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STABILIZING CRAFT LABOR WORKFLOW WITH INSTANTANEOUS PROGRESS REPORTING

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ABSTRACT

Stabilizing workflow is a common goal of research in lean construction, productivity, and production control methods. This study aimed to test the hypothesis that the combination of location-based work packaging and near real-time progress reporting contributes to reducing workflow variability. Some authors agree that daily monitoring allows timely actions to correct deviations from the baseline, which can increase workflow reliability. Thus, the objective of this study is to evaluate this statement in practice. The drywall installation in a healthcare facility served as the scenario for the test study. Drywall activities were divided into multiple tasks. Tasks were associated with locations and individually monitored. Although drywall tasks with unresolved constraints with mechanical activities did experience variations, a comprehensive analysis showed that most variations of workflow were proactively reduced.

KEYWORDS

Workflow, variability, lean, project controls, productivity, real-time.

INTRODUCTION

The production efficiency of the construction industry is fairly unsatisfactory, in spite of its relevant role in global and local markets. Lean construction has emerged as a possible solution for increasing the productivity and efficiency in the construction industry. An efficient management system is the key to achieving this goal. The lean

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production management aims to attack workflow variations, reduce waste, and increase the value of construction projects.

The results of the application of lean philosophy in the manufacturing industry are recognized. Unlike manufacturing, however, the construction environment carries several uncertainty factors. Each construction site has unique conditions and a number of variables such as weather, human resources, equipment, among others, bring uncertainty and unpredictability to the construction process. Controlling these variables can be extremely challenging, and such variability negatively affects productivity and leads to workflow variability and inefficiencies in production systems (Guo, 2002; Seppänen, 2009; Grau et al., 2014). Workflow variability, in turn, often produces a negative impact on cost, schedule, and/or quality (Hamzeh, 2009).

Stabilizing workflow (i.e. reducing workflow variations, increasing workflow reliability) has been a common goal in several past studies aiming to improve the theory and practice of lean construction. Authors have developed powerful frameworks and methodologies such as the Last Planner System, Location-Based Management System, and other location-based approaches to planning and construction (e.g. Ballard, 2000; Ballard and Howell, 2003; Seppänen, 2009; Seppänen, Ballard and Pesonen, 2010). The authors of these methodologies have been making additional suggestions to be tested on their implementation. Among the recommendations is the consistent collection and reporting of progress data and allowing timely alarms to correct deviations (Seppänen, 2009; Grau et al., 2014; Tang et al., 2014). However, there is not enough quantitative evidence that these strategies are successful to stabilize workflow.

This research builds on previous efforts and proposes to integrate a near real-time monitoring approach that allows a proactive progress assessment and timely corrective actions. Through the integration of small work packages and detailed monitoring, the proposed approach leads to a more instantaneous control of the work at the job site.

Indeed, this study has analysed the combination of location-based work packaging and near real-time progress reporting to reducing the workflow variability for drywall activities in a healthcare facility. The drywall packages were divided into work zones with daily supervision, which made possible to monitor the workflow in detail, and to allocate resources accordingly and provide corrective actions when necessary. Such approach allowed detailed productivity data to be collected on a daily basis and leaded to the results described in this paper.

BACKGROUND

Production management is at the essence of lean construction. A lean production management focus in work packaging and project controls is necessary to reduce and manage variability and uncertainty in the execution of planned tasks (Ballard et al., 2003). The primary strategy of lean construction is the look-ahead planning process. That is, the traditional critical path planning approach has been analysed and criticized by many authors, especially by lean thinkers (Ballard and Howell, 1994; Koskela and Howell, 2002; Hamzeh, 2009; Grau et al., 2014; Tang et al., 2014).

According to Koskela and Howell (2002), the lack of theory and understanding of concepts such as planning, execution, and controls lead to a counterproductive approach that undermines performance. Similarly, the traditional project planning is limited in what concerns scheduling. The traditional approach still makes use of the Critical Path Method (CPM). The CPM, however, fails to load resources in the contractor's schedule (Seppänen, 2009). Furthermore, CPM methods violate the principle of flow and lead to an increase of non-value adding activities (i.e. waste). As a response to these issues, Lauri Koskela introduced the theory of lean construction (Koskela, 1992). A core lean construction principle is to minimize variability (Ballard et al., 2005; Hamzeh, 2009).

