INVESTIGATING THE RELATIONSHIP BETWEEN PLANNING RELIABILITY AND PROJECT PERFORMANCE: A CASE STUDY

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ABSTRACT

Variability is an endemic problem in construction projects, which leads to the general deterioration of their performance. During the last decade the Last Planner System (LPS™) has been increasingly applied in construction projects to improve planning reliability as a strategy to increase the project performance. LPS™ promotes a series of actions and methods to increase planning reliability, monitoring the Percentage of Plan Completed (PPC) in a short term planning period. Nevertheless, there is limited evidence studying properly the relationship between planning reliability and project performance. In this paper, the authors developed a detailed research in a home building project analyzing this relationship at activity and project level, in order to understand how changes of planning reliability levels impact over project performance during construction phase. For doing so, two indexes are proposed: A planning reliability index activity-based called Process Reliability Index (PRI), and an aggregated labour productivity index project-based called Project Productivity Index (PPI). At activity level, activity performance indicators are compared with PRI. At project level, PPI is compared with PPC as a project planning reliability index. Statistical analyses for both levels were conducted showing positive and robust trends to improve performance when planning reliability is increased.

KEY WORDS:

Last Planner, Variability, Project Performance, Planning Reliability.

INTRODUCTION: PRELIMINARY REMARKS AND LITERATURE REVIEW

Construction is a complex business, whose projects are increasingly more technically sophisticated as well as subjected to shorter execution schedules and costs due to market demands. During the construction phase, projects are affected by uncertainty resulting from urgent requirements, non-consistent construction sequences, lack of coordination at the supply chain, project scope changes, and poor quality, among other factors. It seems that the combined effect of complexity and uncertainty in projects creates variability in production processes (Horman (2000). Variability is an endemic problem in construction industry, which can induce dynamic and unexpected conditions, unsteadying project objectives and obscuring the means to achieve them.

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On the one hand, variability leads to a general deterioration of project on dimensions such as: cycle time (Ballard, 1993; González and Alarcón, 2006; Shen and K.H. Chua, 2005; Tommelein et al, 1999), labour productivity (Thomas et al, 2003), project cost (Ballard and Howell, 1994), planning efficiency (Alarcón et al, 2005; Howell and Ballard, 1995), among others. On the other hand, current project management practises can help to induce variability for two reasons: 1) They do not consider project complexity and its non-linear nature (Bertelsen, 2003) leading to poor decisions, and, 2) They are focused on project control instead of production control, pushing productive agents in construction (e.g., subcontractors and/or contractors) to manage contractual commitments rather than their production commitments (Ballard and Howell, 1998).

Last Planner System (LPS™) is a production control system based on Lean Production principles, which provides a reliable production environment in projects by reducing workflow variability. LPS™ controls planning reliability by means of Percentage of Plan Completed (PPC). PPC is a ratio between actual completed activities and planned activities of Work Plans over a short term period. LPS™ also acts over Reasons for Non-Completion (RNC) of Work Plans (Ballard, 2000).

LPS™ has allowed different levels of improvement on a wide range of projects in the world since 1992 (Howell, 2003). LPS™ allows to increase the predictability of workflow assuring conditions on-site to work, which should improve productivity at labour level (Ballard, 2000; Howell et al, 2001). Therefore, any growth on planning reliability levels measured through PPC should improve project labour productivity.

However, there is limited research evidence on the relationship between planning reliability and project performance (Thomas et al, 2003; Mundaca, 2006). Several researchers have attempted to describe the LPS™ planning reliability impacts on labour productivity by using the Performance Factor (PF) (Ballard and Howell, 1998; Ballard et al, 1996; Fiallo and Revello, 2002). PF measures productivity as a ratio of actual to earned labour hours. They have reported improvements on PF after LPS implementation; nevertheless, they have not yet reported a clear relationship between PPC and productivity during project execution. Also, according to Ballard (1996), PF is constrained for making visible improvements due to different reasons, among others: 1) It measures real productivity against the expected productivity baseline, and consequently PF may improve and still remain worse than baseline; and 2) When there is greater labour capacity than available work, PF will show poor productivity, regardless of how efficiently available work is performed. Alarcón et al (2000) did measured improvement in labour productivity against PPC improvement, but did not capture a statistical relationship. On the other hand, Chitla and Abdelhamid (2003) used an alternative method analyzing Labour Utilisation Factors (LUF), a metric that measures non-productive time and PPC. Their statistical analysis show that PPC and LUF are not strongly correlated (correlation coefficient reaches a value of 0.40). However, Chitla and Abdelhamid (2003) argue this weak relationship is due to quite partial implementation of LPS™ in analyzed production system.

