THE RELATIONSHIP BETWEEN THE MAKE-READY PROCESS AND PROJECT SCHEDULE PERFORMANCE

Jin Woo Jang[1] and Yong Woo Kim[2]

ABSTRACT

This research investigates the importance of the make-ready process in last planner implementation. The make-ready process has the potential to improve workflow predictability and reliability in construction projects. The construction industry has recognized that timely constraint removal is an important and distinctive requirement of successful projects.

Percentage of constraint removal (PCR) was used as a performance metric for the make-ready process. The authors tested the relationship between PCR and Percent Planned-work Completed (PPC), and hypothesize that PPC depends on the effectiveness of the make-ready process. Correlation and regression analyses were used to investigate how the effectiveness of the make-ready process (as measured by PCR) affects PPC. The results of the correlation coefficients for the relationship between PPC and PCR are significant ($p<0.05$). The regression analysis revealed that PPC positively related with PCR ($p<0.1$). Workflow reliability differed depending on the operational performance of the make-ready process.

KEY WORDS

make-ready process, constraint analysis, percentage of constraint removal, percent plan complete, case study

INTRODUCTION

Since the complexity of construction projects has increased, workflow uncertainty and the interdependency among tasks has increased (Bertelsen, 2003). To resolve these situations of growing complexity, more systematic approaches to make-ready process (i.e. constraint analysis) are necessary in production planning and control.

Since the early 90s, the *Last Planner System* (LPS), a production planning and control tool used to improve workflow reliability, has been widely implemented by lean construction practitioners, with satisfactory results (Ballard, 1994; Ballard and Howell, 2003). Under LPS theory, improving workflow reliability can be achieved both by the make-ready and the shielding processes.

The make-ready process includes all the actions that identify and remove the constraints of the upcoming work (Ballard and Howell, 1998). The shielding process is a methodology that defines criteria for making quality tasks (Ballard and Howell, 1998). In

[1] Ph.D. Candidate, Constr. Engr. and Mgmt. Program, Constr. Mgmt. and Wood Product Engrg. Department, 156 Baker Lab, State University of New York, College of Environmental Science and Forestry, Syracuse, NY 13210, 315/470-6831, FAX 315/470/6879, jijang@syr.edu

[2] Assistant Professor, College of Architecture and Urban Planning, Dept. of Constr. Mgmt., Univ. of Washington, 120 Architecture Hall, Seattle, WA, 206/616/1916, yongkim@u.washington.edu

the LPS, the success of production planning and control is measured in terms of *percent plan complete* (PPC). Currently the shielding process of the LPS has five criteria, whereas the make-ready process does not have any specific criteria. In order to increase workflow reliability, it is important to increase the predictability of production planning.

The scope of this research is limited to the assessment of the current production planning and control system, especially in the make-ready process, in heavy civil construction projects. This research adopted some aspects of LPS. Also, this research adopted a performance measurement of the make-ready process named *percentage of constraint removal* (PCR) to improve make-ready process (Jang and Kim, 2007).

In this research the performance not only of the make-ready process but the entire project phase was measured and analyzed to find opportunities for improvement. Statistical analyses verify that performance of the make-ready process is correlated to project performance and workflow reliability, and is also a leading indicator. The tracking of PCR helps to determine whether the make-ready process has been performed successfully.

RESEARCH OBJECTIVE

The primary objective of this research was to assess the effectiveness of the make-ready process in the project planning and control process especially for last planner implementation.

The measurement generally used in LPS, PPC, is a post production measure. There is no pre-production measure that could be used a leading indicator, or predictor of future productivity. PCR, the ratio of constraint-free tasks to those with constraints, is a contender for a pre-production measure that could be used to predict future productivity.

The research set out to test the correlation between the current after-the-fact measurement, PPC, and PCR to see if it could provide productivity predictions as well as measure the performance of the make-ready process.

