USE OF PERCENT OF CONSTRAINT REMOVAL TO MEASURE THE MAKE-READY PROCESS

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

ABSTRACT

Project process controls have traditionally occurred after-the-fact, and have focused exclusively on finding discrepancies and measuring results after a specific period of time. The Last Planner® System (LPS) is a production planning and control tool focused on the make-ready and shielding processes for improving workflow reliability. In the LPS, percent plan complete (PPC) has been used as a measurement of the shielding process. However, the system lacks a measurement for the make-ready process. This paper proposes a new measurement for the make-ready process called percentage of constraint removal (PCR). This new measurement of constraint removal would be an efficient and flexible means to measure the make-ready process. This measurement provides 1) a leading indicator for work production performance, 2) a performance measurement for the make-ready process, and 3) how appropriately to size the look-ahead window. This paper presents three case studies of heavy construction projects where both performance measurements, PCR and PPC, were applied and investigated. How PCR and PPC are correlated with progress performance was also studied.

KEY WORDS

Last Planner® System, make-ready process, percent plan complete, percentage of constraint removal, case study.

INTRODUCTION

Construction projects have become more complex (Bertelsen, 2003). As a result, uncertainty of workflow and interdependency between tasks has increased. Improving workflow reliability through production control systems has become more important. Lean Construction is a movement that focuses on planning and controls in which interdependency and uncertainty are critical to the project (Ballard, 1994).

The Last Planner® System (LPS), which is widely implemented in the Lean construction community, is a production planning and control tool used to improve workflow reliability (Ballard, 1994). While the LPS provides details of task criteria, it also gives its users flexibility in the make-ready process[3]. Under LPS theory, improving workflow reliability can be achieved both by a systematic make-ready process, and the shielding process[4].

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[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, Constr. Engr. and Mgmt. Program, Constr. Mgmt. and Wood Product Engrg. Department, 153 Baker Lab, State University of New York, College of Environmental Science and Forestry, Syracuse, NY 13210, 315/470-6839, FAX 315/470-6879, ywkim@esf.edu

[3] The main activities of the make-ready process are constrain analysis and constrain removal procedures.

[4] The shielding process is systematic process for making "quality task." Making quality tasks shields production units from workflow uncertainty, by enabling those units to improve their own productivity, and also by improving the productivity of those units downstream (Ballard and Howell, 1998). For low-level workers, the shielding process serves as protection against workflow uncertainty.

Since previous research has focused on the shielding process, it has been hard to measure the make-ready process because there are a lot of types of constraints. Constraints differ from company to company and project to project. There has been reasearch related to measuring the performance of the make-ready process (Mitropoulos, 2005). This paper presents the make-ready process using organizational hierarchy constraint analysis with the LPS, and a new measurement of the make-ready process, Percentage of Constraint Removal (PCR) that would be an efficient and flexible means to measure constraint removal. This systematic approach to the make-ready process and its measurement provide: 1) the leading indicator for work production performance, 2) the performance measurement for the make-ready process, and 3) how appropriately to size the look-ahead window. This paper presents three case studies of construction projects, where both Lean performance measurements, PCR and Percent Planned Completion (PPC), were applied. The correlation between PCR and PPC was investigated as well.

RESEARCH OBJECTIVE

This paper focused on how the LPS and the extensive make-ready process could change workflow predictability and reliability using an important new measurement, PCR.

The representative measurement in Lean construction, PPC, is focused on the shielding process, not the make-ready process. The make-ready process lacks a means of measurement because most production measurements in Lean construction are after-the-fact. As a leading indicator, or predictor of future productivity, PCR would provide the ratio of constraint-free tasks to those with constraints. Thus, the correlation between the current after-the-fact measurements and PCR could provide both productivity predictions and would measure the performance of the make-ready process. In the LPS, a well-performed make-ready process is prescriptive for stabilizing future productivity because constraints could be removed during the make-ready process itself. PCR could be the missing link as it is a predictive measurement of the make-ready process.

The goal of this research was to improve control of the make-ready process, and test PCR as a measurement of the make-ready process in construction projects. The research questions were:

- How does PCR as measurement of the make-ready process correlate with existing Last Planner indicators?
- Can PCR represent workflow predictability in the construction process?