In prior cases, there are improvements on project performance when PPC increases. Nevertheless, these observations did not provide clear information to understand how changes on planning reliability levels can modify project performance during construction phase. Even more, the indicators used did not allow to properly analyze this behaviour.

This paper statistically explores the relationship between planning reliability and project performance through the study of a home building project. The analysis is developed at two production levels, activity and project levels, which allows to quantify the impacts of planning reliability through LPS™ over project performance during construction phase. For doing so, different project performance and planning reliability indexes are proposed for both levels. Next sections describe the proposed indexes, the case study and the developed statistical analyses.

DEFINING PROPER INDICATORS FOR RELATING PROJECT PERFORMANCE AND PLANNING RELIABILITY

PPC is calculated from a cluster of activities in Work Plans. LPS™ uses a binary criterion for activity completion, where activities partially executed during a short term period are computed as non-executed (i.e. 0% completed), not being included with the other activities of Work Plans within PPC calculation. So, the real plan completion of activities is really hidden. Therefore, when 'activity performance indicators' are compared with PPC, it is quite difficult to understand how PPC impacts on individual performance of activities since each activity has a different portion of contribution within PPC calculus and different levels of individual planning fulfilment. Analyses at activity level for understanding the effect of planning reliability improvements over activity performance are necessary.

On the contrary, PPC characterizes an aggregated planning reliability index at project level. If activity performance indicators (e.g. activity labour productivity) are being used to measure the impacts of PPC on project performance, wrong inferences might be obtained since both indicators have different project aggregation levels. Thus, analyses at project level for understanding the impacts of planning reliability over project performance should be performed.

At activity level, this research proposes to reformulate the classical metric of planning reliability used by LPS™ to develop meaningful comparisons with 'activity performance indicators'. So that, a complementary planning reliability index 'activity-based', called Process Reliability Index (PRI) is developed. At project level, a similar notion is introduced to compare PPC with 'project performance indicators'. An aggregated labour productivity index 'project-based' containing the cluster of activities planned in Work Plans called Project Productivity Index (PPI), is proposed.

PROCESS RELIABILITY INDEX (PRI)

Process Reliability Index (PRI) is defined by Equation 1:

$$PRI_{i,j} = \frac{AP_{i,j}}{PP_{i,j}} \times 100 \qquad \text{Equation 1}$$

Where, $PRI_{i,j}$: Process Reliability Index for week i and activity j (%), i=1...n; j=1...m.

$AP_{i,j}$: Actual Progress for week i and activity j, i=1…n; j=1...m.

$PP_{i,j}$: Planned Progress for week i and activity j, i=1…n; j=1...m.

PRI is a ratio of actual to planned weekly progress of an activity and it represents a kind of planning reliability index at activity level. PRI do not compare actual to planned cumulative progress because it is based on partial measurement (weekly progress), though it measures the degree of activity fulfilment from a planning commitment point of view proposed by Ballard (2000). A similar approach is proposed by Peña-Mora et al (2001), but their reliability index is based on the value-added notion of activities over project planning.

PRI values range between 0 and 100%. When AP is higher than PP, the PRI value is limited to 100%. As well, PRI equation considers a short term period of one week; however, this time horizon can be changed and depends on the type of project and/or management preferences. The units of AP and PP can be chosen depending on the type of activity. Nevertheless, they are intended as a ratio between production outputs and time (short term period).

