A Case Study on Applying Lean Construction to Concrete Construction Projects

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Lean construction is aimed at improving construction performance by eliminating wastes that do not add value to the customer. This project studies lean construction and its application in concrete construction projects at both the operation and project levels. In conjunction with a concrete contractor, actual concrete construction projects were observed, and problem areas contributing to delay and other wastes were identified. At the project level, the lack of coordination among subcontractors was cited as one of the major factors contributing to schedule delays. This paper proposes to use the "last planner" concept, the linear scheduling method, and the graphic schedule method to improve communication and look-ahead scheduling. Related software was developed for implementing this scheduling tool. At the operation level, a systematic approach of waste identification, operation re-design, and employee training was applied to reduce wastes found in the field operation. A case study of bulkhead installation was used to demonstrate this approach, and a 3D animation was created for employee training.

Key Words: Lean construction, Look-ahead schedule, Linear scheduling method, 3D animation.

Introduction

Although there are still debates about whether the productivity of the construction industry is increasing or declining, the performance of the construction industry is widely perceived as unsatisfactory when compared with many other industries. "Lean construction" is a production management strategy for achieving significant, continuous improvement in the performance of the total business process of a contractor through elimination of all wastes of time and other resources that do not add value to the product or service delivered to the customer (Womack & Jones, 2003). Lean concepts have resulted in dramatic performance improvements in manufacturing, and the principles behind lean have also been successfully applied to construction. Some of the lean principles that are related to the construction industry are improvements such as the construction planning process, construction supply chain, and downstream performance (Howell, 2007). Attempts have also been made to apply lean principles to all project management processes, including the project delivery system, production control, work structuring, design, supply chain, project controls, and overall construction project management. The value of lean construction has been demonstrated in many case studies. For example, Koskela et al. (1996) closely examined a fast-track office building project and showed how the building process could be made leaner and speedier, and Tsao et al. (2000) illustrated how lean thinking and work structuring helped to improve the design and installation of metal door frames for a prison construction project.

The primary objectives of this project are to observe the barriers to implementing lean construction concepts through an empirical study of a concrete construction project and to develop practical solutions to facilitate the implementation process. With support from a concrete contractor, a concrete construction project was monitored during the summer of 2006 that involved the construction of a 788–unit, mixed-use, high-rise residential tower complex consisting of two towers, each 23 stories high, atop a 6-story parking structure and 22,500 square feet of street-level retail space. Construction was started in December 2005, and during the summer of 2006 the concrete contractor, along with several other subcontractors, was working on concrete structures of the second to the fifth floors and a retaining wall. The study was focused on waste identification and elimination at the field operation level. In the context of lean principles, "waste" is defined as any resources consumed by activities that do not add value to meet a client's needs.

At the project level, waste due to the poor coordination among the subcontractors was also identified. Effective look-ahead scheduling and management of handoff points between different disciplines are the keys to eliminating this type of waste. This paper reviews the current industry practice and proposes a look-ahead scheduling approach that utilizes the last planner concept, the linear scheduling method (LSM), and the graphic schedule method. At the operation level, inefficient sequencing of work procedures and unnecessary movement of laborers and other resources contribute to schedule delays. This project uses a systematic approach of waste identification, work procedure re-design, and employee training to reduce wastes found in the field operation. A major obstacle in applying lean concepts at the operation level is the resistance to changes on the part of employees, so this project uses 3D animation to improve the understanding by field personnel of the re-designed work procedure in order to reduce such resistance.

The following section provides a literature review on current industry practices and recent developments in look-ahead scheduling. The two subsequent sections describe the observations obtained from the above-mentioned concrete construction project and the solutions developed to facilitate the implementation of lean principles at the project and the operation levels, respectively. The proposed look-ahead scheduling method and an employee training program using 3D animation are also described.