BACKGROUND OF RESEARCH

THE LAST PLANNER® SYSTEM COMBINED WITH ORGANIZATIONAL HIERARCHY CONSTRAINT ANALYSIS

Many front line managers tend to try resolving the constraints by themselves rather than sharing information. Sometimes, even when implementing the LPS, a lack of informational transparency arises (Kim and Jang, 2006). "Process transparency requires that information should be shared, communicated and presented in a unified format, and [that] a more autonomous, participatory decision-making process should be established," (Lantelme et al., 2000).

Most companies traditionally perform constraint analysis on their work plans. In most cases constraint removal is done informally, thus the experience, foresight, and general capabilities of the managers make a great deal of difference. The problem is that when removing constraints in this way, it is hard to keep track due to fighting fires resulting from a failure to remove constraints. Missing and delayed access to information constitutes 50~80% of the problems in construction (Howell and Ballard, 1997; Thomas et al., 1997). A lack of informational transparency can result from informal constraint analysis because problems may be hidden. Hidden problems, ones that are small at first, later become much larger and more difficult and expensive to solve.

Constraint identification requires “translating” activities into specific tasks addressed to specific people, so that the organization can identify the requirements for these tasks (i.e., authorizations, resources, and the status of pre-requisite work) (Kim and Jang, 2006). Constraint analysis involves gathering information regarding the status of the work constraints, such as the status of the design, the availability of materials and components needed for each activity, and the likelihood that prerequisite work will be complete when needed. Thus being systematic and having a lot of experience in the industry is key to making good choices and tasks.

The authors did case studies about organizational hierarchy constraint analysis and assert that responsibility should be delegated to the appropriate level of management in the organization when constraints are identified in the course of the make-ready process (Kim and Jang, 2006). In the weekly project meeting, each constraint identified in the six-week lookahead window is assigned to the appropriate level of responsibility in the organization.

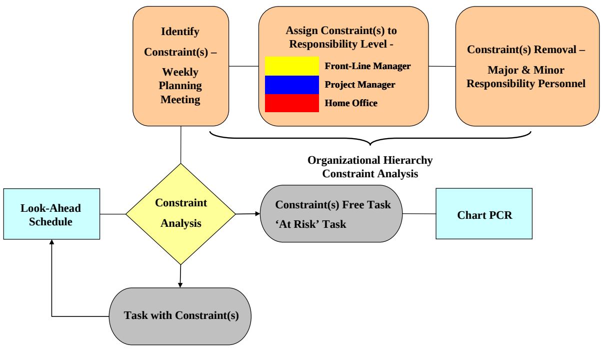

Figure 1: Organizational Hierarchy Constraint Analysis Process (Source from Kim and Jang, 2006)

The authors are suggesting that the work can be assigned under the LPS if the Last Planner is very certain that the constraint can be removed before the start of the work. This is where the previously mentioned experience, foresight, and general capabilities of certain managers might be redirected, PPC acting as a way to measure the accuracy of their forecasts. The degree of uncertainty should be disseminated as well.

There are three triaged levels of tasks in construction projects that must be considered in the process of controlling construction production. The first level contains constraint-free tasks; these are tasks the constraints of which have been removed as per the three to six-week lookahead schedule. The second level of tasks is “at-risk”. This contains tasks that have constraints that are likely to be solved by the beginning of the start of work. Then the third level has constraints that are unsolved or problematic, and obviously cannot be passed downstream by making a work order because the constraints cannot be resolved before the start of the task. Tasks with insoluble constraints were shielded.

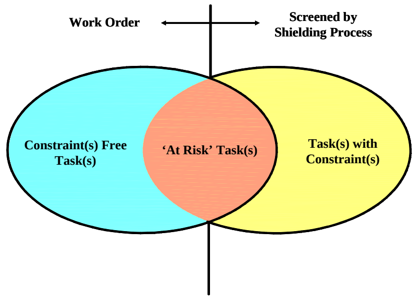

Figure 2: The Three Triaged Levels of Tasks

The authors' concept of using organizational hierarchy constraint analysis with the LPS increased the flexibility of schedule variance, and workflow reliability. This improved informational transparency so that hidden problems were revealed ahead of time (Kim and Jang 2006). The LPS becomes more powerful as a tool for constraint management with the use of organizational hierarchy constraint analysis because it becomes more systematic and responsive.

MEASUREMENTS

There are three measurements in this case studies, PCR, PPC, and Percentage of Planned Work Completed (PWC), which can be derived from the weekly work plan and the lookahead window. Except for the first week of the project, there was always at least one week that came before the present week.

