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USING PERCENT PLAN COMPLETED FOR EARLY SUCCESS ASSESSMENT IN THE LAST PLANNER SYSTEM®

Camilo Lagos[1] and Luis Fernando Alarcón[2]

ABSTRACT

The Last Planner System (LPS) constitutes a systematic method for planning and control based on the generation of short-term commitments by the workforce and the weekly control of their accomplishments in search of continual improvement. This approach allows for the stabilization of workflow and uncertainty reduction in short-term plans, which are assessed using the Plan Percent Complete (PPC) indicator and the systematical collection of Reasons for Non-Compliance (RNC). Our research goal is to contribute to the understanding of how PPC and RNC metrics can be used for early assessment of project performance concerning schedule accomplishment. We used a sample of 25 Chilean projects with weekly information regarding progress, PPC, RNC and time deviation, that was categorized into two groups according to their schedule accomplishment results, using a clustering algorithm. We compared the PPC and RNC indicators from the two groups across project execution to detect significant differences. We found that successful projects evidence a statistically significant increase in the PPC, compared to the less-than successful group, lower PPC variability and a lower number of RNC per week, since early project execution. The results allowed us to conclude that these metrics can help perform early assessments of project performance.

KEYWORDS

Lean Construction, Last Planner System®, Percent Plan Complete (PPC), commitment management, variability.

INTRODUCTION

Traditional Construction Project Management (TCPM) has been characterized as result-oriented; therefore, many authors have criticized its ability to efficiently manage variability and uncertainty in complex construction projects (Ballard and Tommelein 2016; Sarhan and Fox 2012). It uses highly detailed programs with preset buffers to cope with uncertainty and controls them using highly aggregated result-oriented indicators based on financial and overall progress metrics (Koskela et al. 2002). This lack of process-oriented metrics can lead to poor management due to lagging decisions and ineffectively placed corrective actions (Sarhan and Fox 2012).

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The Last Planner System (LPS) proposes a systematic approach to planning and control with the use of process-oriented methods to prepare, execute and control work managed by commitments rather than highly fixed programs (Ballard and Tommelein 2016). The Percent Plan Completed (PPC) and collection of Reasons for Non-Compliances (RNCs) are its most used metrics (Daniel, Pasquire, and Dickens 2015; Salvatierra et al. 2015). PPC measures the production planning reliability in short-term plans as the number of commitments successfully accomplished over the total number of commitments made for a specific period (Sarhan and Fox 2012).

Research shows that the PPC shows a statistically significant increase when LPS is thoroughly implemented and that projects with higher, more stable PPC are more likely to have higher success rates in terms of schedule accomplishment (Alarcón, Salvatierra, and Letelier 2014; Ballard and Tommelein 2016; Lagos, Herrera, and Alarcón 2019). Researchers have found positive correlations between the PPC of specific time periods and their productivity, costs and schedule accomplishment indexes at the project level (González, Alarcón, and Mundaca 2008; S. C. Kim et al. 2015; Leal and Alarcón 2010; Liu, Ballard, and Ibbs 2011), but they have not been able to determine strong correlations between the average PPC of a project and its final schedule or budget accomplishment, partly due to the influence of external factors affecting project performance and partly because of the lack of sufficient standardized project samples (Formoso and Moura 2009; S. C. Kim et al. 2015). Although, we can infer that using standardized data from projects using the same LPS support system, we can identify statistically significant differences between projects grouped by categorical outcomes of schedule performance.

The aim of this paper is to understand how the assessment of the PPC average, PPC deviation and RNCs across project execution can help to evaluate the project expected schedule accomplishment. To do so, two hypotheses were tested: (1) PPC is significantly higher in successful projects across project execution, and (2) successful projects have a significantly lower number of RNCs per short-term period. These hypotheses were tested by conducting statistical analyses of differences between PPC and RNC indicators accumulated at the project end and for standardized progress intervals through project execution. The data sample was obtained from the historical database of the software IMPERA, which was developed by the Pontifical Catholic University of Chile to allow a systematic and standardized implementation of LPS (Alarcón and Calderón 2003; Lagos, Herrera, and Alarcón 2019).