BACKGROUND OF RESEARCH

Most companies perform the make-ready process (constraint removal) on their future work tasks. Constraint analysis is done by examining each activity that is scheduled to start within the next six weeks or so. Three to six weeks is typical in last planner implementation, but the size of the lookahead window may be shorter or longer depending on the length of the project and the lead times required for information, materials and services. When sizing the lookahead window, local conditions and judgment must be taken into account. Lead times longer than the lookahead window are noted as separate items in the project schedule.

Referring to Figure 1, during make-ready process in the lookahead planning, the “SHOULD” assignments are planned for a given period of time (Ballard, 2000). The make-ready and shielding processes are performed simultaneously in this period to make quality assignments. The final shielding process occurs between the lookahead schedule and the weekly work plan. Sometimes, it is hard for the last planner to shield assignments that still have constraints or uncertainties because doing so might affect the schedule and cost of the project (Kim and Jang, 2005). Ballard (1997) measured Assignments Made Ready (AMR). It measured the extent to which assignments that appeared on lookahead schedules appeared on weekly work plans when scheduled.

Currently in the construction process, percent plan complete (PPC) is the lean performance measurement of workflow reliability, and of the accuracy of production forecasts. The calculation of the PPC and PCR was based on same assignment. There were two measurements used in this research: PPC and PCR.

The six-week lookahead schedule was used in this research, thus the constraints on tasks on any weekly work schedule within this project were removed over the preceding six weeks — i.e. quality tasks were produced. Quality tasks are then scheduled at the weekly planning meeting (Figure 1).

There was only one "last planner" on the two cases described here – project manager to the general contractor. (In the Last Planner System the last planners are generally the trade crew foremen or supervisors working collaboratively.)

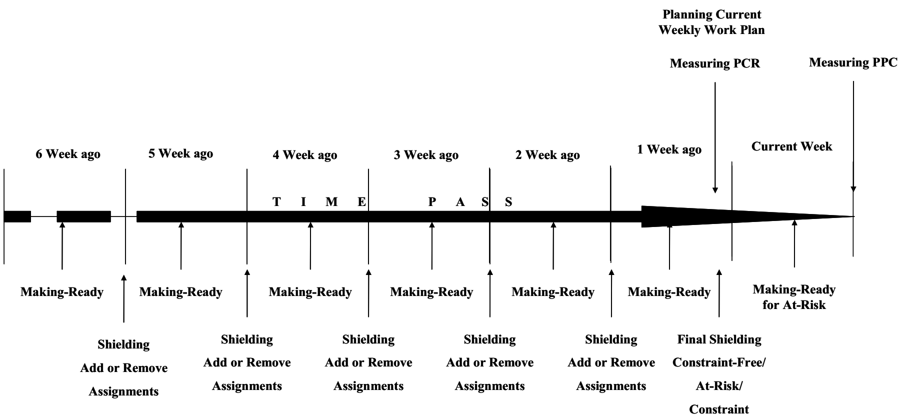

Figure 1: Planning Process and Performance Measurements

How successfully the make-ready process was performed was measured by PCR. This measurement also showed how successfully constraints were removed. In the calculation of PCR, only the 100% constraint-free tasks were counted; tasks with constraints were not counted. The equation for the calculation of PCR in the make-ready process is as follows:

$$PCR(\%) = \frac{Number\ of\ Constraint\ Free\ Assignments\ at\ Weekly\ Work\ Plan}{Number\ of\ Planned\ Tasks\ at\ Lookahead\ Plan} \times 100$$

Only assignments (tasks) listed six weeks the current weekly work planning (six weeks beforehand) were counted. Assignments added after that were not counted.

DATA COLLECTION

The role of authors was neutral observers. Data were collected from two project sites. Methods for data generation were based on two items:

the six-week lookahead schedule and weekly work plans. Data were collected weekly for twelve months. The number of planned assignment for each day was recorded, as was the number actually completed by participants (this was the source for PPC). The status of the make-ready process for each assignment was recorded (this was the source for PCR).

