A Combined Planning and Controls Approach to Accurately Estimate, Monitor, and Stabilize Work Flow

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ABSTRACT

This study investigates a novel approach both to precisely plan for project execution and to monitor execution status in near real-time. In this approach, two lean construction techniques -such as pull planning and integrated project delivery- are combined with the fine-grained planning and near real-time monitoring of the executed work. In order to plan for and monitor the flow of work, work packages are defined at the smallest discernible amount of work, the task. Work packages are divided by unique location sectors, and hence further discretized. Deviations based on predictions of completed work are proactively reported and assessed in near real-time. In addition, productivity ratios for completed projects are utilized to pre-qualify contractors for future project endeavors and to generate accurate bidding information. Thus, an emphasis to stabilize workflow is at the core of the proposed fine-grained production planning and near real-time monitoring approach. Through an intervention test in a facility project, a comparison of relevant metrics is used to quantify and validate the impact of the novel approach.

INTRODUCTION

The construction industry plays a fundamental role in the U.S. economy and welfare of its society. Despite the current economic recession, during 2012 more than five million workers were employed by the construction sector (BLS 2013). Also, during the same year in excess of 800 billion dollars (equivalent to 5.5% of Gross Domestic Product) was generated by the industry (Census Bureau 2013). Thus, the business relevance of construction plays a prominent role in macroeconomics and also in local and regional markets. As such, one would expect such a large and impactful industry to be production efficient.

However, production efficiency in the construction industry lags much behind that of the rest of non-farming industries, such as manufacturing. McKinsey and Company (2013) suggest that appropriate corrective actions to the endemic lack of productivity in construction would not only enhance work ratios but also result in substantial cost savings. In order to increase efficiency, reduce waste, and remain competitive with respect to other sectors, the productivity of construction operations must be addressed.

Construction, as opposed to manufacturing, is highly influenced by a unique combination of quite distinct factors, such as industry fragmentation, variable onsite conditions, exposure to weather, the inherent uniqueness of projects, and skilled labor shortages, among several others. Such unique combination of factors leads to uncertainty along the project delivery process and its execution operations. Uncertainty, at the same time, results in workflow variations during execution, as discussed at large by lean manufacturing thinkers (Ohno and Bodek 1988). Such workflow variations have a direct negative effect on partial and aggregate productivity ratios. Thus, workflow stability, or the reduction of its variability, has a direct relationship with production efficiency. Thomas et al. (2003) have quantified that more than 50% of labor inefficiencies can be attributed to poor work flow management. For example, workspace conflict and congestion disrupts the work pace and hence the production output at equal input of resources (Thomas and Horman 2006; Seppanen, 2009; Guo 2001).

BACKGROUND

To date, traditional project controls and planning tools such as Critical Path Method (CPM) and Earned Value Management (EVM) have failed to stabilize on the site workflow (Koskela and Howell 2002). CPM and EVM account neither for the use of resources during the execution process nor for constraints, other than logic dependencies, in the execution of the planned activities. Traditional construction planning adopts a top-down approach based on contractual information with little consideration for actual workface constraints, such as availability of space, tools, labor, materials, or equipment resources.

In order to respond to these shortcomings, novel planning approaches with the aim to streamline workflow have been recently adopted from manufacturing practices. Lean construction was conceived from lean manufacturing thinking in order to plan for execution with a workflow stabilization focus and hence to minimize the waste of materials, time, and effort (Koskela and Howel, 2002). While Lean Construction is more of a theoretical concept, the Last Planner System™ (LPS) is its principal implementation mechanism. LPS aims at enhancing the reliability of the weekly work plan of activities. Ballard (2000) defines LPS as a "production planning approach that integrates should-can-will-did planning (pull planning, make-ready, look-ahead planning) with constrain analysis, weekly work planning based upon reliable promises, and learning based upon analysis of Plan Percent Complete (PPC) and reasons for variance". The last planner is the individual, typically the foreman, immediately responsible for the execution of the work. Thus, there is a transfer of accountability from management in traditional planning techniques to the workforce in the last planner approach. Pre-fabrication, modularization, pull scheduling, and integrated project delivery are also techniques with an increasing presence in the construction market that tend to result, directly or indirectly, in increased efficiency ratios and a more stable workflow. Such techniques are commonly sought to complement the implementation of the LPS. Building on the success of these and other efforts, this study proposes a novel approach to enhance workflow variation with a fine-grained production planning and near real-time monitoring approach, as discussed immediately below.

