis" stage, 100 shift cycles (1,710 total man-hours sampled) were measured with 129 delays identified and registered on the detention survey. The recorded delays due to waiting were categorized into groups associated with related causes. The details of these are presented in (Table 6) and in (Figure 3).

Table 6. *Delays in diagnosis stage*

Delay	MH lost	Percentage
Waiting for availability of the front	150.42	33%
Waiting for information	90.5	20%
Waiting for materials	69,43	15%
Waiting for equipment availability	38.92	9%
Waiting for services	30.83	7%
Waiting for equipment failure	28.17	6%
Waiting for inspection	27.5	6%
Waiting for ventilation	9.67	2%
Wait post blast	3.5	1%
Rework	3.25	1%
Grand total	452.18	100%

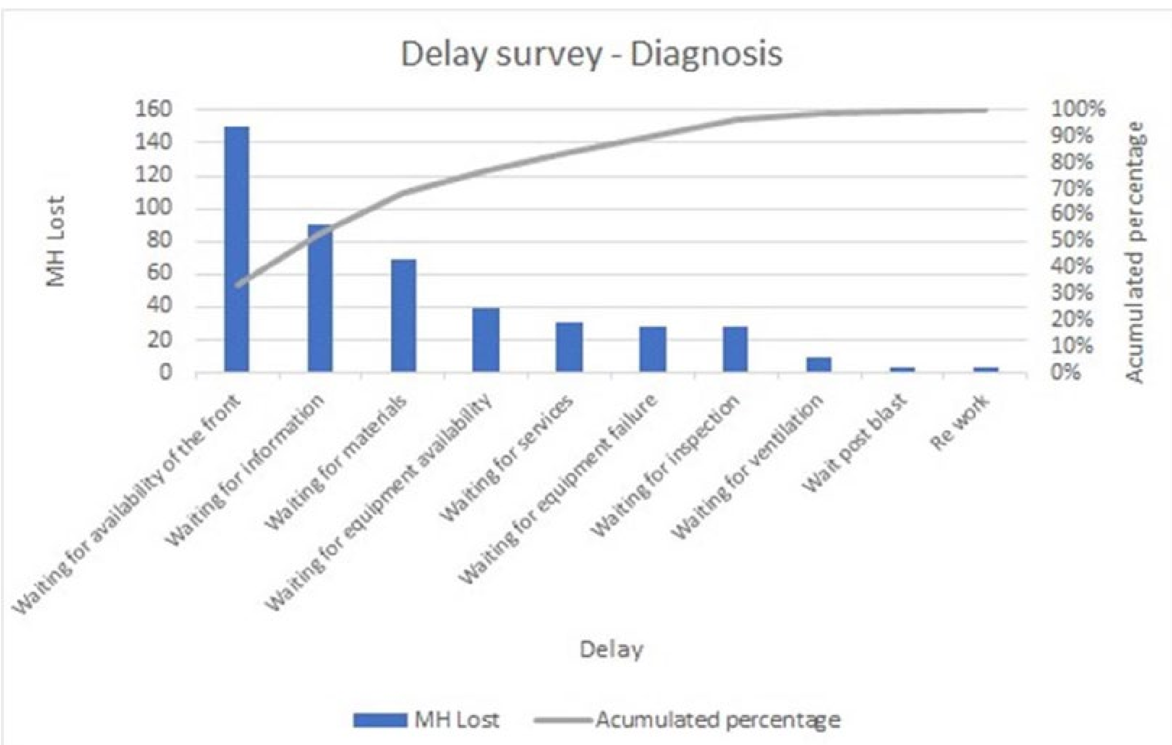

Figure 3. *Pareto delay survey "Diagnosis" stage*

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Based on these results, the delays recorded represent 26.44% of the available time at the front. Introducing the Last Planner® System addressed delays related to "Waiting for availability of the front" (workers waiting for work), "Waiting for information" and "Waiting for availability of Equipment." Initiative 4 (Figure 3) addressed the delays due to "Waiting for materials" by instituting remedial actions related to shotcrete. (Table 7) shows the details of the delays grouped by category.

***Table 7.** Delays grouped by category in diagnosis stage*

Delay	HH lost	% of total
Waiting due to poor planning: Waiting for availability of face + Waiting for information + Waiting for equipment availability	279.84	61.88%
Waiting for materials	69.43	15.36%
Total	349.27	77.24%

Control

During the control stage, 46 shift cycles were recorded (1,048 total man hours sampled), out of a total of 54 observations on the detention survey. The recorded delays have been categorized into groups associated with related causes. The details of these are presented in (Table 8) and in (Figure 4).

