

IMPROVING LABOR PRODUCTIVITY THROUGH PRODUCTION CONTROL

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ABSTRACT

This research collected production data from a pipe installation project to study how construction labor productivity is related to four variables: Percent Plan Complete (PPC, a measure of work flow reliability), work load, work output, and workers per week. The results suggest that productivity is not improved by completing as many tasks as possible regardless of the plan, nor from increasing work load, work output or the number of work hours expended. Productivity does improve when work flow is made more predictable, thus enabling a better match of available work load with capacity (labor hours). These findings can help project managers understand the relationship between work flow and productivity and to focus on actual drivers of productivity. It may also help consulting companies pinpoint responsibility for productivity losses in claims.

KEY WORDS

construction management, labour productivity, work flow, work flow variation, Last Planner™ System

INTRODUCTION

According to Harmon and Cole (2006), labor costs generally make up 30 to 50% of overall project costs in the construction phase. Productivity must be at an acceptable level in order for the contract work to be financially successful (Thomas 1989, Finke 1997). In today's intensely competitive construction market, labor productivity performance thus plays a key role in determining the financial outcome of a project.

Previous research has studied how different factors affect labor productivity performance for construction projects. Koskela (1992

and 2000) introduced the flow view into construction management. Adler et al. (1996) studied work load variation at the organizational level. Ballard (1994, 1999a & b, 2000) introduced the Last Planner™ System to stabilize work flow (Last Planner is trademarked by the Center for Innovation in Project and Production Management, dba Lean Construction Institute). Tommelein et al. (1999) simulated the impact of work flow variability on the performance of successive trades with the Parade of Trades Game. Ballard (2001) and Ballard et al. (2003) applied work flow management principles and the Last Planner™ System in precast concrete fabrication. Ballard (2002) also helped

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project managers understand and improve work flow reliability in the design phase of projects. Choo (2003) computerized the Last Planner™ System in his Distributed Planning and Control software to improve production planning. Thomas (2000) recorded events that caused interruptions in work load for an electronic project. He observed reduced labor efficiencies when those events happened. Thomas et al. (2002) also raised the interesting question of how important it is to maintain a smooth output flow in order to improve productivity.

One aspect of work flow variation that has not been well researched is how work flow variation and labor productivity are related in construction practice. How do changes in work load, work output, and weekly work hours affect labor productivity? Can we test if there is a correlation using real project data? If that correlation exists, how strong is the correlation and why? If the correlation does not exist, why? Ballard and Howell (1995) argued that if work flow can be made more predictable, labor and other resources can be better matched to work load, thus improving productivity. Numerous supporting examples have been published in the literature, especially in the proceedings of the International Group for Lean Construction, but no rigorous quantitative analysis on the relationship between work flow variation and labor productivity has been reported. This paper presents such an analysis with a pipe installation project case study.

RESEARCH ON WORK FLOW MANAGEMENT

In this research, work flow variation is defined as the difference between the specific tasks which are predicted to be completed and those which are actually completed (Howell et al. 2004). Percent Plan Complete (PPC) is used to measure the reliability of work flow. PPC is calculated as the number of tasks actually completed according to the plan divided by the number of tasks that predicted to be completed (Ballard, 1994, 1997 and 2000).

Koskela (1992) first introduced the flow concept into construction management. He proposed that construction should be viewed as flow processes (consisting of both waste and conversion activities), instead of just conversion processes. Koskela (2000) further combined the Transformation view, Flow view and Value view into TFV theory and emphasized the importance of applying it in construction research and practice. He also suggested that TFV theory should be applied to construction and predicted vastly improved efficiency.

Howell and Ballard (1994a) proposed to reduce work flow variation by stabilizing all functions through which work flows from concept to completion. Better understanding the root causes of flow variation, suppliers and customers can act on the causes to reduce variation in shared processes.

Ballard (1993, 1994, 1997 and 2000), Ballard and Howell (1994a, 1994b, 1995, 1998 and 2003), and Howell and Ballard (1994a, 1994b and 1996) introduced the Last Planner™ System (LPS) to construction management. The Last Planner™ is

the front line supervisor; e.g., design squad boss or construction foreman. The initial implementation of LPS started in 1992 and the pace of implementation increased markedly after the publication in 1998 of "Shielding Production" (Ballard and Howell 1998). At the end of each plan period (typically weekly), Percent Plan Complete (PPC) is calculated. PPC measures the release of work from one crew to the next as predicted by a work plan. Lower PPC is understood to indicate greater work flow variation because downstream players are less able to predict what work will be released to them.

