S17-7 Can you predict the production performance using the make-ready performance?: Cases on highway construction projects

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ABSTRACT: The research investigates for the relationship between the operating performances of the make-ready process and project production performance. To this end, the researchers proposed a metric of PCR (Percentage of Constraint Removal) to measure the make-ready performance. The study measured the production performance in two ways: production planning reliability and progress performance. We hypothesized that how well the make-ready process is performed has an impact on the degree of production performance. The statistical analyses are used to investigate that how operating performance of the make-ready process affects project production performance. The results of the regression analysis support our hypotheses ($p<0.25$) and correlation coefficients for the relationship between project production performance and make-ready performance are also significant ($p<0.05$).

Keywords: Production planning; leading indicator, lean construction

1. INTRODUCTION

Since the complexity of construction projects has increased, workflow uncertainty and the interdependency among tasks has increased [1]. To resolve these situations of greater complexity, more systematic approaches to production planning and control are necessary [2].

Planning establishes goals and a desired sequence of events for achieving goals [3]. Control causes events to approximate the desired sequence, initiates re-planning when the established sequence is either no longer feasible or desirable, and initiates learning when events fail to conform to plan [3].

The construction industry can be characterized as having low-informational transparency and unpredictable workflow. Since the early 90s the Last Planner System (LPS), which is a production planning and control tool used to improve workflow reliability, has been widely implemented by lean construction practitioners with satisfactory results [4, 5, 6, 7]. Under the 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 and processes that identify and remove the constraints of the upcoming work [3]. The shielding process is a methodology to define criteria for making quality tasks [3, 6]. In LPS, the success of production planning and control is measured in terms of Percent Plan Complete (PPC). Currently the shielding process of LPS has five specific criteria, whereas the make-ready process of LPS does not. As no such study has been conducted, LPS does not necessarily improve or measure the make-ready process [8].

The objective of this research to investigate the relationship between make-ready process and the production performance. To that end, the authors proposed a metric for measuring the performance of make-ready process. We test the relationship between the operating performances of the make-ready process and project production performance. The study measure the production performance in two ways: production planning reliability and progress performance. We hypothesize that how well the make-ready process is performed has an impact on the degree of production performance. The statistical analyses are used to investigate that how operating performance of the make-ready process affects project production performance.

2. BACKGROUND

2.1 The Last Planner® System Combined with Organizational Hierarchy Constraint Analysis

The LPS produces quality tasks throughout the make-ready and shielding processes; the Last Planner is the person who makes the final decision about ordering work. Making quality tasks shields production units from workflow uncertainty by enabling those units to improve their own productivity as well as by improving the productivity of those units downstream [3, 6]. It proposes that the SHOULD needs adjusting to current reality and then, using lookahead and weekly planning, must be further adjusted to what CAN be done and what WILL be done [6].

The make-ready and shielding processes are performed simultaneously in the lookahead schedule to make quality tasks. The final shielding process occurs between the look-ahead schedule and the weekly work schedule (Figure 1). Sometimes, it is hard for the LP to shield tasks that still have constraints or uncertainties because doing so might affect the schedule and cost of the project [7].

Information transparency and active participation are important to resolving constraints. "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" [9].

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 [10, 11]. 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.

The researchers proposed a systematic make-ready procedure, which is called "organizational hierarchy for constraints analysis (OHCA) [12]" that was adopted for this research. The purpose of OHCA is to increase informational transparency by delegating responsibility to the appropriate level of management in the organization upon identifying constraints during the make-ready process. Constraint identification requires "translating" activities into specific tasks addressed to specific people, so that the organization can identify the requirements for these tasks. The process of OHCA:

- Predefining constraints for each task. Constraints fall into six categories which are resources (labor, equipment and material), authorization, prerequisite work and other; any constraints soluble with more than three days lead time are databased.
- Inputting constraint information. When tasks are put into the lookahead schedule taking into account the Last Responsible Moment (LRM), and the amount of work. The last responsible moment (LRM) is the deadline by which constraint solution should be made without disrupting the schedule.
- Assigning constraints to the appropriate level within the organization (front-line manager, project manager or home office level)
- Performing the make-ready process and the shielding process, combined. In each weekly project meeting, the tasks are screened by the participants.
- Reporting reasons for failure, when constraints cannot be solved within the allotted time framed on the lookahead schedule.

In the case studies, the researchers helped train people who participated in planning process for them to follow the procedure of OHCA.