PLANNING AND CONTROLS FRAMEWORK

The updated reporting of cost and schedule information regarding "performance to date" is critical for industry organizations to make important decisions both at portfolio and project levels. However, previous efforts have investigated project controls through the generation and reporting of coarse productivity data (e.g. at activity level) in a discontinuous, batch mode –typically once a month. In this study, it is hypothesized that, if immediately and accurately provided, task-level production information would expedite decision-making, optimize adjustments in planning and execution strategies, and maximize the chances for project success.

Indeed, we have investigated a novel approach to enhance planning detail, monitoring frequency, and work stability. Such novel approach combines pull scheduling techniques, integrated project delivery techniques, and Building Information Model (BIM) data repositories with the discretization of work packages at both the task level and by work locations. Pull scheduling according to contractual milestones is combined with an integrated project delivery approach and with an expectation of a constant and efficient pace of work. In order to plan for and monitor the flow of work, work packages are defined at the smallest discernible amount of work, the task. Work packages are also uniquely associated with location sectors in the projects, and hence their amount of work hours further reduced. The discretization of work packages is at the core of the proposed approach and aims at increasing the flexibility to allocate resources in the planning stages, and also during execution when unexpected or unplanned events occur. Such location-based work packages also enable the fine-grained monitoring of production in near real-time. Such production awareness, at the same time, is key to detect and correct workflow variances, and hence increase efficiency and reliability.

Figure 1 presents the proposed monitoring and planning approach, which is briefly described herein. Based on the combination of fine-grained productivity ratios recorded in previous projects and the quantities to execute as contained in the BIM model, the duration of tasks and activities are generated, as well it is the estimated cost. Production management makes use of the schedule milestones and the location-based work packages to plan for the execution of the work tasks. As indicated above, a traditional work activity package is divided in the proposed approach into smaller packages that allow for a more stable workflow (see Figure 2). For instance, assume that in traditional CPM scheduling a mechanical activity needs to be completed before the drywall activity can be completed, and hence a start to finish relation is established. That is, the drywall activity cannot start until the mechanical equipment is totally installed. In the proposed approach, however, all drywall tasks except for the final installation of the drywall could be executed irrespective and hence prior to the mechanical installation. In addition, that drywall work packages at the task level are further broken down by location sectors within the project enables the drywall activity to be completed for those sectors where the mechanical equipment is already installed, and hence irrespective of mechanical installation status in the rest of the locations.

Using these task and location-based work packages, their progress is accurately monitored and reported in near real-time (for instance, once a day), and fed into the BIM model. Productivity data is assessed and analyzed, and corrective actions triggered when productivity deviations versus expectations or past productivity ratios are identified. Daily planning and production monitoring eliminates surprises which are often cited (see background section) as the source of cost and schedule deviations. The same productivity data serves to feed the historical database for future use.

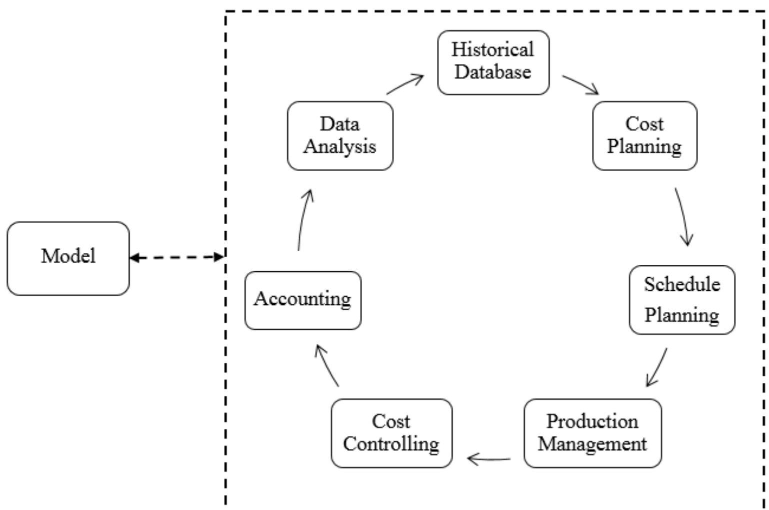

Figure 1: Project Controls Framework

Schedules derived from factual productivity data produce more reliable and accurate estimation of task durations. In the proposed approach, task durations are computed using the production value per unit of work and the number of crews with the following the equation.

$$\textit{Duration} = \textit{Quantity} \times \textit{Production Time (Hrs. /Unit)} \div \textit{Number of Crew}$$

This proposed framework requires trust, alignment, and communication between contractors, subcontractors and engineers. Integrated Project Delivery (IPD) facilitates the implementation of this project controls strategy, and ensures full involvement with the project controls process by all members of the project. The proposed approach has been tested and the results of such test are reported in the following section.