Table 8. *Delays in Control stage*

Delays	MH lost	Percentage
Waiting for availability of the front	62.83	31%
Waiting for equipment availability	29	14%
Waiting for equipment failure	25.92	13%
Waiting for materials	20.92	10%
Waiting for information	19.67	10%
Waiting for inspection	12.42	6%
Re work	11.67	6%
Waiting for ventilation	9.33	5%
Wait post blast	5.08	3%
Waiting for services	5	2%
Grand total	201.83	100%

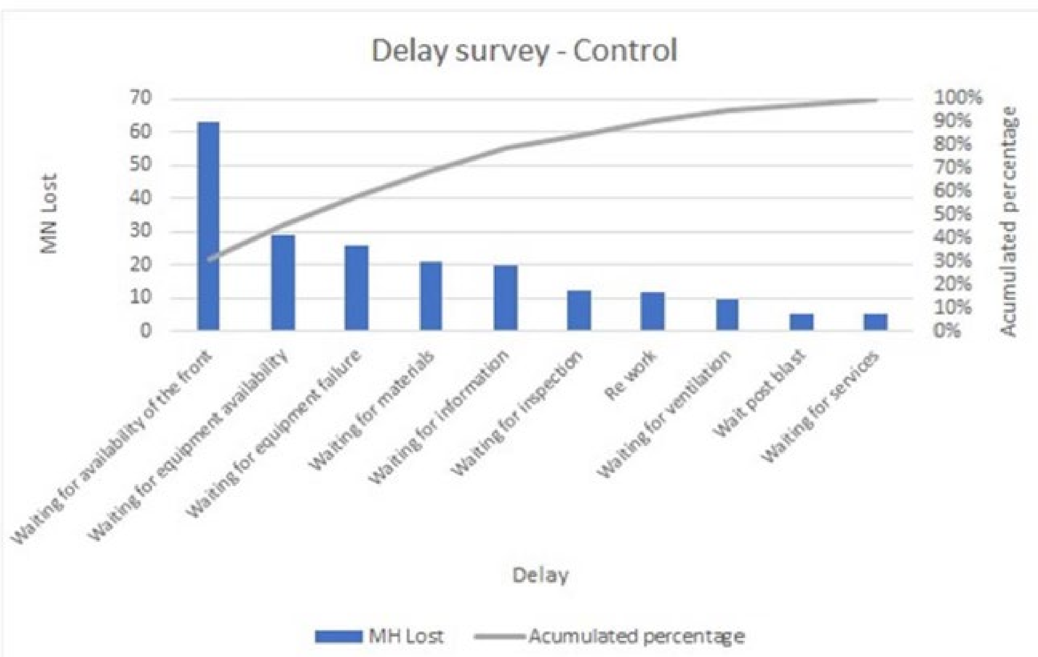

Figure 4. *Pareto delay survey "Control" stage*

The percentage of delays recorded represented 19.26% of the time available at the front. (Table 9) shows the delays grouped by nature, according to the initiatives defined in the implementation plan.

Table 9. Delays grouped by category in control stage

Delay	MH lost	% of total
Waiting due to poor planning: Waiting for availability of front + Waiting for information + Waiting for equipment availability	111.5	55.24%
Waiting for materials	20.92	10.37%
Total	132.42	65.61%

Comparison of "Diagnosis" and "Control" stages

Comparing the first two stages, "Diagnosis" and "Control" shows an improvement in recorded delay due to "Waiting for materials" and a change in ranking from the third to the fourth-greatest reason for delay (Figure 3) and (Figure 4). This is consistent with the objective of "Initiative 4: Reduce waits for shotcrete supply" which sought to reduce times in the delivery of shotcrete, the main factor in waiting for materials. Measured improvements in the delays addressed by "Initiative 3: Improve planning and coordination" can also be seen. A comparison of the detention survey for each of the stages is shown in (Table 10). The data shows that loss of time available at the front dropped from 26% during the diagnostic stage to 19% during the implementation stage. In the same table, the percentage representing each of the waiting periods in relation to the total losses recorded is shown in parentheses. The percentage variation is -26.91%, meaning that, the losses recorded in that stage were reduced.