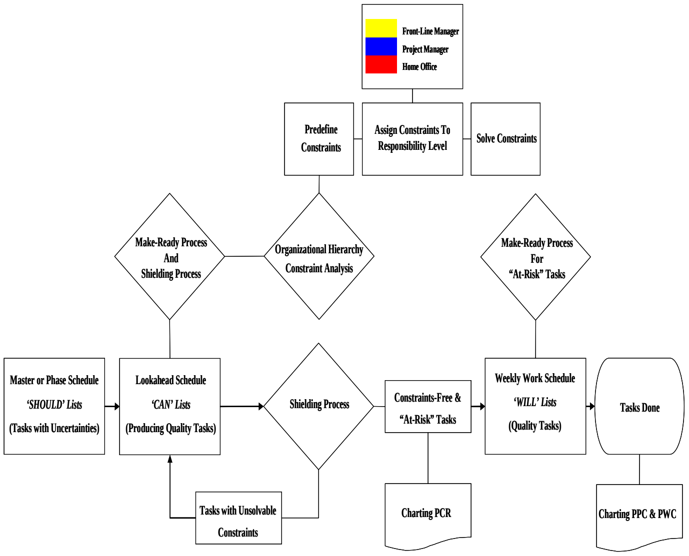

Figure 1. The Last Planner System with Organizational Hierarchy Constraint Analysis

2.2 Measurements

Since the inception of Lean construction theory and methods, there has been less effort to develop a performance measurement. Currently in the construction process, Percent Plan Complete (PPC) is the Lean performance measurement of workflow reliability, and of the accuracy of production forecasts. There are three measurements in this research, PPC, Percentage of Constraint Removal (PCR) and Percentage of Planned Work Completed (PWC).

The six-week lookahead schedule was used in this research. Current weekly work schedules must be planned six weeks previously. During these six weeks, quality tasks are produced. These tasks are to be scheduled at weekly work schedule. How successfully the make-ready process has been performed is measured by PCR [12]. In the calculation of PCR, 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:

$$PCR\ (\%) = \frac{Number\ \ of\ Constraint\ Free\ Tasks\ \ at\ Weekly\ \ Work\ \ Schedule}{Number\ \ of\ Planned\ \ Tasks\ \ at\ Lookahead\ \ Schedule} \times 100 \qquad (1)$$

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

$$PPC\ (\%) = \frac{Number\ of\ 100\ \%\ On - Time\ Work\ Completion\ Tasks}{Number\ of\ Constrai\ nt\ Free\ and\ "At - Risk"\ Tasks\ at\ Weekly\ Work\ Schedule} \times 100 \quad (2)$$

The PWC is widely used in project sites for measuring production performance in the Korea construction industry. This measurement is commonly used by payees for progress payment. The PPC counts only 100% completed tasks within its scheduled duration, however PWC is the percentage of work completed within its planned week. The equation for PWC is as follows:

$$PWC\ (\%) = \sum_{i=1}^{n} \frac{Budgeted\ Work\ Completed\ for\ Task\ i}{Budgeted\ Work\ Planned\ for\ Task\ i} \times 100 \quad (3)$$

As a leading indicator PCR is reported when the tasks are planned at weekly work schedule. However, PPC and PWC are reported after the tasks are executed from the weekly work schedule.

3. RESEARCH METHODS

3.1 Case Studies

The research was done through a series of case studies in order to test the proposed methodology. Multiple case studies allowed the researcher to pursue a progressive strategy, from exploration of a question to a more focused examination of trials [13].

Initially, fourteen projects were tested. However, eight projects were excluded from the database, because there were only data for a period shorter than four weeks. Six case studies were carried out between April and September of 2006. All six case studies were divided into two phases. The duration of each phase is three months. The OHCA was not implemented in the first phase to verify effectiveness of this methodology.

In all cases, we served as a consultant to the project team, and consequently was a participant rather than a neutral observer. Significant education and coaching were provided to the participants.

3.2. Data Collection

Data was collected from project sites. We standardized the work breakdown structure for the six case studies to validate the data. Methods for data generation were based on three documentations; the master, six-week lookahead, and weekly work schedules.

Data were collected weekly for six months (N=24 for each measurement per each project). During the period of data collection, the amount of actual work completed was recorded daily by project personnel at the end of the work day. On each day, the site work controller (i.e., the superintendent) provided details of the activities planned for the next day. The researchers communicated with the site controller weekly and had site visits occasionally for data quality control.