PROOF OF CONCEPT – INTERVENTION TEST

In order to experimentally test the proposed planning and monitoring approach, the drywall activities for the two phases of a health care project were selected. Banner MD Anderson is the project owner and DPR Construction is the contractor. The multi-disciplinary healthcare facility includes medical, radiation, surgical oncology, pathology, laboratory, and diagnostic imaging services, in addition to other supportive clinical services. The gross acclimatized area, for each phase, is above 100,000 square feet. Phase I of the project began in 2009 and is completed, while Phase II began in 2013 and is still in progress. The total installed cost for the project is in excess of 65 million dollars.

The drywall activity was chosen to measure the effect of the proposed planning and monitoring approach by means of an intervention test. Indeed, the drywall activity for Phase I was completed using traditional CPM and PERT methods and without an integrated project delivery approach. Thus, the drywall activity for Phase I became the control measure in the intervention. As such, the execution of large work packages was planned, and the production progress was monitored on a weekly basis. The drywall activity for Phase II was completed with the innovative fine-grained and instantaneous project monitoring approach. Thus, the drywall activity for Phase II represents the actual intervention. For both phases, the contractor directly provided the drywall crews, the composition of which was almost identical. Such crew stability, coupled with the similarity of the drywall work to be executed in the same geographical environment and for the same facility, maintained similar the main influencing factors –other than the planning and monitoring intervention- and hence increased the reliability of the obtained results.

The drywall activity was divided in three main tasks: layout, framing of studs, and hanging of drywall. In terms of dependencies, the drywall could not be hung before the mechanical, electrical, and piping (MEP) ducts had been installed through the wall. The MEP installation activity was not governed by the drywall production approach but was rather controlled using conventional Critical Path Methods (CPM). In Phase II, this inability to streamline the MEP installation workflow led to some disruption of drywall installation work and undermined the benefits of the novel approach.

In Phase II, the Foreman reported a daily production log by work task and location, and invested work hours also. It was observed that most of the foremen completed the daily work-logs in an accurate and correct manner. However, sometimes foremen were reluctant to fill the daily logs and continued with regular weekly work log reporting, with the aim to prioritize the execution work. Thus, in order to ensure the quality of the reported data, a staff individual also reported productivity data with an investment of 16 hours per week for Phase II.

Drywall installation schedule for Phase II was planned at task level based on estimated Start (ES), and Estimated Finish (EF) for each location (Figure 2). Progress tracking was achieved through daily crew reporting of Actual Start (AS) and Actual Finish (AF) dates for each location (Figure 2).

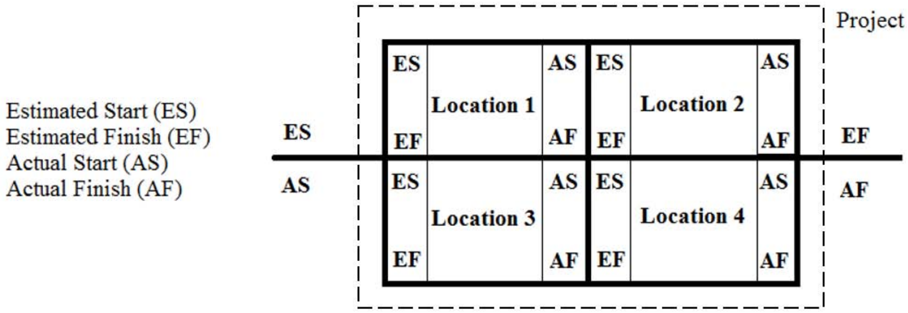

Figure 2: Location based Scheduling Concept

Each floor in the facility was subdivided into different location sectors (Figure 3) to reduce work packages and enable location based scheduling. Workflow trends were generated with VICO Office Suite to analyze productivity rates, and labor and material flows (Figure 4). In order to schedule and control drywall installation based on location and subtasks of layout, framing of studs, and hanging of drywall, drywall task codes were developed. Execution quantities were extracted from the BIM models. Parallel models were updated frequently to capture as built conditions, resulting in simultaneous design and construction.