Workflow variation can be thought as the variation of produced work at any moment in time, even though it is often simplified as the difference between the tasks that are predicted to be completed and the tasks actually completed (Liu, Ballard and Ibbs, 2011). Workflow varies if performance suffers from the impact of resources and constraints, that is, when it becomes unfeasible to predict the singular work that will be completed at any moment in time (Horman et al., 2004). This variation undermines project performance (Hamzeh, Ballard and Tommelein, 2012) and also has a negative impact on cost, schedule, and quality (Hamzeh, 2009). Liu, Ballard and Ibbs (2011) established a correlation between workflow variation and labour productivity. The authors analysed 134 weeks of production data on 10 working areas for a pipe installation project. The results showed a statistically significant correlation between productivity and workflow variation. Thus, reducing workflow variation can help improve labour productivity (Liu, Ballard and Ibbs, 2011). Other study achieved an improvement of 86% in productivity by improving workflow reliability (i.e. stabilizing workflow) (Ballard et al., 2003). Workflow reliability implies workload predictability. Without a predictable workload, capacity cannot be matched to load. Consequently, productivity deteriorates (Horman et al., 2004).

Production control can be defined as the monitoring of the performance of each execution against the plan, with corrective actions responding to possible deviations (Ballard and Howell, 1998). These corrective actions are the opposite as traditional results-oriented control methods. Results-oriented control is understood as the measurement of actual results and their comparison with the plan (desired results). Since this process intends to reveal problems after-the-fact, it is not efficient in timely identifying constraints and keeping the project on track (Ballard and Howell, 1994).

The Last Planner System (LPS) (Ballard 2000) emerged as a methodology to stabilize the workflow, increase planning reliability, and improve production performance (Hamzeh, Ballard and Tommelein, 2012). LPS tools are the look-ahead planning, commitment planning, and continuous improvement and learning (Ballard et al., 2003). In addition, LPS uses Percent Plan Complete (PPC) as a metric to track the work plan reliability. PPC equals to the number of completed tasks divided by the number of planned tasks for a given timeline. Ballard and Howell (1994) refer to an improvement in PPC as an indication of benefits from factors such as a more stable workflow. Indeed, LPS has a positive impact on workflow variation and labour productivity (Hamzeh, 2009).

One of the keys strategies of lean construction is small work packaging. It consists in dividing the work into small chunks of work in order to reduce constraints, such as work dependencies (Ballard et al., 2003). Ballard and Howell (1998) refer to work packaging as the link between scheduling and production control. In LPS, activities are broken down from phases to processes, then to operations or tasks, across the master schedule, phase schedule, look-ahead planning, and weekly work planning (Hamzeh, Ballard and Tommelein, 2012). The next level would be the daily task, or assignment, level (Ballard, 2000). These work assignments have to feasible, that is, their constraints must be timely identified and removed through look-ahead planning techniques.

Space conflicts in the job site can delay schedule and cause productivity losses (Guo, 2002). Location-based methods aim at reducing construction's complexity by planning production based on past production rates for similar projects (Seppänen, 2009). However, many researchers of such methods overemphasized theory and missed opportunities to implement the location-based concepts in production control. Seppänen (2009) proposed the Location-Based Management System (LBMS) as an attempt to fill this gap. Through an empirical study, he concluded that it is possible to use location-based management tools to improve the reliability and performance of a production system, for instance, by limiting dependencies and constraints based on location. As such, location-based planning can be observed as a complement to small work packaging.

LPS and LBMS are harmonizing production techniques. Seppänen, Ballard, and Pesonen (2010) raised the hypothesis that the combination of both approaches potentially reduces workflow uncertainty and increases productivity. LPS covers the human aspects of production, focusing on planning and commitment. LBMS is accountable for the technical aspects of controlling, and aims to streamlining workflow and reducing dependencies (Seppänen, Ballard and Pesonen, 2010). Ballard and Howell (2003) defended the importance of measuring the average duration of each task performed. Indeed, LBMS allows calculating such durations based on the quantities of material for each location, the labour consumption factor, and the crew size or equivalent work hours.

Although both LPS and LBMS have a firm theoretical foundation, various authors have already suggested necessary improvements and developments for a successful implementation. For example, Seppänen (2009) recommended generating timely warnings to allow the managers to respond to deviations with proactive actions. Seppänen also recommended to collect more consistent progress data in order to generate such timely alerts. Ballard et al. (2001) suggested "in-progress inspection" as a measure to reduce rework time and minimize waste. The proponents of LBS and LBMS have done several calls-to-action through their publications.