PROJECT PRODUCTIVITY INDEX (PPI)

Analytically, Equation 2 defines PPI:

$$PPI_i = \frac{\sum_{j=1}^{m} API_{i,j}}{N_i} \qquad \text{Equation 2}$$

Where, PPI_i: Aggregate Productivity Index for week i (%), i=1...n.

$API_{i,j}$: Activity Productivity Index for week i and activity j, i=1...n; j=1...m.

N_i: Number of activities with labour productivity information available for week i, i=1...n.

$$API_{i,j} = \frac{ALP_{i,j}}{MLP_j} \qquad \text{Equation 3}$$

Where, $ALP_{i,j}$: Average Labour Productivity for week i and activity j, i=1...n; j=1...m.

MLP_j: Maximum Average Labour Productivity find for activity j during the analysis period, j=1…….m.

Similarly to PRI, PPI is constructed over a short term period of one week, but its time horizon can be modified. The units of ALP and MLP are variable since they are constructed from activities with different design and execution complexity. However, they are understood as ratio between production outputs and inputs.

MLP is the higher labour productivity indicator for an activity during the analysis period. Clearly, the selected value of MLP can be changed in order to fit into different sizes of analysis period, which result into PPI changes. Anyhow, this research is focused on a fixed time period to understand the impacts of PPC over project performance after using the LPS™.

As for N_i in Equation 2, it represents the number of activities on week ‘i’ included within the Work Plans from which productivity is computed (available activities). There might be activities not included on weekly plans since either they have not started its work within the analysis period or some extraordinary event forces them to stop their normal execution before the week i, and therefore their productivity could not be measured.

Finally, PPI as aggregated performance index overcomes the limitations of other ones like PF. PPI reflects real productivity improvements since it is computed from maximum productivity on-site and not from expected productivity as PF.

DESCRIPTION OF THE CASE STUDY: HOME BUILDING PROJECT

The home building project analyzed was located in Santiago, Chile. Fifty three homes with an area of approximately 123 m2 were executed with a planned schedule of one year calendar (between June, 2004 and June, 2005) and a 5 million dollars budget. Forty five homes were analyzed in this research and the selected processes or activities are chosen from the project finishes stage (See Table 1).

Table 1. Activities analyzed.

Process or Activity	Number of studied weeks	Number of studied days
Concrete	6	30
Stucco	13	65
Roof Structure	9	45
Eaves	8	40
Tiles Installation	11	55
Interior Painting - Varnish	12	60
Exterior Painting	13	65
Wall-Sealing	13	65
Interior Painting-1st Layer	13	65
Interior Painting-2nd Layer	10	50

The project planning process was supported by LPS™. Despite its implementation was partial, the following elements from it were used: 1) Work Plans of one week period and Weekly Planning Meetings. 2) A Lookahead Plan of four weeks was fully implemented. 3) PPC and RNC were recorded weekly. Corrective measures were taken from analysis of these data and weekly meetings.

DATA ANALYSIS AND DISCUSSION

DATA COLLECTION

During a four months period, daily production rates and evolution of men-day for each activity were collected. PPC and RNC were recorded in a project data base, and labour productivity for each activity was computed from the collected data. The following performance indicators were measured (it includes definitions and units):

i) AM (Average Men): Daily average of men working on a process during a week of planning. In this project, weeks had five work-days. Men-day (md)

ii) APR **(**Average Production Rate): Daily average of production rate from a process during a week planning. Square-meter divided per day (m2/day) or linear-meter divided per day (lm/d).

iii) ALP (Average Labour Productivity): Daily average of labour productivity from a process during a week planning. In this research, labour productivity is defined as ratio between units of work and men-day. Square-meter divided per men-day (m2/md) or linear-meter divided per men-day (lm/md).