Microsoft Excel and Access were used for data collection. This format was modified with inputs from the sites. The data was processed by using Microsoft Visual Basic. The application format is simple and easy to use for calculations of performance. The PCR and PPC were recorded daily and reported weekly.

The fifty-three sets of performance measurement data from each case study were collected to conduct the analyses.

STATISTICAL MODEL DESIGN

This research examined how well the projects performed the make-ready process to manage production planning and control according to their operational performances as measured by PPC.

As PCR measures the rate of task preparation, it can help to predict future production and measure the quality of the make-ready process. Although this was the first time PCR was utilized with the make-ready process, it seemed intuitively obvious that PCR would improve not only the performance of the make-ready process, but also, over-all project performance. Thus, the authors hypothesized the following:

Hypothesis: PCR is a leading indicator of PPC.

Under the hypothesis, regarding the improvement of project performance, differences in the regression coefficients from project to project would likely have been found. A multiple linear regression model was developed to investigate the relationship between project performance and an explanatory variable. We ran the following regression model for the current study:

$$Project\ Performance(PPC) = b_0 + b_1 PCR$$

The following variables relating to project performance were included in the regression model:

- Percentage of Constraints Removal (PCR) in week *n*. This assessed performance of the make-ready process.
- Project Performance (PPC) in week *(n+1)*. This was a dependent variable that assessed the on-time task completion rate and measured project performance by focusing on workflow reliability.

CASE STUDIES

The case studies were two bridge construction projects, which were carried out between January and December of 2007.

The *pre-cast concrete beam* process (PC-Beam) was the focus of this research, as the process cycles require large crews and heavy equipment. The standardized scope of tasks was used for data validation in the case studies.

We added a PPC column onto the current weekly work plan and added columns onto the six-week lookahead window to include the last responsible moment (LRM), constraints and responsibility levels, all of which helped to create the weekly work plan (Figure 2). The purpose of the constraints column was to check constraint removal on each task and calculate the number of tasks made-ready. A weekly coordination meeting was used in these cases to address the status of constraints, allocate constraint levels, and discuss how to resolve constraints by all participants.

The LRM was calculated by subtracting "longest lead time of resources" from "scheduled early start times". The LRM indicated the last time when the procurement order on resources ought to be placed. This was done in order to notify the person in charge about the deadline for solving that constraint. Constraints past the LRM were shielded, however when making the weekly work plan "at-risk" tasks were released if the constraints could be solved before work was to start. Tasks with unsolvable constraints were shielded. For example, the longest lead time of resources in a driving H-pile task is ten days and the task is scheduled to start June 10. In this case, the LRM is June 1.

Weekly Constraint Tracking Reports

ID.	Assignments Level			In Charge		Schedule Date	Execution Date	Duration	Constrant Codes					LRM					Cost Info	Re
	L1	L2	L3	Major	Minor				C1	C2	C3	C4	C5	C1	C2	C3	C4	C5		
17-1001	Tunnel	Earth Work	Tunneling(PS-3B)	Smith	Kim	3/5/2007	3/26/07	2	01-02	01-03	02-01			3/15/07	3/17/07	3/21/07			[redacted]	
17-1003	Tunnel	Earth Work	Tunnelin(PS-4A)	Smith	Kim	3/5/2007	3/26/07	2	01-03	01-02	02-01	02-03	04-01	3/15/07	3/17/07	3/17/07	3/24/07	3/24/07	[redacted]	
17-																			[redacted]	

Figure 2: Weekly Constraint Tracking Reports

RESULTS

CASE A

During the research, the average PCR of Case A was 85%, ranging from 70% to 100%. The average PPC was 86%, ranging from 64% to 100%. The average numbers of the assignments were 93.7.