Measuring the productivity is essential to validate the quality of planned work (Ballard and Howell, 1994). The main contribution of this paper is the analysis of daily quantitative data to track the variation on produced work through a combination of geo-located work packages and real-time reporting mechanisms. The tested hypothesis is that such combination can contribute to stabilizing the workflow and improve the production control. The fundamental assumption is that a higher productivity variation (i.e. the difference between planned and actual productivity), exist when timely reporting mechanisms lack.

OBJECTIVES AND SCOPE

The objective of this study is to analyse the impact from the combination of geo-located and small work packages with a near-real time reporting capability on production workflow through immediate corrective actions. Thus, the hypothesis of this study is that small work packages provide an opportunity, as discussed above, to increase production, but also that a near-real time reporting or monitoring function is actually necessary to alert managers in a timely manner when deviations in the flow of work actually occur. This study adopted an Instantaneous Project Controls (IPC) approach to measure the difference between planned and actual field productivity in a near real-time manner. This project uses the drywall activity of a healthcare project located in Phoenix, AZ, as the test study.

METHODOLOGY

INSTANTANEOUS PROJECT CONTROLS APPROACH

The basis for the IPC approach is the relationship between construction quantities, labour resources, and tasks durations (Figure 1). The method starts with the extraction of construction quantities from as-designed data or models (e.g., Building Information Models). The production rate (quantity/time) for that particular task is then selected from a historical database of previously completed projects. These rates are useful to estimate the needed resources, such as crew, materials, and equipment properly. At the same time, the actual availability of resources is the basis to determine the task duration.

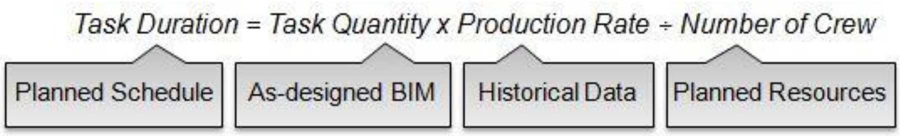

Figure 1: Relationship between quantities of construction, labour resources, and duration of tasks.

After estimating the amount of needed resources, the planners allocated them. This phase involves the subdivision of the facility's work areas into work location packages through the combination of scheduling and the assignment of small work packages at each work zone. The ideal size of work package should reduce dependencies in order to allow a more continuous workflow. In this study, the authors designed work packages of about 200 man-hours size. Then, the tasks (i.e. the smallest evident entity of work) are assigned to each work zone.

The crew reports on a daily basis: 1) the Actual Start (AS) and Actual Finish (AF) dates for each location; 2) the man-hours and resources needed for each period of time and task, and 3) the actual quantities completed and the corresponding degree of completion for each task for the recorded time. Finally, the production manager adjusts resource allocation and works to solve constraints in order to correct deviations from planning. The daily monitoring allows the crew to make timely corrective actions to drive the productivity back to the planned values. The assumption is that, once the difference between actual and planned productivity reduces, the workflow variations also decreases. In summary, this process allows a constant flow of factual production rates in the job site, while the adjustment of resources allocation reduces the variation of productivity and hence workflow.

The data analysis and update of the historical database follows the completion of the construction phase. The database should guide decision-making in future projects (e.g. resource allocation, contractors' selection), thus contributing to a continuous improvement of workflow stabilization methods. The envisioned controls and planning approach is summarized and illustrated in Figure 2.