RELATIONSHIP BETWEEN ACTIVITY PERFORMANCE AND PPC

Initially, activity performance indicators were compared with PPC using correlation coefficients (R). PPC is calculated from analyzed activities, which are a subset of all project activities planned every week. Table 2 shows a correlation matrix between both variables. 'Performance Indicators' column shows selected indicators. Resulting R-values are shown below each 'Activity' column. 'R-Ave' column shows the average correlation coefficients for each 'Performance Indicator'. '$|\#R| \geq 0.5$' column and row states the amount of R absolute values higher or equal to 0.5, for 'Performance Indicator' and 'Activity' respectively. R-values higher or equal than 0.5 are considered acceptable for this type of research according to Cohen (1998).

Table 2 shows that R-Ave for all performance indicators are lesser than 0.5 with a maximum value of 0.24. Only 40% of R-values show a higher or equal level to 0.5 (12 over 30 values). |#R| column shows that AM, APR and ALP have a regular distribution without predominance of any of them. On the other hand, |#R| row shows a irregular distribution for its R-values by activity, with a light predominance of Tiles Installation activity.

Table 2. Correlation Matrix of Activity Performance Indicators and PPC.

	PPC (%)											
PERFORMANCE INDICATORS	**Conc.**	**Stucco**	**Roof Str.**	**Eaves**	**Tiles Inst.**	**Int. Varn.**	**Ext. Paint.**	**Wall-Seal.**	**Int. Paint.1st L.**	**Int. Paint. 2nd L.**	**R-Ave**	**|#R| ≥0.5**
AM (md)	-0.23	**0.71**	**0.79**	0.37	**0.94**	0.14	0.39	**-0.58**	-0.10	-0.34	0.21	4
APR (m2/d) - (lm/d)	**-0.51**	**0.70**	**0.79**	0.49	**0.92**	0.05	0.40	**-0.64**	0.24	-0.09	0.24	5
ALP (m2/md)- (lm/md)	**-0.76**	0.37	0.20	**0.74**	**0.70**	-0.30	0.20	0.12	0.04	0.38	0.17	3
|#R|≥0.5	2	2	2	1	3	0	0	2	0	0		

Note: Numbers marked in bold are |R|≥0.5.

A closer review on Table 2 shows negative and positive R-values without any pattern. Ballard (2000) states that improvements on planning reliability should imply better production conditions on project to execute activities. Therefore, production rates and labour productivity could increase. Consequently, APR and ALP should show constant and positive correlations with PPC, though Table 2 does not show this behaviour. On the other hand, the amount of labour could be decreased when production conditions improve meaning a more efficient use of labour. So that, relationship between the amount of labour and planning reliability could be negative. But this kind of relationship is harder to prove due to is not always possible to reduce or to vary the amount of on-site labour and it is easier to increase the efficiency of a given amount of men on-site. Anyway, Table 2 does not show a rational pattern for AM and PPC.

A detailed inspection between low and high R-values could explain best the remarkable differences among activities. For instance, in Table 2 Tiles Installation activity for APR has R-value equal to 0.92 better than Exterior activity Painting with an R-value of 0.40.

Figure 1 shows time evolution of APR for both activities and PPC. During time Tiles Installation activity is better suited to variations on PPC level than Exterior Painting activity. According to in-site observations and personnel interviews, Tiles Installation activity balanced better its work capacity with work load, i.e., this activity suits its labour resource to the available work produced by LPS™, better than other activities, as Exterior Painting. This could explain the reason why there are activities with higher R-values than others.

The poor results showed in Table 2 do not clearly allow to infer patterns to describe performance improvements by activity based on PPC increasing. The reason can be found on analysis levels: performance indicators are analyzed at activity level, and PPC at project level. This supports the idea discussed in prior sections about different levels of analysis for developing reliable comparisons between performance and planning reliability. Next sections explore different indexes and assumptions for two different levels of analysis: activity and project level.

RELATIONSHIP BETWEEN ACTIVITY PERFORMANCE AND PRI

Table 3 shows correlation matrix between activity performance indicators and PRI. In Table 3 similar variables and analyses to Table 2 were developed to compare activity performance indicators and PRI.