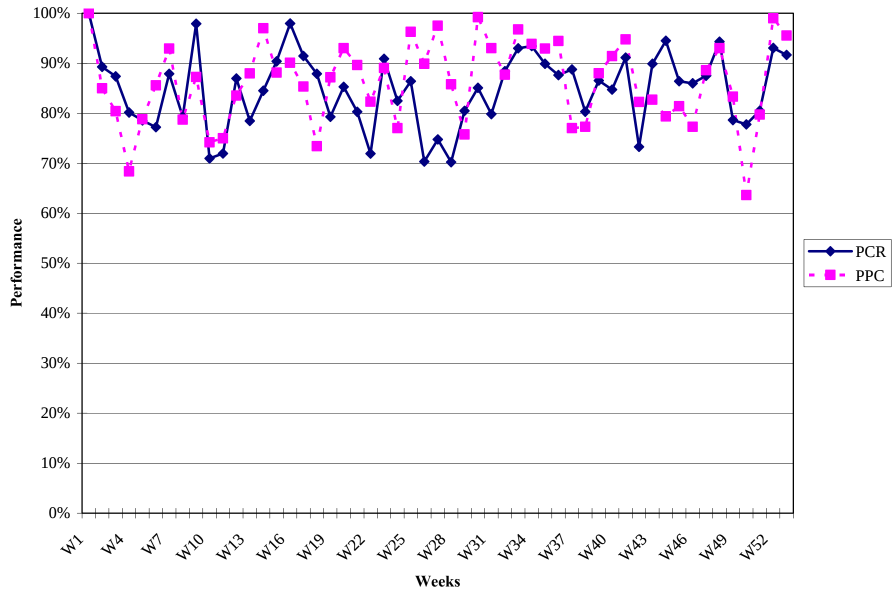

Figure 3: Percentage of Constraint Removal (PCR) and Percent Plan Complete (PPC) for Case A over a 53 week period.

CASE B

During the research, the average PCR of Case B was 77%, ranging from 47% to 100%. The average numbers of the constraint-free assignments were 85.3 and 114.6. The average PPC was 84%, ranging from 65% to 100%. The average numbers of the assignments were 146.5.

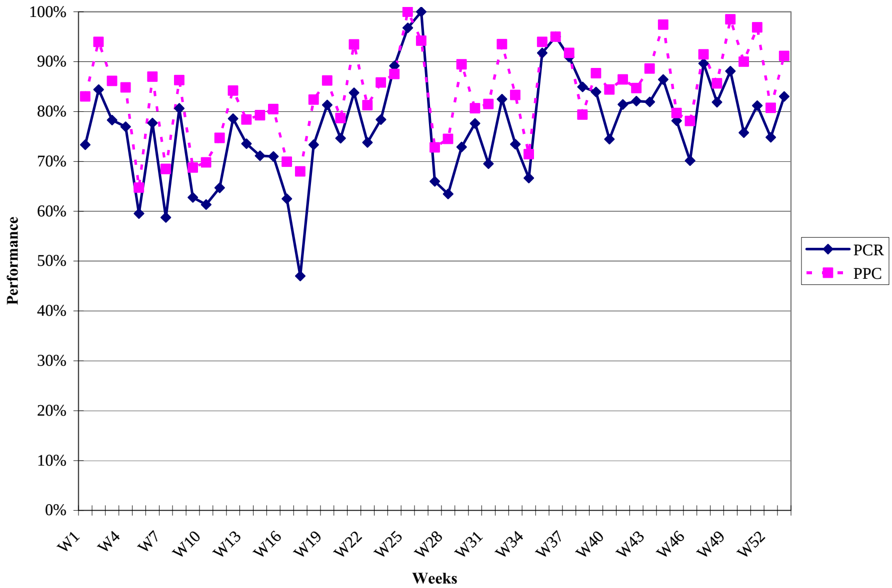

Figure 4: Percentage of Constraint Removal (PCR) and Percent Plan Complete (PPC) for Case B over a 53 week period.

CORRELATION ANALYSIS

Under the hypothesis, we expected to find a positive correlation between PPC and PCR. The results of the correlation analysis are summarized in Table 1.