3.3. Statistical Model Design

The study examines how well the projects have utilized the make-ready process to manage production planning and control according to their operational performances as measured with PPC and PWC.

Considering that this was the first time OHCA was utilized with the make-ready process, it seemed intuitively obvious that OHCA would improve not only the performance of the make-ready process, but also over-all production performance. Thus, the first hypothesis is that implementation of OHCA improves production performance.

The rate of task preparedness is measured by PCR, hence the rates to which future production could be predicted and preparations made for performing that work. It also seems intuitively obvious that increasing PCR should increase PPC and PWC to some extent. The second hypothesis is that PCR affects the production performance as a leading indicator.

Under the hypotheses regarding the improvement of project performance, we should find differences in the regression coefficients across different projects. A multiple linear regression model was developed to investigate the relationship between the project performance and explanatory variables. We ran the following regression model for the current study:

$$P\,roject\ Performanc\,e = b_0 + b_1 PCR + b_2\ OHCA \quad (4)$$

Related to project performance, the following variables were included in regression model.

- Percentage of Constraints Removal (PCR): This assesses performance of the make-ready process (see equation 1).
- Systematic Approach of the Make-Ready Process (OHCA): This is the dummy variable that takes on the value of 1 if OHCA is implemented, and 0 if it is not.
- Project Performance (PPC): This is dependent variable. This assesses on-time task completion rate. This measures project performance which focused on workflow reliability (see equation 2).
- Project Performance (PWC): This is dependent variable. This measure project performance (see equation 3).

4. RESULTS ON CASE STUDIES

4.1. Correlations Analysis

Under the second hypothesis, we expected to find a positive correlation between production performance and PCR. If the make-ready performance increased, the correlations between production performance and PCR were strongly positive. The results of the correlation analysis are summarized in Table 1.

The results showed that the correlation coefficients were quite high. The variables were significantly associated with one another, furthermore, PPC and PCR in case F stands out as being highly correlated (0.92). According to correlation between PPC and PCR, project B shows that there is a modest positive correlation existing between PPC and PCR, and that 46 percent of the change in PPC can be accounted for from changes in PCR (0.682=0.46). This means that 46 percent of the variance in PPC is due to PCR. The result of the correlation analysis showed that PCR, as a leading indicator, was an effective measurement of workflow predictability.

The relationship between PPC and PCR is more significant than between PWC and PCR. Project A, C, and D show a high positive correlation, and case E and F show a very high positive correlation between PPC and PCR. In the case of PWC and PCR, project A, B, and D show a modest positive correlation and otherwise show a high positive correlation. There is no very high positive correlation between PWC and PCR [14].

Reducing workflow variability is critical to improving productivity on construction projects [15, 6].. The higher the PCR value, the higher the predictability of the work flow.

4.2. Multiple Regression Analysis

The hypotheses were tested with a multiple regression model employing the previously described explanatory variables form the systematic make-ready process. Table 2 reports the results of the two project performance models: the PPC and PWC models.

The regression analysis revealed that production performance was positively related with PCR and OHCA ($p<0.25$). In this research, systematic make-ready process and level of preparation of the tasks were the significant predictors of project performance. According to the regression results, the coefficient of PCR was positive, which indicated that a project performance would increase as PCR increased. The dummy was also statistically significant. As discussed, the dummy took on the value of 1 if OHCA was implemented, and 0 if it was not. The results indicate that the relationship between project performance and PCR is very strong when OHCA is implemented. This implies that as the performance of the make-ready process increases, production performance tends to increase as well. Note from Table 2 that hypotheses were confirmed through regression analysis.

The coefficient determination, R2, PPC model is higher than PWC model in all projects. The explanatory variables for the PPC model are statistically significant with the expected signs in the most projects. This is consistent with the correlation result. The PPC model is more reliable model in estimating the project performance than that of the PWC model. This is an expected results because, PPC measures workflow reliability which is focused on hand-off the task. The progress of tasks is 100% or 0% in this measurement. If task is not finished on-time, PPC is 0%, however, in the PWC measurement, the progress of work is counted whatever amount of work done within schedule time. We believe that the present findings reinforce that, improving workflow reliability is strongly related improving workflow predictability.