LITERATURE REVIEW

LIMITATIONS OF TRADITIONAL CONSTRUCTION PROJECT MANAGEMENT

The traditional view of production in construction, often referred to as transformation theory, states that value is only added through the conversion of supplies and labor into project scope outputs (Koskela et al. 2002). Accordingly, the scope can be divided into several increasingly detailed transformations coordinated according to resource constraints and project goals to obtain a schedule that reflects the production rates needed to complete the project under a determined time frame and budget (Koskela 1999). Since value is achieved by completing transformations, management focus is placed on executing them as efficiently as possible; in other words, completing the scope fast and with as little resource consumption as possible (Howell and Koskela 2000). Detailed schedules represent the best possible sequence of transformation tasks, and their expected resource consumption allows the creation of planned value (PV) and earned value (EV) curves, also known as S-curves, which represent project execution goals and their rate of accomplishment (Ponz-Tienda et al. 2015).

Traditional Construction Project Management (TCPM), based on the transformation view, follows the assumption that schedules should be fixed as long as the production rates are met and there are no deviations from the schedule or the planned value. Since both requirements are result oriented, most control metrics or Key Performance Indicators (KPI) used in TCPM measure the degree of accomplishment and deviation from the PV (Power and Taylor 2019). Therefore, TCPM uses KPI such as the percentage of the total planned value achieved by the actual earned value to assess overall progress or the percentage of the expected planned value represented by the actual earned value to assess schedule accomplishment (Abdel Azeem, Hosny, and Ibrahim 2014). The Earned Value Method (EVM) is a control system often used in the TCPM. It follows budget and schedule accomplishment by measuring rates of accomplishment and deviation from Planned Value (PV) and Planned Schedule (PS), which are obtained from the project baseline program and then compared to Earned Value (EV), Earned Schedule (ES) and Actual Cost (AC) (Lipke et al. 2009). Table 1 presents the main indicators used in EVM.

Table 1: EVM indicators (Lipke et al. 2009; Azeem et al. 2014)

Indicator	Full name	Formula	Description
SPI	Schedule Performance Index	EV / PV	Earned Value over Planned Value, measured in percent terms
CPI	Cost Performance Index	EV / AC	Earned Value over Actual Cost, measured in percent terms
SV	Schedule Variance	EV - PV	Difference between Earned Value and Planned Value, by cost or progress
CV	Cost Variance	EV - AC	Difference between Earned Value and Actual Cost, measured in cost terms
TV	Time Variance	ES - Actual date	Difference, in days, between the Earned Schedule and actual date of control
SD	Schedule Deviation	(ES - Actual date) / ES	Difference between Earned Schedule and Actual Date, over Earned Schedule
CD	Cost Deviation	(EV - AC) / EV	Difference between Earned Value and Actual Cost, over Earned Value

The exclusive use of EVM in project management presents three limitations. First, result-oriented KPIs can conceal variations in project schedule since the value earned by all the project activities is aggregated into a single indicator, thus averaging the variance from the different activities (Alarcón, Salvatierra, and Letelier 2014). Second, these KPIs are referred to as lagging indicators since they need significant deviations from the project schedule or planned value to alert the need for a corrective action (Sarhan and Fox 2012). Third, estimations of expected duration and budget that use aggregated indicators such as the SPI and CPI are less precise at early stages of project execution (Lipke et al. 2009), and their confidence intervals can be significant if not corrected with less aggregated data (Abdel Azeem, Hosny, and Ibrahim 2014; Lipke et al. 2009). Therefore, authors have recommended that they be complemented with process-oriented indicators such as the compliance and variability indicators used in LPS (Alarcón, Salvatierra, and Letelier 2014; Sarhan and Fox 2012).

THE LAST PLANNER SYSTEM ®

The LPS (Ballard and Tommelein 2016) is based on the systematic task of increasing the level of detail of the plan as the execution time approaches, preparing it by the generation of a 4- to 12-week Lookahead Plan, which allows the detection of work impediments, called constraints, and then preparing plans to prevent or remove them before planned activities enter the short-term period, usually in a range of 1-2 weeks. Constraint-free tasks enter a Workable Backlog of Tasks, used by the workforce to establish progress commitments for each workable activity. These factors compose the short-term plan in which the PPC is measured at the end of the week to assess how well promises are being made and the compliance with the committed plan. The project then analyses each task that did not fulfill its commitment and registers a Reason for Non-Compliance (RNC). PPC and RNC evolution is monitored weekly to assess variability, compliance and recurrent problems (Ballard and Tommelein 2016). In addition, constraint management and work preparation are also controlled using quantitative metrics such as Percent Constraints Removed (PCR) and Tasks Made Ready (TMR) (Jang and Kim 2007; Y. W. Kim 2019). Other complementary indicators have been proposed to further connect work preparation, short-term execution and learning from RNCs and corrective actions (Hamzeh, El Samad, and Emdanat 2019; Samad, Hamzeh, and Emdanat 2017).