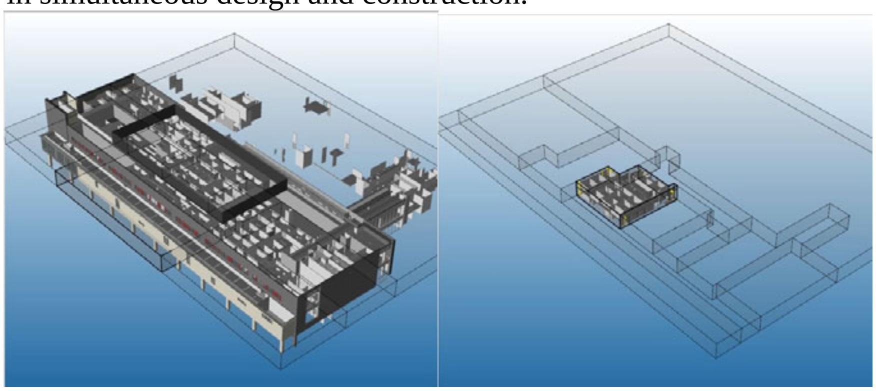

Figure 3: Discrete Zones on Each Floor (Courtesy of DPR Construction)

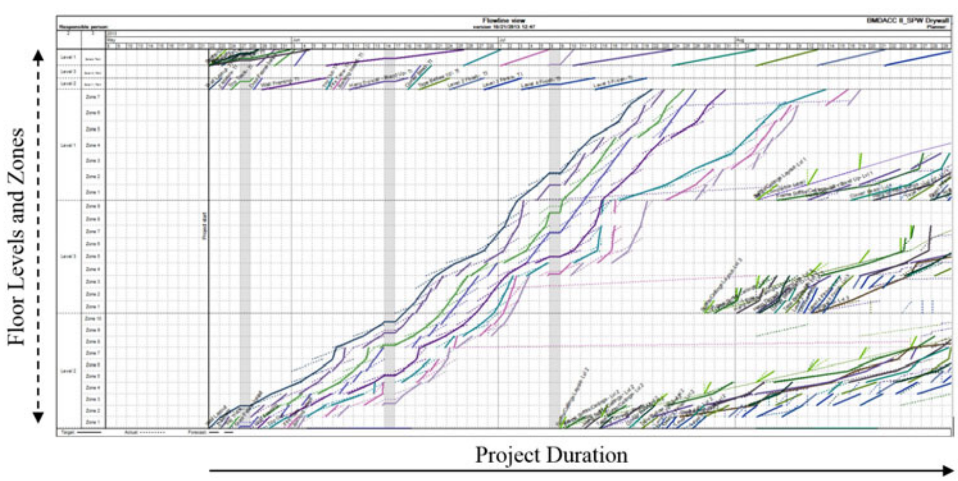

Figure 4: Location Based Scheduling – Flowline View (Courtesy of DPR Construction)

INTERVENTION RESULTS

Preliminary measurements on the execution of the drywall activity between Phase I and Phase II indicate significant improvements. The actual work-minutes per square feet of drywall installed reduced from 5.7 min/sqft to 4.7 min/sqft -an improvement of 17%. Percentage of overtime to total work-hours reduced from 3.7% to 2.7% -an improvement of 43%. Percentage of hours spent on rework to total work-hours reduced from 6.6% to 2.2% -a 66% improvement. As Phase II progresses, this study expects to collect and report more information at the ICCCBE conference.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The proposed planning and monitoring approach has shown the potential to reduce workflow variation and to increase the control on work status in a timely manner. The novel combination of object oriented databases and location-based work packages can greatly increase the efficiency of the project delivery project. Hence, this study signifies that work efficiency is not only related to planning, but also on the level of detail through which the work can also be monitored. Small work packages defined at the smallest identifiable work level, i.e. task, provide for a flexible work planning in front of unplanned constraints and events, and hence enable the continuous utilization of work resources in a stable manner. Nonetheless, the benefits of such effort cannot be realized without the allocation of resources to implement and maintain such planning and production controls approach. Thus, future research should investigate the benefits and the cost of investment necessary to undertake the proposed approach.

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