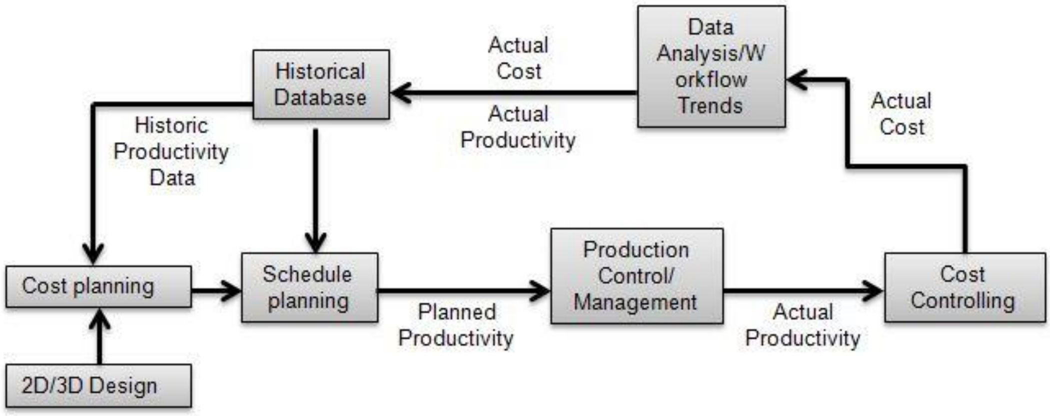

Figure 2: Instantaneous Controls and Planning Framework

DATA COLLECTION

The installation of 333 square meters of drywall in a hospital project supported this study. The total cost and duration for this particular activity were respectively $124,387 and 12 weeks. The contractor directly and continuously employed the drywall crews.

The contractor planned for 12 different drywall tasks: 1) Layout of walls, 2) Installing top track, 3) Framing full height wall, 4) Installing hollow metal frames, 5) Hanging drywall above ceiling, 6) Installing shaft wall, 7) Wall insulation, 8) Installing strap backing, 9) Hanging drywall below ceiling, 10) Framing of ceilings, 11) Framing of soffits, and 12) Hanging drywall at the ceiling level. The installation of mechanical, electrical, and piping (MEP) ducts was a constraint for the activities above the ceiling (framing of ceilings, soffits, and hanging of drywall at ceiling level). In addition, MEP activities were controlled by conventional Critical Path Methods (CPM) rather than through a lean planning approach.

A member of the contractor company spent 16 hours per week collecting productivity data. The contractor's foreman also invested work hours on reporting daily production log by work task and location. The BIM models were regularly updated according to the actual field production. The general contractor's project management database system (PMDS) provided data on production rates for drywall activity. This study collected drywall task data on schedule, planned production rates, resource crew allocation, cost estimates, and detailed actual field production data, such as: 1) planned start date, 2) planned end date, 3) planned total quantity, 4) planned duration, 5) planned man-hours, 6) actual quantity, 7) actual duration, and 8) actual man-hours.

ANALYSIS OF RESULTS

Each of the 12 different tasks related to drywall activity were analysed regarding planned and actual production data. This analysis has two stages. The first stage categorized the 12 observed tasks per the unit data (linear feet or square feet). An aggregate productivity analysis was performed for each task. The second stage analysed the 6 tasks with a minimum amount of data points (8 or more).

Individual Productivity Analysis

We performed an individual task productivity analysis for each task. Table 1 summarizes the planned and recorded production data of the 6 selected tasks in the drywall activity. The production data were used as a basis to compute the following:

Planned Production Rate. The planned productivity was computed by dividing planned total quantity by planned work-hours.

Actual Production Rate. The actual productivity per recorded field data was computed by dividing actual total quantity completed by actual work-hours consumed.

Mean Productivity differential. The actual productivity differential was computed as the difference between actual and planned productivity measures.

Table 1: Task Productivity Analysis

	Layout Walls	Frame Wall	Frame Ceilings	Frame Soffits
Unit	m/h	m/h	m^2/h	m^2/h
Planned Production Rate	8.37	1.29	1.84	0.28
Mean Productivity Differential	-1.79	1.28	-60	-0.12

The research team selected for individual analysis the six tasks with more collected data points. Through trend-timeline graphs, this study presents the productivity differential over a sequence of records. Productivity differential can be read as the variation of the productivity (i.e., the difference between actual and planned production rates).

The following graphs (Figures 3 and Figure 4) show an interesting production trend for each of the tasks in Table 1. In spite of the total productivity differential for each task, the trend after a reported deviation enabled to team to drive the production rates to the baseline or planned production rate. In the figures, the triangles represent the deviations. The horizontal line represents the baseline (planned) while the line represents the behavior of the productivity variation and changes. For example, analyzing the “hanging drywall below ceiling” task (Figure 4), the absolute value of productivity variation is significant, which means a considerable difference between actual and planned production rates. However, after each deviation was report, the line of actual production rate tends to approximate again to the baseline. Another result is that, for the tasks “framing ceilings” and “framing soffits”, most of the deviations were reported to be far below the planned. The reason for that is the existence of unresolved interdependencies with MEP tasks. Such positive trends are extensible to the analyzed 4 task below ceiling, while the trend of large deviations was observed for the two above-the ceiling analyzed tasks.