Although LPS has been implemented for 27 years (Daniel, Pasquire, and Dickens 2015; Ryan, Murphy, and Casey 2019), many projects exhibit partial implementations (Salvatierra et al. 2015). Most projects register weekly information regarding commitments, PPCs and RNCs, but many fail to use quantitative metrics based on the evolution of historical KPIs for decision making (Dave, Hämäläinen, and Koskela 2015; Lagos, Alarcón, and Salvatierra 2016). This can lead to a short-term management scope in which available information is not used properly to assess needs for continual improvement (Dave, Hämäläinen, and Koskela 2015). The lack of complete implementation is due partially to a lack of understanding of how to use information and partially to the time and effort needed by project managers to process data (Daniel, Pasquire, and Dickens 2015). The latter issue can benefit from the use of computer tools to support LPS, which have been continuously developed over the last decade (Lagos, Herrera, and Alarcón 2019), while the lack of understanding requires an academic and industry effort to further produce quantitative research (Daniel, Pasquire, and Dickens 2015).

RESEARCH METHODOLOGY

CASE SELECTION

We assessed 48 Chilean high-rise building projects executed between 2014 and 2019 that had used IMPERA to support LPS implementation. To capture a complete view from project execution, we selected the projects that had registered weekly LPS information from earlier than 20% real progress and until at least 99% planned progress or the completion of the project. We had to eliminate from the sample the projects that changed their baseline at late execution stages since this change would invalidate the schedule performance data. In addition, we also removed projects that did not follow a systematic LPS process, for example, by changing commitments after execution was completed or that missed several weeks of short-term planning. We obtained a sample of 25 projects, belonging to 7 Chilean companies, which had an average planned duration of 74 weeks and an average real duration of 82 weeks, with weekly information for an average of 60 weeks, representing a total of 1495 short-term periods of LPS management.

COLLECTION OF INFORMATION

Each short-term period was characterized by its baseline planned progress, the real progress achieved at the end of the week, and the resulting PPC and the number of RNCs registered. We constructed representative accumulated indicators for each project, specifically, the average PPC of each project, the standard deviation observed in the total PPCs registered in each project, their total number of RNCs and the average number of RNCs per week. We also constructed standardized evolution curves for the PPC by dividing the planned project schedules into 10% progress intervals. We then calculated the average PPC and its standard deviation for each interval and the accumulated average PPC and PPC standard deviation from the first period until the final period of each interval.

DATA CLUSTERING

In order to determine an objective classification rule according to their success, we applied a recursive algorithm based on the K-means method (Jain 2010), which has been used previously in clustering criteria for success in similar construction management research (Cheng, Wu, and Wu 2010). It established K centroids randomly located in a two-dimensional space containing the data sample and assigned each data point to its closest centroid, creating K clusters. Then, it moved each centroid to the center of each cluster and reassigned the data points until it minimized the distance from each data point to its centroid and maximized the distance between centroids. The algorithm allows to obtain project groups with similar results, thus, the criteria for classification can be obtained analyzing the differences between clusters. We used 4 clusters and obtained the classification rules as the vectors equally distant to the two clusters in the middle, as shown in figure 2.

DATA ANALYSIS

First, we tested correlations over the entire sample between the accumulated indicators and the projects' schedule accomplishment, represented by their final SPI and SD, using the Pearson correlation coefficient r and considered the existence of a highly strong correlation when the absolute value of r was greater than 0.8, strong if r equals 0.79-0.6 and moderate if r falls between 0.4-0.59 (Hernández, Fernández, and Baptista 2006). After classifying projects as successful or less-than successful, we performed statistical tests of mean differences between the PPC average, PPC standard deviation, average number of RNCs and number of RNCs per week between groups using the t-test when samples followed a normal distribution and the Mann-Whitney U test for nonparametric samples (Hernández, Fernández, and Baptista 2006). We also calculated the relative difference as the difference between the successful and less-than successful means over the less-than successful mean.