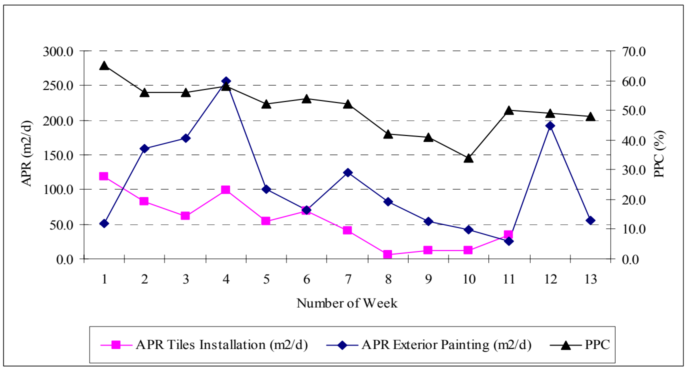

Figure 1. Evolution Average Production Rates and PPC versus time.

Table 3 shows that R-Ave for APR and ALP are higher than 0.5 with R-values of 0.60 and 0.82, respectively. Only AM shows an R-value of 0.48 lesser than 0.5, but this R-value double the one shown in Table 2. R-values with a higher or equal level to 0.5 reach a total of 73% (22 over 30 values) improving the amount of acceptable R-values from Table 2 by almost 50%. |#R| column shows an improvement of R-values on every performance indicator. But, ALP shows the highest |#R| with good R-values in all activities. In addition, |#R| row shows at least one R-value higher or equal to 0.5 for all activities, with a more balanced distribution of |#R| against Table 2.

Table 3. Correlation matrix of Activity Performance Indicators and PRI.

	PRI (%)											
PERFORMANCE INDICATORS	**Conc.**	**Stucco**	**Roof Str.**	**Eaves**	**Tiles Inst.**	**Int. Varn.**	**Ext. Paint.**	**Wall-Seal.**	**Int. Paint.1st L.**	**Int. Paint. 2nd L.**	**R-Ave**	**|#R| ≥0.5**
AM (md)	0.45	**0.64**	0.11	**0.67**	**0.64**	0.12	**0.61**	0.14	**0.79**	**0.69**	0.48	6
APR (m2/d) - (lm/d)	**0.82**	**0.69**	0.46	**0.79**	**0.67**	0.34	**0.71**	0.27	0.46	**0.75**	**0.60**	6
ALP (m2/md)- (lm/md)	**0.93**	**0.86**	**0.80**	**0.88**	**0.69**	**0.89**	**0.74**	**0.80**	**0.83**	**0.82**	**0.82**	10
|#R|≥0.5	**2**	**3**	1	**3**	**3**	1	**3**	1	**2**	**3**		

Note 1: Numbers marked in bold are |R|≥0.5.
Note 2: Marked row in leaden colour show clear and good correlations between ALP and PRI.

Table 3 shows positive and good R-values between APR and ALP with PRI. However, a weak correlation was found between AM and PRI (as expected). In Table 3 the strongest relationship occurs between ALP and PRI. To test the robustness of the relationship between ALP and PRI, the data from Table 3 were subjected to regression analyses and analysis of variance (ANOVA) (See Table 4). For each activity, it was estimated the 'Regression Model' or linear model where ALP is assumed as dependent variable (response) and PRI as independent variable (predictor). The t-values for 'Constant' and

'Predictor' were estimated for α=0.05, while the Coefficient of Determination (R^2) was computed for each Regression Model. Additionally, an ANOVA process was developed to complement analyses of statistical significance for relationship between ALP and PRI. According to Table 4, all R^2-values show good fit to linear models. Statistically the t-values show the high significance of the linear relationship between ALP and PRI. Tiles Installation and Interior Varnish activities have a linear model whose constant is not different to zero according to t-Constant values. However, t-Predictor values show a relevant linear relationship. Besides, the ANOVA process shows that all relationships are highly significant, even for Tiles Installation and Interior Varnish activities.

Table 4. Regression Analysis and ANOVA for relationships between ALP and PRI.