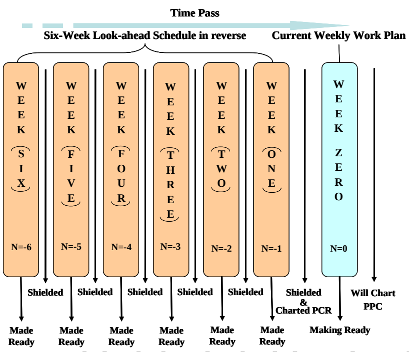

Figure 3: Six-week lookahead schedule and weekly work plan.

Figure 3 is an example of the planning procedure for the weekly work plan. The six-week lookahead schedule is used for making the weekly work plan in week zero. The size of the lookahead window is six weeks. In the planning system, if a company has a six-week lookahead window, the range of the PCR calculation is negative six to one. Week 0 is always the current week, or the weekly work plan. Let negative three or (3) indicate week three of the previous three weeks of the last lookahead window.

The metric to measure how successfully the make-ready process has been performed is PCR. In the PCR calculation, only the 100% constraint-free tasks are counted. The 'at-risk' tasks and tasks with constraints are not counted. The equation for the calculation of PCR in the make-ready process is as follows:

$$PCR_{(n)}(\%) = \frac{Number\ of\ Constraint\ Free\ Tasks\ When\ Scheduling\ WWP^{1}}{Number\ of\ Planned\ Tasks\ at\ Week\ (n)^{2}\ Lookahead\ Window} \times 100$$

(1)

The PPC is a measure of workflow reliability (Ballard, 2000) and focuses attention on the workflow of the production planning of the upstream production units, as they are sources of information regarding workflow to downstream production units (Ballard, 2000). The equation for PPC is as follows:

$$PPC(\%) = \frac{Number\ of\ 100\%\ On-Time\ Work\ Completion\ Tasks}{Number\ of\ Constraint\ Free\ Tasks + Number\ of\ 'At-Risk'\ Tasks\ at\ WWP} \times 100$$

(2)

The PWC is widely used in project sites for checking project work progress. PPC counts only 100% completed tasks within its scheduled duration, however, PWC, which is the amount completed divided by the amount planned (a percentage) within its weekly work plan. The PWC was calculated as an average for each task. The equation for PWC is as follows:

$$PWC(\%) = \frac{\sum_{n=1}\left[\left(\frac{Amont\ Completed\ Task1}{Amont\ Planned\ Task1} \times 100\right) + \cdots + \left(\frac{Amont\ Completed\ Task\ n}{Amont\ Planned\ Task\ n} \times 100\right)\right]}{n}$$

(3)

As a leading indicator PCR will be calculated before the current week's weekly work plan starts; PPC and PWC will be calculated after the current weekly work plan (Figure 3).

CASE STUDIES

These case studies focused on how the LPS and extensive make-ready process could change workflow predictability and reliability by measuring PCR in construction projects. The case studies were three highway construction projects, which were carried out between April and September of 2006, and were divided into two phases.

In the first phase, there was no Lean implementation because it was used as a basis for comparison to the performance after the implementation in the second phase. In both of the first and second phases, performance was measured with PCR, PPC, and PWC.

The same three types of schedules standardized the scope of tasks to create a work breakdown structure used for data validation in the case studies: the master, and six-week lookahead, and the weekly work plan. In these case studies, the phase schedule was not used, because the general contractor released phase schedules based on flaw-free design to the company doing the case studies.

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[5] WEEKLY WORK PLAN: Weekly Work Plan, Here, the WEEKLY WORK PLAN is done between week -1 (n=-1 or (1)) and week 0 (n=0 or 0) in order to plan for week 0, or WEEKLY WORK PLAN

[6] Week (n): n^{th} lookahead window week number, here (n) is a negative number. For example, week (0) means weekly work plan, week (3) means third week of six week lookahead schedule. In these case studies, the six-week lookahead window was implemented, and $PCR_{(6)}$ was calculated.

FIRST PHASE

The first phase was from April to June 2006. The planning system did not need to change during the first phase. They made a six-week lookahead window directly from the master schedule. The week negative one lookahead window (Figure 3) becomes automatically the current weekly work plan. They did not systematically or consistently implement either shielding or make-ready processes.

SECOND PHASE

In this phase the LPS was implemented with organizational hierarchy constraint analysis. The authors wanted to know how the LPS and extensive constraint analysis could change workflow reliability in the second phase by monitoring PCR in the make-ready process.

The second phase was from July 2006 to September 2006. This phase involved (1) implementing the LPS, and (2) developing a six-week lookahead window through organizational hierarchy constraint analysis.