We formulated the null hypothesis H0 "there is no significant difference in the means between groups" and established a confidence level of 95%, meaning that the null hypothesis could be rejected if the p-value obtained was not greater than 0.05. To select when to use parametric or nonparametric tests, we applied a Shapiro Wilk normality test. We formulated the null hypothesis H0 "the sample follows a normal distribution" and established a confidence level of 95%, meaning that it could be rejected if the p-values were higher than 0.05. We performed the aforementioned tests over the accumulated indicators and for each progress interval to validate the assumption that the PPC and RNC metrics can be used as early assessment tools of expected project performance.

RESULTS

CORRELATION ANALYSIS

We found one strong correlation, which corresponded to the negative relation between the PPC average and SD. According to a regression of the relationship, a 1% increment in the PPC, between PPC values 50% to 100%, can explain a reduction of 0,8% in SV. We also found 6 other moderate correlations, and only one pair of variables resulted in a weak or nonexistent correlation, which was the relation between the SPI and PPC standard deviation. Figure 1 shows the strong relationship between the PPC average and SD, and Table 2 summarizes the correlation results.

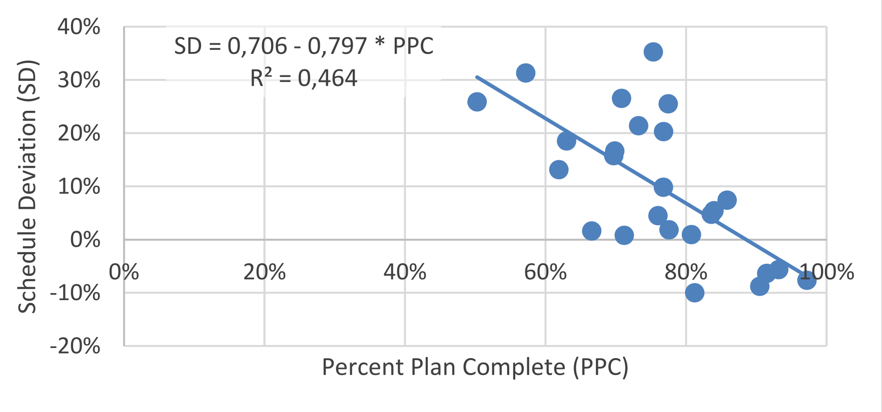

Figure 1: Correlation between PPC average and Schedule Deviation

Table 2: Results of the correlation analyses

Pearson r correlation coefficients between indicators				
	PPC Average	PPC standard deviation	Total RNCs	RNCs per week
SV	0.68*	0.50**	0.50**	0.49**
SPI	0.58**	0.24	0.55**	0.57**

* r is considered strong if ≥0.6 and **moderate if between 0.59-0.4

SUCCESS CRITERIA OBTAINED FROM CLUSTERING

After applying a K-means clustering algorithm to the SPI and SD, we found that only one data point (SPI = 92,5% and SD = 9,8%) significantly changed clusters between iterations, so the clusters were found to be representative. The results allowed to characterize highly successful projects as having a SPI higher than 99% and an SD lower than -2% and the least successful projects as having a SPI≤88% and SD≥23%. The middle groups were separated by an SD value of 8%, as shown in Figure 2. Therefore, we stated the following categorical classification rule: Successful projects, as considered in our analysis, have a SD < 8% and SPI ≥ 94%, and we obtained 13 successful and 12 less-than successful projects.

DIFFERENCES IN ACCUMULATED INDICATORS BETWEEN SUCCESS GROUPS

We found, as expected, that successful projects exhibited a higher PPC average and lower standard deviation. The average PPC of successful projects had a relative positive difference of 21% compared to the less-than successful group, while the PPC standard deviation from successful projects was 27% lower.