ACTIVITIES	REGRESSION MODEL	t-CONSTANT (1)	t-PREDICTOR (1)	R^2	ANOVA P-value≤α (1)
Concrete	ALP=0.003*PRI + 1.700	3.930	5.112	0.87	0.007
Stucco	ALP=0.106*PRI + 2.930	2.349	5.699	0.75	0.000
Roof Structure	ALP=0.118*PRI + 5.320	2.596	3.472	0.63	0.010
Eaves	ALP=0.017*PRI + 1.450	7.286	4.523	0.77	0.004
Tiles Installation	ALP=0.172*PRI + 5.970	**1.572**	2.897	0.48	0.018
Interior Paint. - Varnish	ALP=0.105*PRI + 1.660	**1.220**	5.097	0.79	0.001
Exterior Painting	ALP=0.567*PRI + 43.300	4.376	3.646	0.55	0.004
Wall-Sealing	ALP=0.303*PRI + 41.100	8.842	4.365	0.63	0.001
Interior Painting-1st Lay.	ALP=0.552*PRI + 24.200	2.705	4.666	0.69	0.001
Interior Painting-2nd Lay.	ALP=0.263*PRI + 14.800	3.448	4.081	0.68	0.004

(1) Significance level, α=0.05

Statistical tests showed in Table 3 and 4 support the use of PRI as a proper activity planning reliability index. Also, results from these tables indicate that there is a strong relationship between performance improvements and planning reliability at activity level.

RELATIONSHIP BETWEEN PPI AND PPC.

This section studies the relationship between project performance and planning reliability at project level, by using PPI and PPC. Table 5 summarizes the results of PPI for each selected activity. The Interior Painting-Varnish activity starts to work the second week and Interior Painting-2nd Layer starts the forth week. Also, Interior Painting-Varnish and Interior Painting-1st Layer activities have weeks marked with 'X' for indicating weeks without labour productivity measurements. The latter is due to lack of specialized labour, which is an extraordinary event during project execution early communicated to project management. As a result, PPC and PPI are computed over weeks and activities really planned and executed.

Figure 2 shows a scatter plot from data of Table 5 between PPI and PPC. This figure indicates a good R-value equal to 0.82 and it suggests a linear relationship between both variables, with PPI as dependent variable and PPC as independent variable. A regression analysis was developed showing good and meaningful t-values for constant (tc) and predictor (tp) on linear model at α level of 0.05 (See Figure 2). Also, a R^2 equal to 0.68 was obtained indicating a well fit of data to a linear model. Figure 2 indicates that for every positive unitary change on PPC, the positive change on average PPI is 0.72%. In other words, the higher levels of PPC, the higher levels of labour productivity are obtained.

Besides, data from Table 5 were subjected to ANOVA process, which allows to obtain a P-value equal to 0.002 lower than α. This complementary statistical analysis shows a significant linear relationship between PPI and PPC too.

Table 5. PPI and PPC for all selected processes.

Number of Week (i)	API										PPI (%)	PPC (%)
	Conc.	Stucco	Roof	Eaves	Tiles Install.	Int. Paint.- Varnish	Ext. Paint.	Wall-Seal.	Int. Paint.- 1st L.	Int. Paint.- 2nd L.		
1	0.3	1.0	0.8	0.9	1.0		0.5	0.9	0.7		76.3	62.5
2	0.7	0.8	1.0	0.9	0.7	0.4	1.0	1.0	0.7		80.0	55.6
3	0.8	0.5	0.6	1.0	0.7	1.0	0.7	0.7	XXXX		75.0	62.5
4	1.0	0.8	0.8	0.9	0.9	0.7	0.7	0.9	1.0	0.5	82.0	60.0
5	0.9	0.9	0.5	0.6	0.7	0.3	0.8	0.8	0.6	0.6	67.0	50.0
6	0.8	0.9	0.9	0.7	0.7	0.6	0.6	1.0	0.7	0.9	78.0	60.0
7		0.9	0.9	0.6	0.5	1.0	1.0	1.0	0.3	0.7	76.7	55.6
8		0.6	1.0	0.6	0.6	XXXX	0.8	0.9	0.5	0.5	68.8	37.5
9		0.8	0.4		0.6	0.9	0.5	0.7	0.9	0.5	66.3	37.5
10		0.6			0.6	XXXX	0.4	0.9	0.7	0.5	61.7	33.3
11		0.7			0.6	XXXX	0.4	0.9	0.8	0.6	66.7	50.0
12		0.4				0.6	0.9	0.8	1.0	0.8	75.0	50.0
13		0.1				1.0	0.9	0.6	0.7	1.0	71.7	50.0
Number of Activity (j)	1	2	3	4	5	6	7	8	9	10		