Tommelein et al. (1999) studied the impact work flow variability has on the performance of construction trades and their successors. The Parade Game consists of simulating a construction process in which resources produced by one trade are prerequisite to work performed by the next trade. The game shows that it is possible to reduce waste and shorten project duration by reducing the variability in work flow between trades. This Parade system also simulates the impact of work flow variability on succeeding trades performance and on project completion by the Parade Game. The findings help project managers understand work flow variability's impact on succeeding trade performance.

Choo (2003) developed computer software, WorkMovePlan, to support the distributed planning and control method. WorkMovePlan uses synchronization technology for the collaborative creation of production plans based on explicit resource and space assignments. This software has been adopted in Strategic Project

Solutions and applied on numerous construction projects.

Lee et al. (2004) defined work flow as the movement of workers or crews from one location to another (This might better have been called "worker flow" or "resource flow"). They presented a causal model to explain the relationship among those two labor factors and the movement. One case study of a building construction project was used to implement the causal model.

RESEARCH ON WORK LOAD, WORK OUTPUT, WORK HOURS AND LABOR PRODUCTIVITY

Thomas (2000) and Thomas et. al (2002) studied how different flow variations are related to labor productivity. They studied three types of variations: 1) variation in the amount of available work load, 2) variation in construction output, and 3) variations in construction input (changes in labor capacity expressed in weekly work hours).

1. Variation in the amount of available work load: Thomas (2000) studied the variation in the amount of available work load and the net weekly Inefficient Work Hours, in the electrical work on a project. He calculated Gross Weekly Inefficient Work Hours as the difference between the actual work hours and earned work hours. He then multiplied the Gross Weekly Inefficient Work Hours to 0.82 and used the result as the net weekly Inefficient Work Hours. He analyzed the chronology of events that happened from the beginning to the end of a project. Labor inefficiencies were found to be related to interruptions in the normal flow of work available for the contractor to perform. The problems with this

approach are 1) use of the 0.82 multiplier is not explained, and 2) the analysis of the relationship is based on a description of events, i.e., a precise quantitative analysis is not provided.

2. Variation in construction output: Thomas et al. (2002) ran tests on data from 14 construction projects and found low correlation between output variation and the Project Waste Index (PWI). PWI is defined as:

$$\text{Project Waste Index (PWI)} = \frac{\text{Cumulative Productivity} - \text{Baseline Productivity}}{\text{Expected Baseline Productivity}} \quad \text{Eq. 1}$$

This research consisted of a quantitative study of the relationship between output and productivity. The analysis of production data collected from 14 projects raises the interesting question of how important it is to maintain a smooth output flow in order to improve productivity. However, it did not explain why the cumulative output at 20, 50, and 80% milestones represent variation of output or how those milestones were chosen. The Baseline productivity in Eq. 2 was calculated using Thomas's Baseline productivity method, which has flaws (Ibbs and Liu 2005, Liu 2007). It also did not explain clearly how the expected Baseline productivity was calculated.

3. Changes in the amount of labor hours input: Thomas (2000) reports research on the relationship between the change in labor flow and labor inefficiency. He used three accelerated electrical projects and divided 250 weeks into 4 phases (2, 0.4Mp, and Mp. Mp is the maximum planned number of workers). He defined Performance Ratio (PR) as Actual Work Hours divided by Earned Work Hours. In phase 3, he found that PR is correlated with the change in the percentages of weekly work hours. He did not define the degree of acceleration these projects encountered.

DESCRIPTION OF THE PROJECT

The research reported in this paper was done on a pipe installation project. The objective was to understand the relationships between work flow variation and labor productivity. Construction started in March 2005 and finished in May 2006. The installation work includes 10 working areas A-H, J and K. Area F was the most complex installation. Working areas H, J and K are mostly large bore piping (18" to 30" diameter piping with a high percentage of chrome alloy) to overhead fin fan coolers. Areas A-E and G had similar pipe size and work complexity level. The difficulty level of making accurate work plans is expected to be the same within the similar working areas (A-E & G). Consequently, the difficulty level of accomplishing those work plans is expected to be similar. Therefore, the comparison of PPC values among those working areas is more appropriate, and we believe this group more accurately represents the relationship between work flow variation and productivity. Therefore the analysis was focused on working areas A-E and G.

A standard work process for the piping work was developed and all ten areas utilized the standard process. All the pipe installation work was

standardized into Delivery, Shake-out, Erect, and Weld as shown in Figure 1.

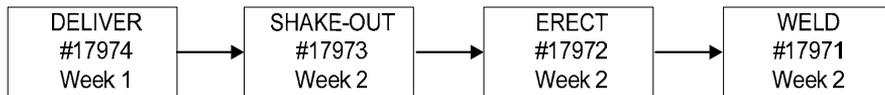


Figure 1: Standardized Work Assignments for Pipe Installation

The crews were all composed of union journeymen. Crew size varied between 8 to 12 workers each week depending on the amount of available work in each area. Basically, each foreman and a largely stable crew worked on the same working area until that work was completed. According to the project manager, crowding was not an issue for any of the ten working areas, all of which were outdoors. At the end of the project, welders were tested before being placed in production and the contractor had a reject rate below 3%.