Table 10. *Comparison of delays group by category in each stage "Diagnosis" and " Control"*

	Diagnosis	Control
Total MH lost	452.18 (100%)	201.83 (100%)
Waiting due to poor planning	279.84 (61.88%)	111.5 (55.24%)
Waiting for materials	69.43 (15.36%)	20.92 (10.37%)
MH sampled	1,710	1,048
% Delays	26%	19%
Variation	-26.91%	

3.2 Statistical Correlation Between PPC and its Coefficient of Variation

The activities tracked correspond to the activities that make up the drill and blast cycle, i.e., surveying, drilling, charging explosives, blasting, loading, hauling, scaling, and reinforcing (bolting & shotcrete). The PPC was calculated daily and an average PPC was calculated weekly. The evolution of the average of the weekly PPC and its CV is shown in (Figure 5). For this analysis, 21 weeks of PPC measurements were considered.

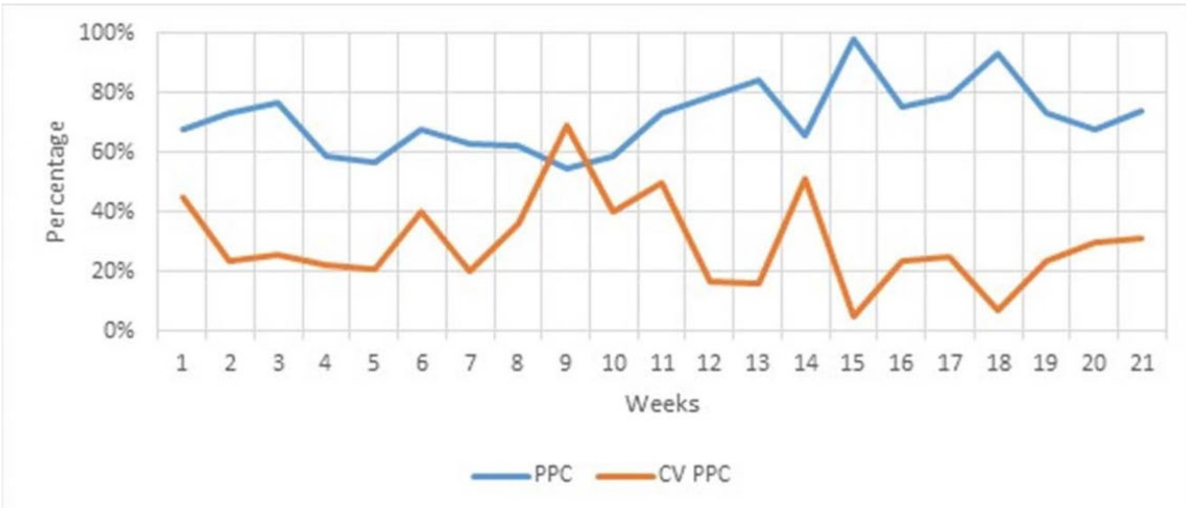

Figure 5. *Evolution of PPC and its Coefficient of Variation*

The correlational analysis of the PPC and the CV is shown in (Figure 6) and in (Table 11). This analysis indicated a statistically significant relationship between these two variables, with a coefficient of determination (R^2) of 0.4097. The Pearson coefficient is -0.629, with a significance level of 0.01. Considering a level of significance of 0.05, it can be stated that this relationship is statistically significant.