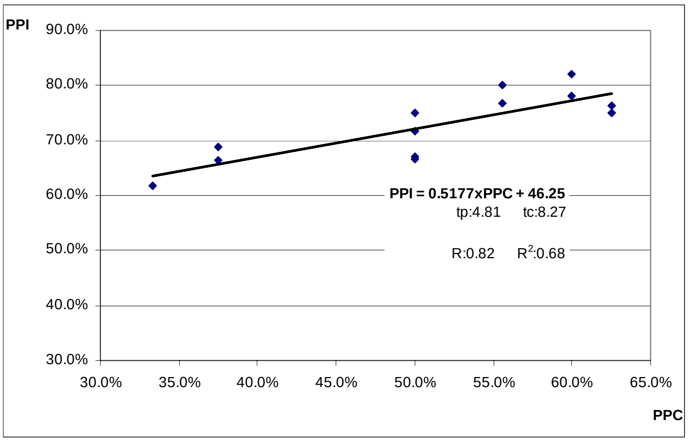

Figure 2. Scatter plot for PPI and PPC.

Statistical tests in Figure 2 states PPI as a proper aggregated labour productivity index at project level. LPS™ was the only initiative for project performance improvement implemented in the project, therefore the PPI improvement trend observed in Figure 2 can be related to planning reliability improvements obtained using LPS™. Results from Figure 2 indicate that there is a strong relationship between performance improvements and planning reliability at project level.

CONCLUSIONS

Several analyses to study the relationship between project performance and planning reliability in the case study were performed. The main results state:

- Two levels of analysis, activity and project, seems to be necessary to understand how improvements on planning reliability by LPS™ impact project performance.

- PRI is a complementary index of planning reliability that overcomes limitations of PPC for doing analyses of LPS™ impacts at activity level. So that, activity performance is better correlated with planning reliability indexes as PRI.
- PPI is an aggregate performance index that overcomes the limitations of other aggregate performance indexes (e.g. PF) and it allows to understand the real effects of planning reliability improvements through LPS™ at project level. Project performance through PPI is better correlated to planning reliability indexes as PPC.
- This exploratory research analyzed only one project, and currently this type of analysis is being investigated in other projects to obtain more general conclusions about relationship between planning reliability and project performance. Additional conjectures might need controlled experiments to properly study the causality of this relationship. This would help to fully understand how improvements on planning reliability increase project performance. Nevertheless, the research contribution is to statistically show that there is a positive and strong relationship between planning reliability and project performance during construction phase.

On the other hand, this research contributes to develop a preliminary methodology to forecast the LPS™ impacts through the proposed performance indicators and the application of regression analysis to construct relationships between planning reliability and project performance. In this way, PRI and PPI are new production indicators to measure planning reliability and project performance respectively on construction industry.

Finally, a proper understanding of planning reliability impacts, e.g., over labour productivity could allow project decision-makers to know how much effort is necessary to dedicate on improvement initiatives of planning reliability. If project decision-makers know the magnitude of improvements on labour productivity based on planning reliability increasing (approximately, at least), they could easily estimate the cost-benefit of applying planning reliability initiatives on construction projects.

REFERENCES

Alarcón, L.F., Diethelm, S., Rojo, O. and Calderón R. (2005). Assessing the Impacts of Implementing Lean Construction. Proceedings of IGLC-13, Sidney, Australia, July.

Alarcón, L. F., Ashley, D. B. and Cruz, J. (2000). The Impact of Planning Strategies on Project Performance: Learning from Real and Model Projects. CIB Conference, Information and Communication in Construction Procurement, Serpell, A. (Editor), P. Universidad Católica de Chile, Santiago, Chile, April 24th – 27th.