Subsequent to the training and meeting sessions, the research team 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)[7], constraints, and responsibility level, all of which helped to create the weekly work plan. 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.

CASE STUDIES FINDINGS

PCR, PPC, and PWC were recorded daily and reported weekly. PPC and PWC were analyzed in order to determine how these measurements correlated with PCR. All three cases achieved PPC levels of 76% or higher, with Case C consistently above 90% in the second phase. The case study findings clearly showed improvement in all measurements of performance. Also, PCR, PPC, and PWC correlated highly to one an other. A systematic approach to monitoring the make-ready process and the ongoing education of participants made visible contributions to the LPS.

PERCENTAGE OF CONSTRAINT REMOVAL (PCR)

PCR within the previous six-week lookahead window ($PCR_{(6)}$) was tracked.

[7] 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 to solve 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.

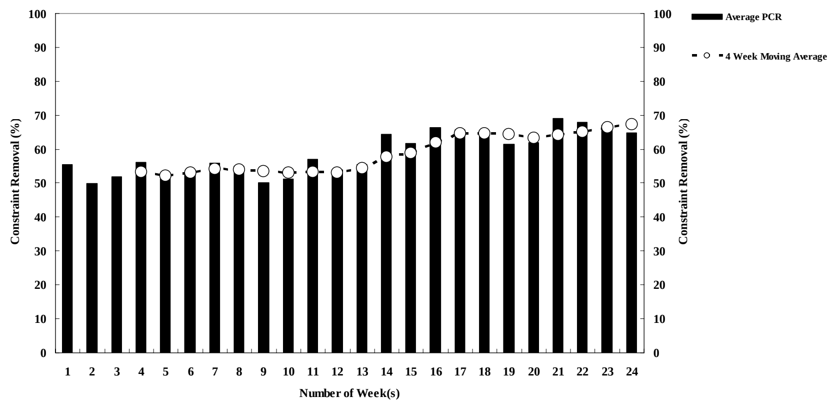

Figure 4: Average of Percentage of Constraint Removal (PCR) and the 4-week moving average for the six-case studies over a 24 week period.

During the case studies, the average PCR(6) was 54%, ranging from 48% to 69% (Figure 4). The average of the PCR increased by 19% in the first phase compared to the second phase.

The make-ready process was improved by monitoring PCR in the second phase. It clearly indicated that the organizational hierarchy constraint analysis increased informational transparency and systematically helped to solve constraints. During the six-month case studies, the number of tasks (constraint-free and "at-risk") in each weekly work plan was 67 ranging from 61 to 74 tasks. The "at-risk" tasks directly influenced the results of the PCR (see equation one). The average of the "at-risk" tasks decreased by ten percent in the second phased; possible explanations for this trend were the implementation of organizational hierarchy constraint analysis, and monitoring PCR in the second phase.

As a leading indicator, PCR not only provided a way of monitoring the make-ready process, but forecasted future production of planned tasks. This prompted management both to plan and control more carefully, especially the "at-risk" tasks.

PERCENT PLANNED COMPLETION (PPC) AND PERCENTAGE OF PLANNED WORK COMPLETED (PWC)

The average PPC was 67%, ranging from 53% to 80% and the average PWC was 90% during the case studies. The range of the PWC was 81% to 98% (Figure 5 and 6).

There was a steady period of improvement between Weeks 9 and 13 up to the level of 70% PPC and 88% PWC. The possible explanations for the increase are that there were more tasks made-ready and shielded due to a training session in the LPS and the monitoring make-ready process in the second phase. The change was due to a more systematic approach adopted after this training session.

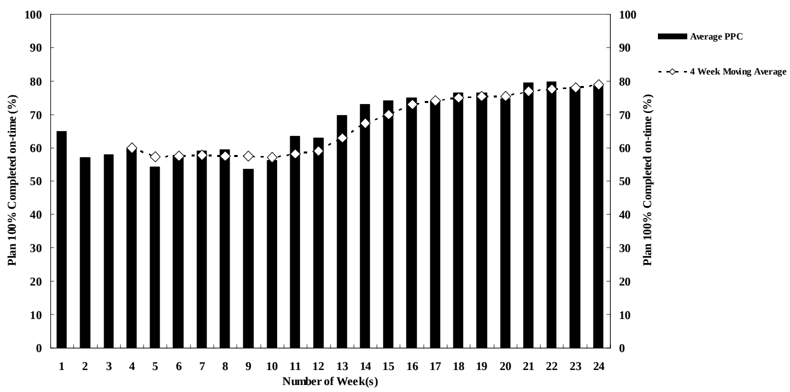

Figure 5: Average of Percent Plan Completion (PPC) and four-week moving average for six-case studies over a 24 week period.