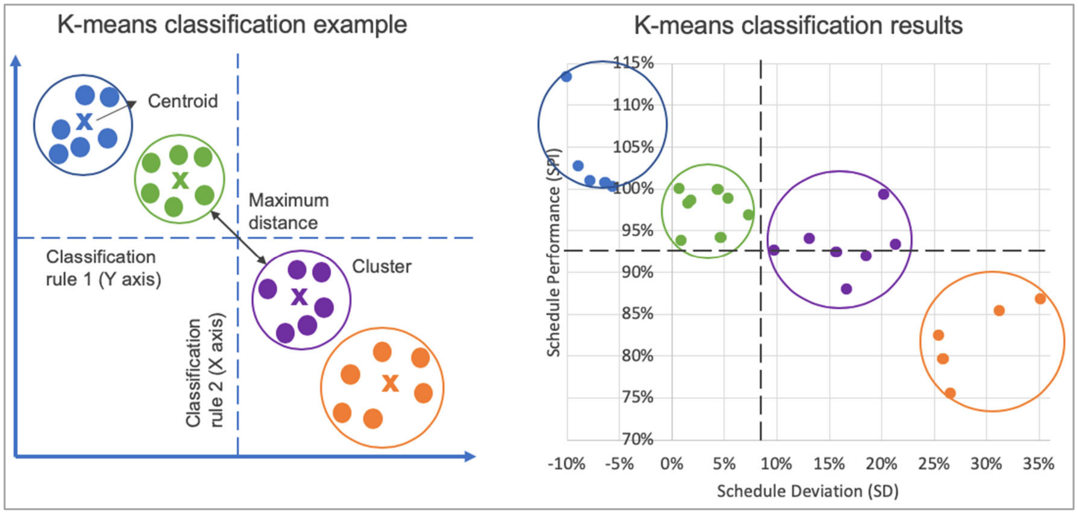

Figure 2: Sample clusters for successful and less-than successful groups

Additionally, it was observed that the success group had 55% fewer RNCs and 47% fewer RNCs per week. It must be noted that, even though a greater PPC implies less RNCs, RNCs are also dependent of the number of tasks committed in the short-term plan, so their decrease in number is found to be relevant. All differences between groups were significant at a 95% confidence level. Table 3 summarizes the results of the accumulated indicators.

Table 3: Comparison of accumulated indicators

Data	Successful projects	Less-than successful projects	Relative difference	P-value
Average PPC	83,0%	68,5%	21,1%	0,000
PPC Standard Deviation	10,9%	14,9%	-26,6%	0,048
Total number of RNCs	478	1056	-54,7%	0,023
RNCs per week	8,7	16,3	-46,9%	0,048

EVOLUTION OF THE PPC AVERAGE AND STANDARD DEVIATION

The upper section of table 4 represents the PPC evolution for each group in ten standardized project progress intervals, each of them representing the periods corresponding to a 10% increase in baseline planned progress. In addition, the lower section of the table represents the PPC evolution considering all short-term periods from start until the upper limit of each interval. It must be noted that not all projects had the same duration and not all intervals were composed of the same number of periods; therefore, accumulated indicators cannot be obtained by a simple average of the partial indicators. Progress intervals marked as 0-X% represent accumulated indicators.

After applying the Shapiro Wilk test, we found that all accumulated indicators followed a normal distribution and thus could be tested for mean differences using the t-test. Regarding the partial indicators, we detected several intervals in which we could not ensure normality and therefore used Mann-Whitney's U test for those specific points. In both cases, we rejected the null hypothesis and stayed with h1 "There is a significant difference between group means" when the p-value ≤ 0.05. All differences were significant except for the partial PPC standard deviation in the last two progress intervals. Table 4 shows that PPC averages tend to be 13 to 15 points higher in the successful group, while standard deviation is 6 to 9 points lower in this group. Figures 3 and 4 show the stability of the differences found between successful and less-than successful projects along the project expected progress.

Table 4: Differences in PPC evolution

PPC Average				**PPC Standard deviation**			
Progress	Failure	Success	p-value	Progress	Failure	Success	p-value
00-10%	61%	74%	0,009	00-10%	18%	9%	0,002
10-20%	66%	78%	0,042	10-20%*	16%	7%	0,000
20-30%*	65%	82%	0,011	20-30%*	13%	6%	0,001
30-40%	67%	81%	0,032	30-40%*	11%	7%	0,002
40-50%*	69%	84%	0,001	40-50%*	10%	6%	0,028
50-60%	70%	84%	0,004	50-60%	15%	6%	0,000
60-70%	69%	83%	0,005	60-70%*	10%	5%	0,073
70-80%	67%	84%	0,000	70-80%	9%	6%	0,010
80-90%*	62%	85%	0,001	80-90%*	11%	7%	0,253
90-100%	69%	84%	0,001	90-100%	12%	9%	0,355
Intervals	Failure	Success	p-value	Intervals	Failure	Success	p-value
0-10%	61%	74%	0,001	0-10%	19%	9%	0,001
0-20%	64%	77%	0,000	0-20%	19%	9%	0,000
0-30%	65%	78%	0,000	0-30%	18%	9%	0,000
0-40%	66%	79%	0,000	0-40%	16%	9%	0,000
4-50%	68%	80%	0,001	4-50%	16%	10%	0,001
0-60%	68%	81%	0,000	0-60%	16%	10%	0,000
0-70%	69%	81%	0,000	0-70%	16%	9%	0,000
0-80%	68%	82%	0,000	0-80%	15%	9%	0,000
0-90%	68%	83%	0,002	0-90%	15%	10%	0,002
0-100%	68%	83%	0,004	0-100%	15%	10%	0,004