In the projects B, C, and E, the project performance model was confirmed at $p<0.25$; otherwise it was, $p<0.1$. One possible explanation is that other undefined variables, such as labor productivity or project surroundings affected project performance. A lot of uncertainties exist in the construction projects. However, the evidences of statistical analysis show the importance of the make-ready performance that influences construction project performance. Balanced replication increases our confidence in the existence of a positive relationship between OHCA and project performance.

4.3. Discussion

One of the most interesting aspects of the findings of this research was that PCR was confirmed by correlation and regression analyses for the leading indicator of the project performance. Also, OHCA played significant role in the regression results. Recall that these variables utilized in the regression equation, made significant contributions.

The performance of the production planning and control can be measured by PPC and PWC. The higher the PPC and PWC values, the higher the reliability of the workflow. However, these measurements are after-the-fact and have been traditionally used for production controls [5]. Increasing work flow predictability is critical to improving reliability in construction projects. The leading indicator of the production performance is needed to help managements better predict productivity, which is one of the critical preconditions for improving productivity.

The use of OHCA coupled with the LPS increased the performance of make-ready process and workflow predictability. The systematic make-ready process, OHCA, improved informational transparency so that hidden problems were revealed ahead of time. It became clear that the LPS is a planning tool for improving workflow reliability of the construction projects.

5. CONCLUSION

The research employed statistical analysis methods to examine the hypotheses. Based on the hypotheses, production performance and weekly production plan reliability were highly correlated with operating make-ready performance. We believe that this replication provides strong support for the existence of a positive relationship between systematic make-ready process and production performance.

A systematic approach to the make-ready process improved both workflow predictability and reliability. The OHCA of the make-ready process improves informational transparency in production planning. This methodology gives relevant information to stakeholders, which helps to remove constraints before releasing assignments.

Table 1. Correlation coefficient for Six Case Studies (N=24 on each case)

Project	Correlation between PPC and PCR		Correlation between PWC and PCR	
	Coefficient	Coefficient of Determination	Coefficient	Coefficient of Determination
A	0.86**	0.74	0.67**	0.45
B	0.68**	0.46	0.46**	0.21
C	0.85**	0.72	0.75**	0.56
D	0.73**	0.53	0.53**	0.28
E	0.91**	0.84	0.73**	0.53
F	0.92**	0.85	0.74**	0.54

** Correlation coefficient is significant at the 0.05 Level (two-tailed).

Table 2: Results of Multiple Regression Analysis (N=24 on each case)

Case	Performance	Variables	Coefficients	t ratios	P level*	R^2
A	PPC	Constant	0.18	2.09	0.048	0.82
		PCR	0.78	5.05	0.000	
		OHCA	0.08	3.05	0.006	
	PWC	Constant	0.60	5.55	0.000	0.57
		PCR	0.39	2.00	0.058	
		OHCA	0.08	2.39	0.026	
B	PPC	Constant	0.25	1.82	0.083	0.67
		PCR	0.61	2.55	0.018	
		OHCA	0.12	3.75	0.002	
	PWC	Constant	0.80	6.69	0.000	0.61
		PCR	0.07	2.36	0.226**	
		OHCA	0.13	4.63	0.000	
C	PPC	Constant	0.16	2.13	0.044	0.86
		PCR	0.78	5.15	0.000	
		OHCA	0.10	4.43	0.000	
	PWC	Constant	0.59	8.36	0.000	0.57
		PCR	0.49	3.59	0.001	
		OHCA	0.01	1.69	0.196**	
D	PPC	Constant	0.20	1.28	0.211	0.69
		PCR	0.74	3.03	0.006	
		OHCA	0.07	3.26	0.003	
	PWC	Constant	0.63	3.74	0.001	0.36
		PCR	0.40	1.55	0.138	
		OHCA	0.05	1.66	0.112	

E	PPC	Constant	0.10	1.62	0.119	0.85
		PCR	0.94	6.49	0.000	
		OHCA	0.02	1.95	0.240**	
	PWC	Constant	0.64	8.17	0.000	0.58
		PCR	0.40	2.34	0.029	
		OHCA	0.04	1.47	0.155	
F	PPC	Constant	0.05	2.87	0.189	0.86
		PCR	0.99	7.34	0.000	
		OHCA	0.03	1.71	0.239	
	PWC	Constant	0.67	10.71	0.000	0.59
		PCR	0.34	2.73	0.012	
		OHCA	0.04	1.56	0.013	

* Significant at the 0.10 level (two-tailed).,** Significant at the 0.25 level (two-tailed).

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