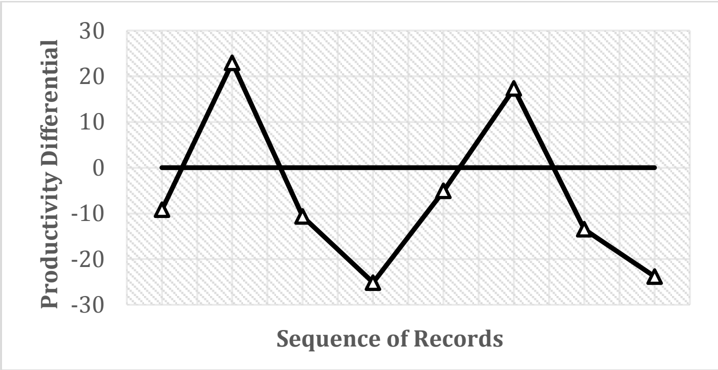

Figure 3: Productivity variation for Layout of Walls

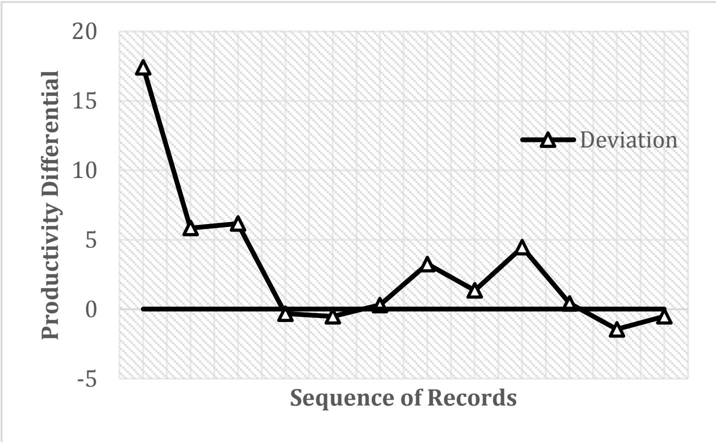

Figure 4. Productivity variation for Framing of Walls

Aggregate Productivity Analysis

The aggregate analysis assessed the mean productivity differential of the total group of tasks (i.e., 12 tasks previously mentioned). There are two different categories of tasks per unit quantity data, as shown in Table 1: linear (meter) and area (square meter). The authors decided to do a different aggregate analysis for each category due to the large difference between the mean range of planned production rates for area and length. The tasks measured in square feet were: 1) Hanging drywall above ceiling, 2) Wall insulation, and 3) Hanging of drywall below ceiling and hanging drywall at the ceiling. The tasks measured in linear feet were: 1) Laying out of walls, 2) Installation of top track, 3) Framing of walls, 4) Installation of shaft wall, 5) Installation of strap backing, 6) Framing of ceilings, and 7) Framing of soffits.

Overall, deviations actually fluctuated around the planned productivity (i.e. around a 0 deviation value) confirming the previous results for individual tasks. In other words, the deviations were frequent around the planned productivity and infrequent as those deviations were larger when compared to the planned productivity. In some cases the shape of such deviations resembled a normal distribution with the mean at the null deviation from the planned productivity. Such trend was also evident for both square and linear meters measured tasks.

Observations

The manual data collection technique used in this study was time-consuming. Indeed, the foremen showed a resistance to change to a proactive and semi-continuous data collection approach. To mitigate these issues, this research identified some opportunities for improvement of production control, such as the development of both an automated process and mobile applications to improve data collection techniques.

CONCLUSIONS AND FUTURE RESEARCH

This study investigated how the combination of geo-located work packages with daily progress reports can contribute to stabilizing workflow. Indeed, the proposal of small work packaging should always be accompanied by near real-time reporting functions. A continuous feed of data and read of information from the analyze data is necessary in order to provide an opportunity for the implementation of corrective actions. If not implemented, the benefits of small or geo-located work packaging approaches may not be fully realized. Importantly, the ability to monitor and correct production controls should also have an impact on the predictability of the planned work, so that both the planned work is supported by past performance data and the current production rates match the plan. Future research should expand the range of tested activities to a full project across trades, so that the results from this study can be further discussed.

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