*p-values are calculated using the nonparametric Mann-Whitney's U Test

DISCUSSION

We found that increasing compliance with short-term commitments, which can be assessed with the use of the PPC, improves the probability of schedule accomplishment and project success. It was also observed that successful projects have a higher PPC average while retaining a lower standard deviation, which can be interpreted as reducing the variability in short-term compliance by making sound promises. These criteria can be observed not only in aggregated data at the end of a project but also as early as the start of its execution. As successful projects progress, they increase their partial and accumulated PPC averages while maintaining a relatively stable variability, as measured by the standard deviation. Since these trends can be observed throughout the whole execution process, two assumptions can be made, but will require further analysis: A – "projects that make sound promises since the start can expect a better outcome" and B – "projects that effectively apply early corrective actions improve their expected outcome".

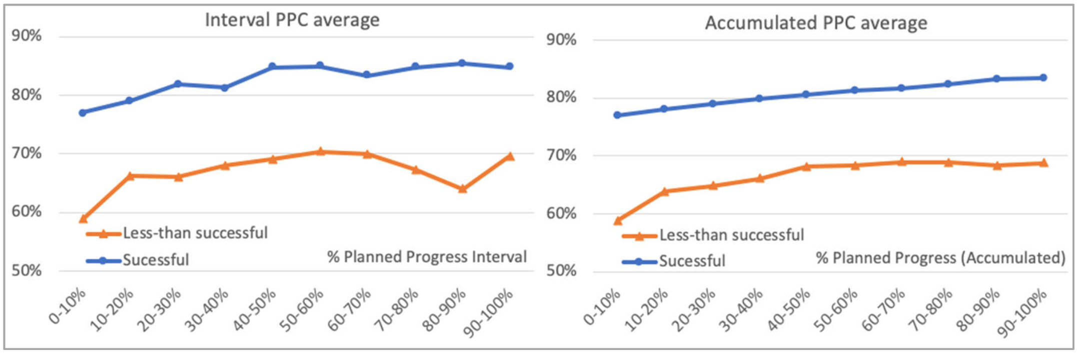

Figure 3: Partial and accumulated PPC average across baseline progress

We also observed that the success group increased their PPC approximately 1% after each interval of 10% progress, from a PPC average similar to 75% to almost 85% at the project end. In regard to the variability of successful projects, we found it to be higher at the first and last thirds of the project execution, which means that project compliance in successful projects is more stable during mid execution, where a greater number of activities are being performed and there is more flexibility to modify lookahead plans.

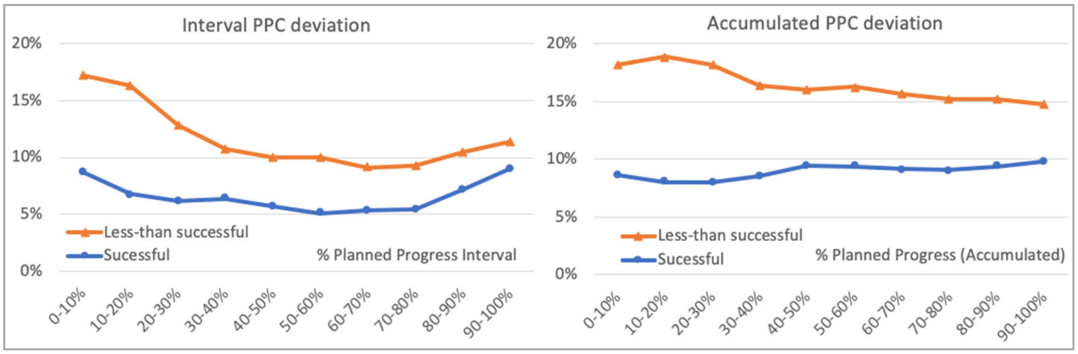

Figure 4: Partial and accumulated PPC deviation across baseline progress

The PPC evolution in less-than successful projects, shows a similar increment in their accumulated PPC, of almost 10% during project execution, but, if we look at the partial PPC averages of each interval, it is notable that the increase in PPC is not stable and that it presents a peak at the middle third, followed by an almost continual decrease during the last third. This can be caused by projects not following an optimal process of work preparation during mid-term planning, which could lead to facing several constraints to complete work during the last stages of project execution.