Table 11. *Correlational analysis of PPC and its coefficient of variability*

Correlation	
Pearson´s correlation	-0,629
Sig. (1-tailed)	0.001
N	21

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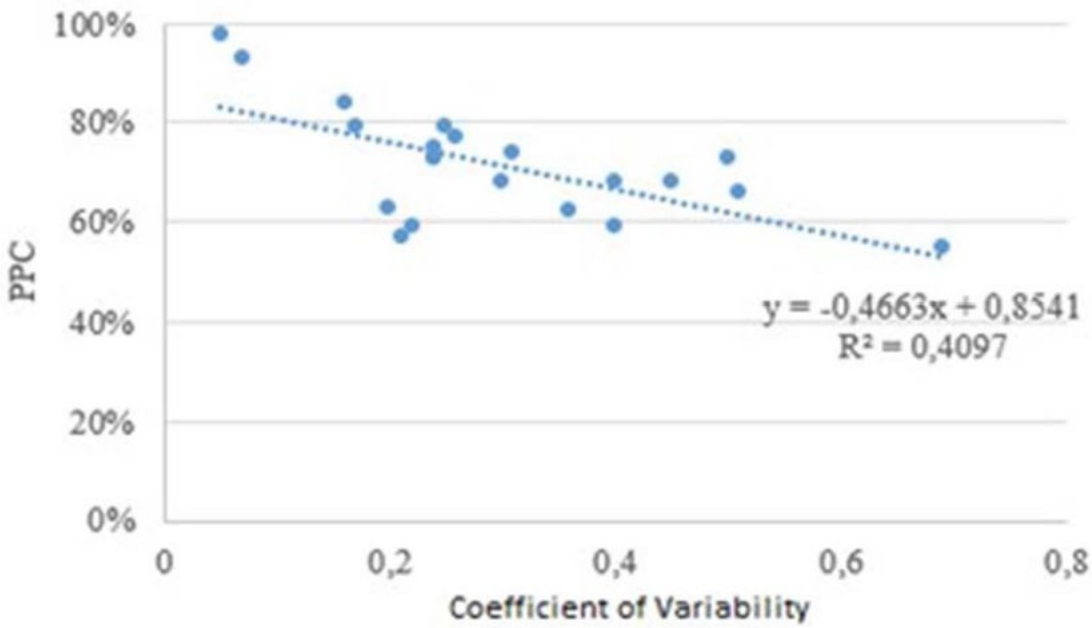

Figure 6. *Correlational analysis of PPC and its Coefficient of Variation*

3.3 Organizational Results

A survey was carried out to measure the impact of Lean implementation on six key organizational attributes: teamwork, leadership, communication, commitment, contractor-client relationship and motivation. This survey was given during the "Control" stage to participants belonging to the contractor and owner companies who were directly involved in the defined initiatives. The objective was to measure the level of consensus regarding the improvement of certain key organizational attributes. This survey was structured in two sections: one conformed by questions evaluated in a Likert scale and another by open questions. The questions evaluated using a Likert scale enabled to collect the perceptions of teams regarding the impact of the implementation on key organizational attributes. The open questions allowed the researchers to collect opinions on the main barriers and difficulties when implementing Lean methods in the project.

The results of the survey are presented in (Figure 7). For the attributes teamwork, leadership, commitment, mandate-contractor relationship and motivation, over 75% of the respondents said that they "Totally Agree" or "Agree" with the existence of a positive impact on the measured attributes. Communication did not show as strong results, with 68% indicating that they "Agree" with the existence of a positive impact.

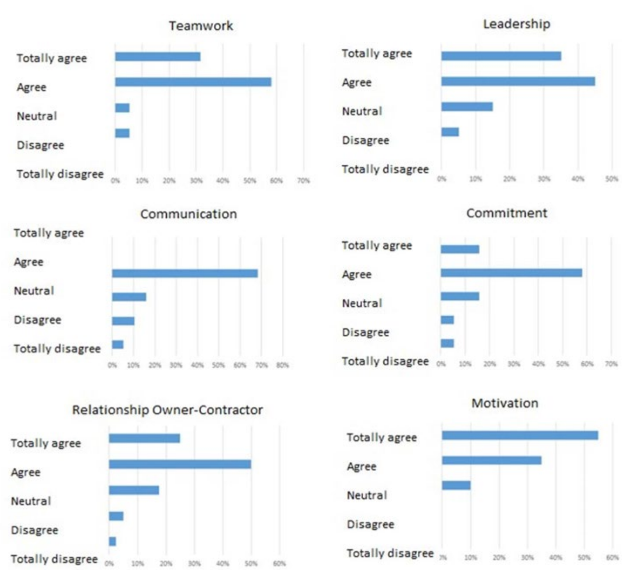

Figure 7. *Organizational impacts*

4. Recommendations for practitioners

Based on learning from this implementation experience, recommendations are made for future implementation of lean methodologies in mining projects, especially underground development projects:

- *For the development of "Initiative 3: Improving planning and coordination" and the implementation of the Last Planner System, visual management associated with indicators that are relevant to the work teams and that allow decisions to be made about the work to be done daily was fundamental. For instance, the possibility to see the plan, the status of equipment, the causes of non-compliance and their root causes were essential. Also, the use of painted maps for planning and assignment of the work fronts for the crews was valued. These maps allowed the identification of the active work fronts those in which the conditions to work are effectively found, both in services and in seismicity. In addition, the identification and release of constraints was key to improving the planning and control system. These are important visual management tools for the management of shifts assignments and handovers.*
- *In this case, structural aspects of the shift were intervened, such as transfers and talks at the beginning of the shift, together with the elimination of losses within or between the activities of the mining cycle, such as waiting for information or materials. However, due to the lack of a formal contractual agreement between the client and the contractor to enhance productivity, it was not possible to apply methodologies in the operation of the mining cycle activities. However, for future implementations and based on the literature, there is potential to apply certain methodologies such as 5S, VSM, SMED, Standardization, to increase the productivity of the work.*
- *Sorting and standardizing the shotcrete request form allowed to clearly know the concrete requirements, the time when this material was requested and required, which increased the probability of timely arrival of this material at the work front.*
- *Standardizing the parking for minibuses, leaving clearly defined destinations and arrival and departure times, helped to reduce waiting times for transportation.*
- *Creating a format of tasks to be carried out by the team (where the order of the fronts on which the team must work on that day is indicated to the team) reduced the time lost due to lack of information regarding the front in which the team must go to work.*
- *Develop and disseminate a communication plan (materialized through posters, talks and leaflets) on the tools that were implemented, the fundamental concepts that support them and the benefits that can be obtained by using them, is key to promoting the involvement and participation of key stakeholders.*
- *Transferring knowledge and skills through training prior to implementation and conducted in a cross-cutting manner (strategic, tactical and operational level) allows for: (1) generating a common vocabulary and vision among those involved, which helps to maintain the focus of implementation; (2) understanding the purpose of implementation, in order to disseminate and promote its application; and (3) visualizing that lean transformation is not a form of tax work, but rather a participatory one.*
- *To develop people to lead continuous improvement initiatives, in order to strengthen their execution and to carry out the analysis of the effectiveness of the implemented initiatives. It is necessary that these people are properly prepared to carry out these initiatives, so it is essential to develop people. Thus, as a recommendation, the profile that companies could develop internally is a leader and agent of change. These people can contribute by generating improvement initiatives or serve as facilitators for external consultants or implementers.*

5. Conclusions

The research demonstrates that the implementation of Lean methodologies such as the Last Planner System in mining development projects in the execution phase improves the mean of indicators associated with progress, program compliance and performance to a statistically significant degree. This is true for every indicator measured and subjected to statistical analysis during the course of the research.

In addition, some of the indicators studied also exhibited reduced variability as a result of the use of Lean methods. Although this was not demonstrated for all the indicators studied, the majority of them showed a considerable reduction in the CV, indicating increases in the stability and reliability of management processes. With regard to the delays identified during the research, Lean methods served to measurably increase the amount of time in which productive work could be carried out. This allowed the contractor to increase the available time to accomplish the work at hand.

Additionally, this research showed that the indicators associated with the implementation of The Last Planner® System in mining development projects behave similarly to other type of construction projects, such as industrial and multistory building. In particular, the relationship between planning reliability (PPC) and its CV has a statistical significance *of 0.1%. Accordingly, observations in the existing literature regarding multistory building construction can be extended to mining projects, nevertheless, it is important to notice that this this result is limited by its small sample. The small sample size is due to the amount of time that results were monitored (21 weeks). Therefore, this could be considered a preliminary result that needs more data-rich analysis to be broadly proven.*

This investigation also indicates that the implementation of Lean methods in the execution phase of mining development projects reduces the amount of time wasted in delays. Specifically, in this case study, it was shown that there was a 26% reduction in the amount of time crews were prevented to perform their work due to delays.

The implementation of Lean methods produced an improvement in key organizational attributes consistent with what is found in the literature, and thus the authors conclude that this type of implementation, in which teamwork, leadership, commitment and motivation were fostered, strengthened, and required, has an overall positive impact on the organization and its people. In addition, other attributes such as the owner-contractor relationship and quality of communication were evaluated positively.

However, there are limitations to the research and findings. Continued focus and work is called for to observe whether, and for how long, the results will be sustained after the initial implementation. Additionally, the use of a small sample size limited measurement of the correlation between the PPC and its CV. Although the research was statically valid, the use of greater sample data could strengthen the results. Future studies and research could also focus on extending and enhancing the analysis in this research through the addition of other indicators, such as those measuring for safety.

6. Data Availability Statement Conclusions

Data generated or analyzed during the study are available from the corresponding author by request.

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