Literature Review

Waste exists in different forms, including over-production, waiting, unnecessary movement, carrying unnecessary inventory, and rework (Womack & Jones, 2003). Time studies and different process analysis techniques have been applied to systematically identify and quantify wastes during the construction process (Lee et al., 1999). Specifically, delay and other types of wastes due to poor coordination among various project participants have been well documented in many previous studies. The highly fragmented nature of the construction industry has caused considerable low productivity, cost and time overruns, and conflicts and disputes, all potentially resulting in claims and time-consuming litigations (Latham, 1994). Higgin and Jessop (1965) argued that there is seldom a full awareness of all the steps necessary to realize an optimum overall project outcome without loss of time and that the means of ensuring coordination are often not clear.

To improve coordination of field operations, two different types of schedules are frequently used in construction projects, namely master schedule and look-ahead or short-interval schedule. A master schedule provides a global view of the entire project and the general sequence of major work packages. A look-ahead schedule is a more detailed plan that is developed to bridge the gap between the overall master project schedule and the assignments performed at the crew level. It provides the necessary details for field personnel to operate on a day-to-day basis. The “last planner” concept proposed by Ballard (1996) is based on principles of lean production to minimize the waste in a system through assignment-level planning or detailed look-ahead scheduling. The last planner method is a very proactive approach in that it provides forward information for control and forces problems to the surface at the planning stage, thus facilitating close project coordination. When reliable workflow is generated, simultaneous improvement in all key criteria, including time, cost, quality, and safety, can be achieved.

For master schedules, bar chart schedule and the critical path method (CPM) are predominately used because of its simplicity in communicating schedule information in the construction industry. In many cases, bar chart schedule is the only acceptable format for project reporting purposes. For look-ahead schedules, however, the industry uses a number of different formats, ranging from calendar schedules and check lists to daily planning charts, punch lists, daily work plans, and graphic schedules (Hinze, 2008).

One of the primary goals of look-ahead scheduling and the last planner concept is to improve coordination and have resources work continuously. Bar chart schedule and CPM has been attacked in lean construction for its inability to model non-value-adding activities such as waiting, inspecting, and moving (Koskela, 1992). When CPM is applied to schedule repetitive projects, the early start schedule may not be optimal because floats attached to repetitive activities represent significant amounts of unforced idleness (Harris and Ioannou, 1998). Yang and Ioannou (2001) proposed a “pull system” approach that automatically pulls activities and/or activity segments to later start times so that unforced idleness can be eliminated. The term pull system encompasses the pull concept in a Kanban system, which pulls upstream material and off-site work to match the progress on site (Tommelein, 1998). The pull scheduling algorithm has been shown to successfully eliminate idleness in repetitive linear construction projects such as pipeline construction.

One of the objectives of this paper is to implement a look-ahead scheduling method that encourages the use of the pull-driven philosophy and the last planner concept to improve coordination of and communication among subcontractors. The scheduling method should be a graphical scheduling tool that allows planners to model and analyze interactions among different construction disciplines in terms of time, space, logic sequence, and work continuity.

Lean Construction at the Project Level

Close coordination of project participants during the construction stage is critical to the overall project success. Traditionally, productivity study has been mainly focused on observing and improving individual construction operation. The lean concepts emphasize the management of handoff points between different trades and identification and elimination of waste related to coordination issues. Therefore, in the case study, observations were made not only of individual operations but also of their interaction and coordination.

Site Observations at the Project Level

In the sample project, the overall concrete construction process consisted of formwork, reinforcing, embedment installation, concrete pouring and curing, and formwork stripping. Several contractors were involved, including a general contractor, an electrical subcontractor, a plumbing subcontractor, a rebar subcontractor, an insulation subcontractor, and the concrete contractor. As with many other construction projects, the general contractor maintained a master schedule showing the general flow of activities and milestones for the overall project coordination. Look-ahead schedules were prepared by project managers for the upcoming three to five weeks in a bar chart format using scheduling software, and look-ahead schedules for superintendents and foremen were presented in a calendar view format by manually transferring information from the bar chart look-ahead schedule to the calendar schedule. Look-ahead schedules were updated on a weekly basis and shared with other subcontractors during a weekly project meeting. These schedules provide an additional level of detail but are still limited to major assignments conducted by the concrete and the rebar subcontractors because manual preparation and updating of these schedules is very time consuming.