Finally, less-than successful projects exhibit a decrease in their PPC standard deviation until the end of the second third of project execution. This decrease then stabilizes during the last third. Thus, even though these projects did not perform according to expectations, they were still able to improve their initial performance and reduce variability, although not as much as projects in the successful group. The later could indicate that, despite not achieving successful results, their use of LPS still improved their short-term planning.

CONCLUSIONS

The systematic monitoring of PPC and RNCs is one of the most widespread practices used in LPS construction projects. Their ease of registering and assessing allows for a close and continual assessment of short-term compliance. Previous research shows that maintaining a higher PPC leads to better performance, productivity and schedule accomplishment, when it is combined with following the right work sequence and acting early on RNCs to prevent future recurrences. We tested a sample of 25 Chilean high-rise building projects to understand how the assessment of the PPC average, PPC deviation and RNCs across project execution can help to evaluate the project expected schedule accomplishment. We found statistically significant differences that allowed us to infer that the assessment of these metrics since the start of the project execution can help to determine the need for corrective actions before the occurrence of significant schedule deviations.

Our findings showed that projects that maintained a PPC equal to or higher than 75%, with a PPC standard deviation lower than 11%, were likely to obtain a lower schedule deviation and, thus, had a higher probability of success, which increased significantly when reaching accumulated PPC averages higher than 85%. Therefore, we presented graphs that can help practitioners and project managers in a practical manner to control project execution. Although, it must be noted that our results do not indicate that projects should lower their PPC objectives since setting a lower standard would mean asking for less-than optimal commitments, and also, that our conclusions are limited to high-rise building projects using an standard LPS support system and should be revised with more data from different types of projects and support systems. Finally, even though the limitations, our findings show the importance of closely monitoring PPC and RNCs throughout the project execution and how it can help to prevent deviations from schedule.

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REFERENCES

Abdel Azeem, S.A., Hossam E. H., and Ahmed H. I. 2014. “Forecasting Project Schedule Performance Using Probabilistic and Deterministic Models.” *HBRC Journal* 10(1): 35-42.

Alarcón, L. F., and Calderón, R. 2003. “A Production Planning Support System for Construction Projects.” *11th Annual Conference of the International Group for Lean Construction*, Virginia, USA.

Alarcón, L. F., Salvatierra, J. L., and Letelier, J. A. 2014. "Using Last Planner Indicators To Identify Early Signs Of Project Performance." *Proceedings for the 22th Annual Conference of the International Group for Lean Construction*: 547-58.

Ballard, G., and Tommelein, I. 2016. "Current Process Benchmark for the Last Planner System." *Lean Construction Journal* 13(1): 57-89.

Cheng, M. Y., Wu, Y. W., and Wu, C. F. 2010. "Project Success Prediction Using an Evolutionary Support Vector Machine Inference Model." *Automation in Construction* 19(3): 302-7.

Daniel, E., Pasquire, C., and Dickens, G. 2015. "Exploring the Implementation of the Last Planner® System Through Iglc Community: Twenty One Years of Experience." *Proceedings for the 23rd Annual Conference of the International Group for Lean Construction, Perth, Australia.* (February 2016): 153-62.

Dave, B., Hämäläinen, J. P., and Koskela, L. 2015. "Exploring the Recurrent Problems in the Last Planner Implementation on Construction Projects." *Proceedings of the Indian Lean Construction Conference (ILCC 2015)*: 1-9.

Formoso, C. T., and Moura, C. B. 2009. "Evaluation of the Impact of the Last Planner System on the Performance of Construction Projects." *Proceedings of IGLC17: 17th Annual Conference of the International Group for Lean Construction*: 153-64.

González, V., Alarcón, L. F., and Mundaca, F. 2008. "Investigating the Relationship between Planning Reliability and Project Performance." *Production Planning and Control: The Management of Operations* 19(5): 461-74.