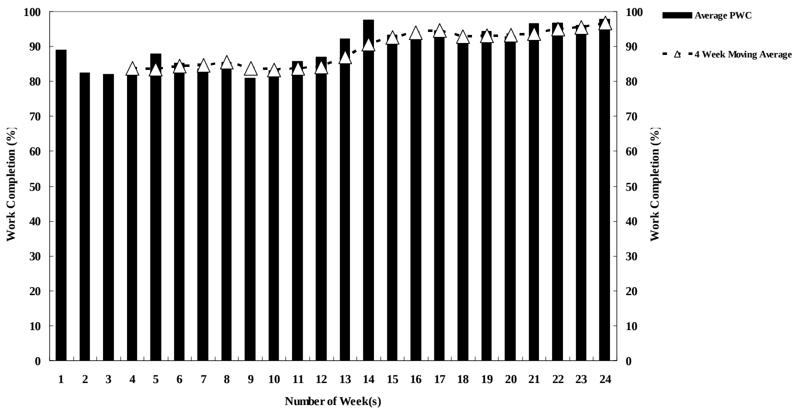

Figure 6: Average of Percentage of Work Completion (PWC) and 4-week moving average for six-case studies over a 24 week period.

CORRELATIONS AMONG PERCENTAGE OF CONSTRAINT REMOVAL, PERCENT PLANNED COMPLETION, AND PERCENTAGE OF PLANNED WORK COMPLETED

All three measurements showed similar trends in these case studies (Figures 4, 5, and 6). Since the LPS was adopted, production control and planning system performance is measured only by PPC in Lean construction (Ballard and Howell, 1998). Increasing workflow reliability is critical to improving productivity on construction projects (Howell et al., 2004). However, there is lack of measurement of workflow predictability (i.e. a leading indicator) in the construction production system. Without predictable workflow, productivity and the ability to plan deteriorate.

The conceptual relationships among PCR, PPC, and PWC seem intuitive, but nonetheless they need to be tested and measured, hence a statistical analysis is warranted to explore how these measurements are related in practice. The hypothesis was the PCR, PPC, and PWC correlated to one another on construction projects.

The correlation coefficient analysis of case studies is listed in Table 1. In all of the case studies, the correlation coefficient tested at 0.05 significance level. The results of PCR do correlate closely both with PPC, and PWC in these case studies, showing that PCR was an effective measurement of the make-ready process and provided workflow predictability as a leading indicator.

Table 1: Correlations among Percentage of Constraint Removal (PCR), Percent Plan Completion (PPC), and Percentage of Work Completed (PWC) , (Liner Regression model, N=24, Significant at the 0.05level for each case study)

	PCR-PPC		PCR-PWC		PPC-PWC	
	R^2	P Value	R^2	P Value	R^2	P Value
Case A	0.875	<0.001	0.853	<0.001	0.891	0.003
Case B	0.837	0.002	0.887	<0.001	0.907	<0.001
Case C	0.901	<0.001	0.871	<0.001	0.932	<0.001

CONCLUSION

Traditional project production controls have been comprised of after-the-fact detection measurements (Lantelme et al., 2000). There is no direct link between the metric and the improvement of performance. However, performance measurements, such as PPC and PCR, reveal information on the shielding and make-ready processes which would otherwise be obscured. The result of their performance motivates staff to change their behaviour. So, these metrics indirectly, but continuously influence the mechanism of production planning. As a leading indicator of productivity, PCR fosters the realization of plans, and thus the project management's desire to supplement workflow predictability in production management.

The systematic approach to the make-ready process improved both workflow predictability and reliability. As this offers tremendous potential improvements in engineering and construction performance, it is appropriate to focus research questions on improving workflow reliability, with confidence in its benefits to project performance.

The measurement and monitoring of the make-ready process improve informational transparency in production planning, and help to solve constraints before starting work. These result in a traceable percentage, enabling “at-risk” tasks to be better performed due to an increased awareness of their volume and nature. The tracking of PCR helps to determine whether the make-ready process has been performed successfully.

As a result of the case studies we concluded:

- Measuring and monitoring PCR can help to decide whether the make-ready process has been successfully performed.
- PCR as a leading indicator can forecast production progress.

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