Ballard, G. (2000). The Last Planner System of Production Control. Ph.D. Dissertation, School of Civil Engineering, Faculty of Engineering, The University of Birmingham, Birmingham, U.K.

Ballard, G. and Howell, G. (1998). Shielding Production: Essential Step in Production Control. J. Const. Engr. Mgmt., ASCE, Vol 124, N° 1, pp. 11-17.

Ballard, G., Casten, M. and Howell, G. (1996). Parc: A Case Study. Proceedings of IGLC-4, Birmingham, U.K.

Ballard, G. and Howell. G. (1994). Implementing Lean Construction: Stabilizing Work Flow. Alarcón, L. F. (ed), Lean Construction, A.A. Balkema, The Netherlands, 497 pp.

Ballard, G. (1993). Lean Construction and EPC Performance Improvement. Alarcón, L. F. (ed), Lean Construction, A.A. Balkema, The Netherlands, 497 pp.

Bertelsen, S. (2003). Complexity – Construction in a New Perspective. Proceedings of IGLC-11, Blacksburg, Virginia, U.S., July 22th - 24th.

Chitla, V. R. and Abdelhamid, T. S. (2003). Comparing Process Improvement Initiatives Based on Percent Plan Complete and Labour Utilisation Factors. Proceedings of IGLC-11, Blacksburg, Virginia, U.S., July 22th - 24th.

Cohen, J. (1988). Statistical power analysis for the behavioural sciences (2nd ed.) Hillsdale, NJ: Lawrence Erlbaum Associates, 600 pp.

Fiallo, M. and Revelo, V. H. (2002). Applying the Last Planner Control System to a Construction Project: A Case Study in Quito, Ecuador. Proceedings of IGLC-10, Gramado, Brazil, August 6th – 8th.

González, V., Alarcón, L.F. and Gazmuri, P. (2006). Design of WIP Buffers in Repetitive Projects: A Study Case. Proceedings of IGLC-14, Santiago, Chile, July 25th – 27th.

Horman, M. J. (2000). Process Dynamics: Buffer Management in Building Project Operations. Ph D Dissertation, Faculty of Architecture, Building and Planning, The University of Melbourne, Melbourne, Australia.

Howell, G. and Ballard, G. (2003). An Update on Last Planner. Proceedings of IGLC-11, Blacksburg, Virginia, U.S., July 22th - 24th.

Howell, G., Ballard, G. and Hall, J. (2001). Capacity Utilisation and Wait Time: A Primer for Construction. Proceedings of IGLC-9, Singapore, Korea, August 6th – 8th.

Howell, G., and Ballard, G. (1995). Factors Affecting Project Success in the Piping Function. Alarcón, L. F. (ed.), Lean Construction, A.A. Balkema, The Netherlands, 497 pp.

Mundaca, F. (2006). Análisis de Variabilidad y Mejoramiento de la Confiabilidad de la Planificación en Proyectos de Construcción. Bachelor's Tesis. Universidad Técnica Federico Santa María, Valparaíso, Chile.

Peña-Mora, F. and Li, M. (2001). Dynamic Planning and Control Methodology for Desing/Build Fast Track Construction Projects. J. Const. Engr. Mgmt., ASCE, Vol 127, N° 1, pp. 1-17.

Shen, L. J. and K. H. Chua, D. (2005). Impact of Variability on Construction Schedule. Proceedings of IGLC-13, Sidney, Australia, July.

Thomas, H. R., Horman, M. J., Minchin, R. E. and Chen, D. (2003). Improving Labour Flow Reliability for Better Productivity as a Lean Construction Principle. J. Const. Engr. Mgmt., ASCE, Vol 129, N° 3, pp. 251-261.

Tommelein, I. D., Riley, D. R. and Howell G. A. (1999). Parade Game: Impact of Work Flow Variability on Trade Performance. J. Const. Engr. Mgmt., ASCE, Vol 125, N° 5, pp. 304-310.