According to the project managers, this is the first time the crews used the LPS. Foremen made weekly work plan under the instruction of project managers. Project managers also maintained a record of weekly earned hours and actual hours. The Last Planners and project managers maintained a Lookahead plan which includes the tasks that are near their scheduled start date (usually a few weeks ahead) with constraints not yet completely removed. At the end of each work week, the Last Planner™ team updated the database with current work status: 1) if tasks were done according to the plan from last week, the database releases successor tasks, making them eligible for inclusion in daily and weekly work plans, 2) if tasks were not completed according

the plan, then reasons are input, and 3) if additional tasks were completed but they were not on the plan, reasons for that are also provided. After updating with the new information, the database calculated PPC and generated reports on the reasons why tasks were not completed as planned. The Last Planner™ team received that feedback and incorporated it into the next plan loop. The database also automatically released the tasks with all the constraints removed and put them to the “Released” status. Last Planner™ teams formed next week’s plan from released tasks. The intent was that only tasks meeting certain quality criteria (definition, soundness, sequence, size, and learning) were to be included in the next week work plan. Constrained tasks could be included “at risk”, but that decision was to be made explicitly and recorded in the database.

RESEARCH FINDINGS

In order to investigate the relationships between labor productivity and work flow reliability, work load, work output, and weekly work hours, production data of the pipe installation project was collected. In this research, labor productivity of those working areas was measured by:

$$\text{Productivity} = \frac{\text{EarnedHour}}{\text{ActualHour}} \quad \text{Eq. 2}$$

Correlation analysis was done on productivity and each of the following five variables for the working area A-E & G. The result is shown in Table 1.

1. PPC
2. Taskplan = number of Weekly Planned Tasks

3. Totalcom = number of Weekly Total Completed Tasks
4. Nworker = number of Workers Per Week
5. TotalcomTaskPlan = number of Weekly Total Completed Tasks/number of Weekly Planned Tasks

Table 1: Correlation Coefficient Tests on Productivity and Four Variables

(1)	PPC (2)	Taskplan (3)	Totalcom (4)	Nworker (5)	TotalcomTaskPlan (6)
productivity	0.318**	-.051	-0.027	-0.014	0.048

**Correlation is significant at the 0.01 level (2-tailed).

The correlation coefficient is 0.318 at 0.01 significant level. This shows that work flow reliability and productivity are significantly and positively correlated. The overall trend is that as PPC increases, productivity increases as well (see Figure 2). None of the other four variables has significant correlation with productivity in this project. The correlation coefficient between the number of Weekly Planned Tasks (Taskplan) and productivity is -0.051, not significant. The number of Weekly Planned Tasks represents the amount of available work load. It is not significantly correlated with productivity on this project. Presumably, making the constraint-free status of scheduled tasks transparent enabled the project to adjust labor capacity (the number of workers in a crew) to better match changing work load in each area.

The number of Weekly Total Completed Tasks (Totalcom) represents the weekly construction output. In this pipe installation project, a significant correlation

between the output and productivity is not observed either. This indicates that construction output does not necessarily correlate with productivity performance. An explanation for which is that input labor hours were adjusted to better match available work load.

The number of Workers per Week is not significantly correlated with productivity either. This shows that productivity will not be affected by the variation of work hours so long as work flow remains reliable. The key for productivity improvement is not to increase the amount of workload, work output or work hours, but rather to have a predictable work flow and thus be able to match the available work load with capacity (work hours). The predictable work flow can be achieved by implementing LPS: empower the Last Planner™, commit to work plans that consist of constraint-free tasks only, continuously update the production information, and learn from previous failures.

To quantify the relationship between work flow variation and

productivity, a linear regression was performed. Figure 2 shows the linear regression line to predict Productivity from PPC. This regression line shows that PPC and Productivity are positively correlated. As the PPC value increases, productivity increases as well, yielding the following equation:

$$\text{Productivity} = 0.530 + 1.095 * \text{PPC} \dots \text{Eq. 3}$$

This means that a rise of one unit of PPC predicts a rise in productivity of 1.095 unit. An F-test was also conducted for statistical significance of this regression. It is obtained by

dividing the explained variance by the unexplained variance. The F-value for equation 4 is $F=8.093$, significance level is 0.006, which means that F is statistically significant and the regression PPC-productivity relationship in equation 4 is reliable. A T-test for statistical significance of the coefficient is conducted by dividing the value of the regression coefficient (b) by its standard error (for equation $Y=a+b*X$). The T value for coefficient b is 2.845 with significance level of 0.006, which means PPC has a statistically significant relationship with productivity.