Table 1: Correlations between Percentage of Constraint Removal (PCR) and Percent Plan Completion (PPC)
(N=53, *Significant at the 0.05level for each case study)

	PPC	
	CASE A	CASE B
PCR	0.793	0.833
P-Value*	7.68E-10	8.72E-13

The results showed that the correlation coefficients were quite high. The variables were significantly associated with one another. According to the correlation analysis (Bryman and Carmer, 2005), both results showed a high positive correlation existing between PCR and PPC ($p<0.05$).

Reducing workflow uncertainty is critical to improving productivity on construction projects (Howell, 1981; Thomas, R. et al., 2003). The higher the PCR value, the higher the predictability of the resulting workflow. As a result, project managers are better able to predict workflow reliability (PPC) in the planning stage, which is one of the critical preconditions for better productivity.

MULTIPLE REGRESSION ANALYSIS

The hypothesis was tested with a regression model employing the previously described explanatory variable. Table 2 reports the results of the two cases.

Table 2: Results of Regression Analysis
(N=53, *Significant at the 0.1 level for each case study)

Case	Variables	Coefficients	t ratios	P level*	Adjusted R^2
A	Constant	0.329	7.01	5.16E-9	0.62
	PCR	0.659	11.32	1.58E-15	
B	Constant	0.273	6.44	4.12E-8	0.78
	PCR	0.735	13.51	1.77E-18	

The regression analysis revealed that workflow reliability positively related with PCR ($p<0.1$). In this research, the level of task preparation (PCR) was a significant predictor of project performance. According to the regression results, the coefficient of PCR was positive, which indicated that project performance would increase as PCR increased. These results indicated that the relationship between project performance and PCR was significant ($p<0.1$). The PPC measures workflow reliability, a process focusing on the hand-off of tasks. The progress of tasks is either 100% or 0% when using this measurement. If a task is not finished on-time, PPC is 0%. The authors believe these findings confirm that improving workflow reliability is strongly related to improving workflow predictability. Note in Table 2 that the hypothesis is confirmed through regression analysis.

The coefficient determination, R^2, was high enough for all of the cases. According to Sawyer and Ball (1981), the R^2s are in the range that is often considered theoretically important in social science research.

The evidence provided by the correlation and statistical analyses showed the importance of the make-ready performance, which influenced PPC. As a leading indicator, PCR not only provided a way of monitoring the make-ready process, but was a good indicator of production reliability in the next week.

DISCUSSION

By measuring the PCR of these case studies, this research focused on how the performance of the make-ready process could change workflow predictability and reliability.

One of the most interesting findings of this research was that PCR was confirmed by correlation and regression analyses to be a leading indicator of project performance. The strong relationship between the dependent and independent variable in this regression model could be used by management for determining its own project performance; management may take into account the leading performance indicator and the systematic approach to the make-ready process.

The performance of production planning and control can be measured by PPC. The higher the PPC value, the higher the reliability of the workflow. However, PPC is a post-production process measurement. The PCR is useful because it measures a process that is critical to successful production and so reduces the need for subsequent improvement of that part of the process. Increasing workflow predictability is critical to improving reliability in construction projects (Ballard, 1999). A leading indicator of production performance is needed to help management better predict productivity, which is one of the critical preconditions for improving productivity.

CONCLUSION

For this research, the authors employed statistical analysis methods to examine the hypothesis. Based on the hypothesis, workflow reliability was highly correlated with the performance of the make-ready process. As a result, the case studies provide strong support for the existence of a positive relationship between a performance of the make-ready process and PPC.

Tracking the make-ready process improved both workflow predictability and reliability. As this has tremendous potential for improving engineering and construction performance, it is appropriate to focus future research on improving the make-ready process, confident of its benefits to project performance.

Tracking PCR helps to determine whether the make-ready process has been performed successfully. We also concluded that as a leading indicator, PCR can forecast project performance.

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