Hamzeh, F., El Samad, G., and Emdanat, S. 2019. "Advanced Metrics for Construction Planning." *Journal of Construction Engineering and Management* 145(11): 1-16.

Hernández, R., Fernández, C. and Baptista, P. 2006. McGraw-Hill Interametricana *Metodología de La Investigación*. México D.F.

Howell, G., and Koskela, L. 2000. "Reforming Project Management: The Role of Lean Construction." *Proceedings of the 8th Annual Conference of the International Group for Lean Construction*.

Jain, A. K. 2010. "Data Clustering: 50 Years beyond K-Means." *Pattern Recognition Letters* 31(8): 651-66.

Jang, J. W., and Kim, Y. W. 2007. "Use of Percent of Constraints Removal to Measure the Make-Ready Process." (July): 529-38.

Kim, S. C., Kim, Y. W., Park, K. S., and Yoo, C. Y. 2015. "Impact of Measuring Operational-Level Planning Reliability on Management-Level Project Performance." *Journal of Management in Engineering* 31(5).

Kim, Y. W. 2019. "The Impact of Make-Ready Process on Project Cost Performance in Heavy Civil Construction Projects." *Production Planning and Control,* 30(13): 1064-71.

Koskela, L. 1999. "Management of Production in Construction: A Theoretical View." *Proceedings IGLC-7*: 241-52.

Koskela, L., Ballard, G., Howell, G., and Tommelein, I. 2002. "The Foundations of Lean Construction." *Design and Construction: Building in Value*, 211-26.

Lagos, Camilo, Luis Fernando Alarcón, and José Luis Salvatierra. 2016. "Improving the Use of Information Management for Continuous Improvement With the Last Planner System." *Memorias del VII Elagec, Bogotá, Colombia.*: 737-45.

Lagos, Camilo, Rodrigo Fernando Herrera, and Luis Fernando Alarcón. 2019. "Assessing the Impacts of an IT LPS Support System on Schedule Accomplishment in Construction Projects." *Journal of Construction Engineering and Management*

145(10): 04019055.

Leal, M., and Alarcón, L. F. 2010. "Quantifying Impacts of Last Planner^{TM} Implementation in Industrial Mining Projects." *Challenging Lean Construction Thinking: What Do We Think and What Do We Know? - 18th Annual Conference of the International Group for Lean Construction,* 518-27.

Lipke, W., Zwikael, O., Henderson, K., and Anbari, F. 2009. "Prediction of Project Outcome. The Application of Statistical Methods to Earned Value Management and Earned Schedule Performance Indexes." *International Journal of Project Management* 27(4): 400-407.

Liu, M., Ballard, G., and Ibbs, W. 2011. "Work Flow Variation and Labor Productivity: Case Study." *Journal of Management in Engineering* 27(4): 236-42.

Ponz-Tienda, J. L., Pellicer, E., Alarcón, L. F., Rojas-Quintero, J. 2015. "Integrating Task Fragmentation and Earned Value Method Into the Last Planner System Using Spreadsheets." In *Proceedings for the 23rd Annual Conference of the International Group for Lean Construction, Perth, Australia*, 63-72.

Power, W., and Taylor, D. 2019. "Last Planner® System and Planned Percent Complete: An Examination of Individual Trade Performances." *Proceedings for the 27th Annual Conference of the International Group for Lean Construction*-12.

Ryan, M., Murphy, C., and Casey, J. 2019. "Case Study in the Application of the Last Planner® System." *Proc. 27th Annual Conference of the International Group for Lean Construction*, 215-26.

Salvatierra, J. L., Alarcón, L. F., López, A., and Velásquez, X. 2015. "Lean Diagnosis for Chilean Construction Industry: Towards More Sustainable Lean Practices and Tools." *Proceedings for the 23th Annual Conference of the International Group for Lean Construction,* 642-51.

El-Samad, G., Hamzeh, F., and Emdanat, S. 2017. "Last Planner System - The Need for New Metrics." In *Proceedings of the 25th Annual Conference of the International Group for Lean Construction*, 637-44.

Sarhan, S., and Fox, A. 2012. "Performance Measurement in the UK Construction Industry and Its Role in Supporting the Application of Lean Construction Concepts." *Australasian Journal of Construction Economics and Building* 13(1): 23-35.