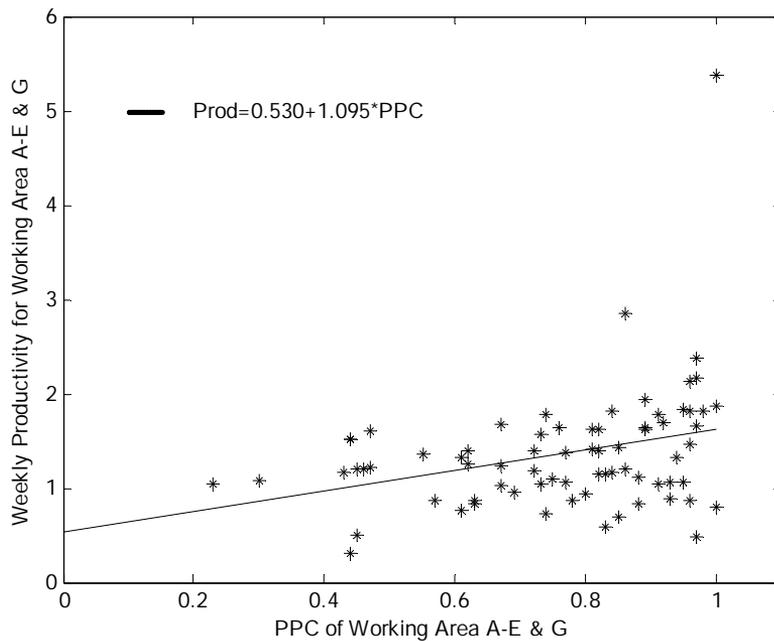


Figure 2: Scatter Plot and Linear Regression between Productivity and PPC

CONCLUSIONS

This study shows that work flow reliability and labor productivity were significantly correlated in the pipe

installation project, that LPS can reduce work flow variation if correctly applied, and that reducing work flow variation can also help improve labor productivity.

The findings of this research can help project managers and consultant companies in two ways.

1. The results can help project managers to understand the relationship between work flow variation and productivity, and the importance of work flow management in terms of improving labor productivity and the entire project's profitability. Implementation of LPS ensures that only the tasks with all constraints removed are included in work plans. As a result, crew delays and time spent 'hunting and gathering' are reduced, and productivity is improved. Project managers can use this finding to enhance work flow management through production planning to improve productivity. Improved work flow reliability and productivity can also help to reduce project duration and improve estimation accuracy on project completion time (O'Connor 2004). It will be beneficial to both public and private projects.

It was also found that productivity is not significantly correlated with the ratio of weekly total tasks completed to the number of weekly tasks planned, with the number of weekly tasks planned, with the number of weekly tasks completed, or with the number of workers per week. The results indicate that the key for productivity improvement is not to complete as many tasks as possible, or to maximize the number of workload, work output or work input hours without following the work plan. The key is rather to focus on maintaining a predictable work flow and thus be able to match the available work load with capacity (work hours). Managers can do many more things to improve productivity. Technology can be changed. Methods

can be improved. Skills can be enhanced and workers can be better motivated. But these findings suggest that the first and fundamental management action should be to reduce work flow variation from plan.

2. These findings will also be helpful for consultant companies to identify productivity loss, and pinpoint who should be responsible for what. Since work flow variation is significantly correlated with labor productivity performance, the party who caused work flow variation should also be responsible for the reduced productivity. Applying this work flow variation analysis in labor productivity claims can help contractors and owners reach an agreement on who caused productivity losses and who should be responsible for it. Therefore, it can help save time and money in productivity claims.

One limitation of this study is that was the first time the crews used LPS. There is likely a learning curve with learning the system and this project's results may be somewhat colored by that learning curve. Project managers and workers may think they understand the LPS strategies and how to apply it to work flow management while they may not, especially in the beginning. It may also affect the accuracy of data collected.

Another limitation is the lack of PPC and productivity data for preceding and following trades. The inventors of the Last Planner™ system have said that the primary impact on productivity is in the ripple effect of predictable handoffs through the 'parade of trades'. Their hypothesis could not be confirmed in this case for lack of data, but assuming that they are correct, the causal relationship between PPC and productivity may be

even stronger than we have been able to demonstrate in this paper. Support for this assumption may exist in the fact that the piping contractor underran their estimated labor cost by 24% on the case study project, and did so without paying overtime in a saturated market with competing projects using overtime to attract better craft workers.

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