Several issues with regard to coordination among different subcontractors were observed to cause schedule delays. First, there was inadequate technical engineering review during look-ahead scheduling. Efforts were put heavily on the planning of construction methods and physical construction resources, such as labor, material, and equipment loading, but technical engineering review of upcoming work received much less attention. When design problems are identified on a construction site, delays are almost inevitable. For example, the rebar subcontractor changed the direction of the post-tensioning cable run to ease the concreting work, but did not obtain appropriate approval from the design engineer and the general contractor. When spotting this change, the general contractor halted the construction and called for an engineering review to evaluate its impact. Although the change was eventually approved, delay was incurred. If these design issues had been identified and solved during look-ahead scheduling, the delay could have been avoided.

Second, although look-ahead schedules provided more details than the master schedule, they did not contain enough detail for coordination of crews in terms of their productivity rates, time, and space constraints. For example, concrete work on columns and walls must be completed before the formwork for the next floor can start, and these two activities must maintain a proper space buffer. When time and space buffers and productivity rates are not coordinated properly, stacking of these activities will take place, and the overall productivity of the operation will suffer. In other cases, because electrical and plumbing activities are not formally included in the look-ahead schedule, potential conflicts between their assignments and those of concreting may not be identified properly. Third, all subcontractors should be actively involved in the look-ahead scheduling process so that they are clear about their responsibilities and are given the opportunity to buy into the schedule. As an example of the problem, a crew of the insulation subcontractor was sent to the site at the right time but without enough instruction to start their work.

These performance issues are all directly or indirectly related to current look-ahead scheduling practice and suggest the need for a more effective look-ahead scheduling procedure. This project proposed a computerized solution that uses the last planner concept, LSM, and a graphic schedule. These concepts are described and the computerized solution is presented in the following sections.

Last Planner and the Linear Scheduling Method

The last planner concept is aimed at improving productivity by eliminating bottlenecks and implementing look-ahead planning by the people at the work-face (Ballard, 1996). Last planners are individuals who decide what work is to be done the following day, and they are typically superintendents, foremen, or site supervisors. The work that is scheduled for the next day is called assignment, and the last planner relies on a so-called “should-can-will” analysis. In other words, he or she is expected to make commitments (“will”) to doing what should be done (“should”), but only to the extent that it can be done (“can”). The last planner focuses on assignment-level planning and determines the amount of work that should be done based on the master project plan. The constraints of performance, such as work sequence and resource availability, determine what can be done. Based on the latest available information, the last planner then evaluates and commits to the work that will be done.

LSM is a graphical scheduling tool designed for scheduling repetitive linear construction projects, such as roadways, pipelines, and high-rise construction projects, that contain identical or similar production units. An example of LSM for a high-rise concrete construction operation can be found in Figure 1. An activity, such as formwork installation, is represented as a sloped line, called a production line, in a two-dimensional time and space coordinate system, and activities are differentiated by line color or style. The horizontal axis represents time, and the vertical axis is the location of an activity. The slope of a production line graphically represents its productivity rate and the direction of construction progress. For example, varying slopes indicate variability in productivity rate due to many factors, such as quantity and complexity of work, crew composition, and labor skill level. The horizontal distance between two activities is a graphic representation of the float between the activities, or the time buffer, and, similarly, the vertical distance represents the physical distance between the activities, or the space buffer. LSM allows better representation of scheduling information than the conventional CPM or bar charts in terms of space constraints and productivity rates, and it also graphically depicts the start and the end times and locations of activities so that work continuity and progress direction can be easily monitored.

A daily graphic schedule is also used to further improve communication of scheduling information on a daily basis at the crew level. The graphic schedule shows, intuitively, activities in their actual location on the site layout drawing for a specific day. A set of graphic schedule charts is usually prepared for each day for a period of three to five weeks. In addition to activity location, interference among activities and site logistics can be easily captured in the chart. Figure 2 shows a sample of a manually prepared graphic schedule for a working day of a high-rise construction project. Activities and their locations are marked on the building floor plan.

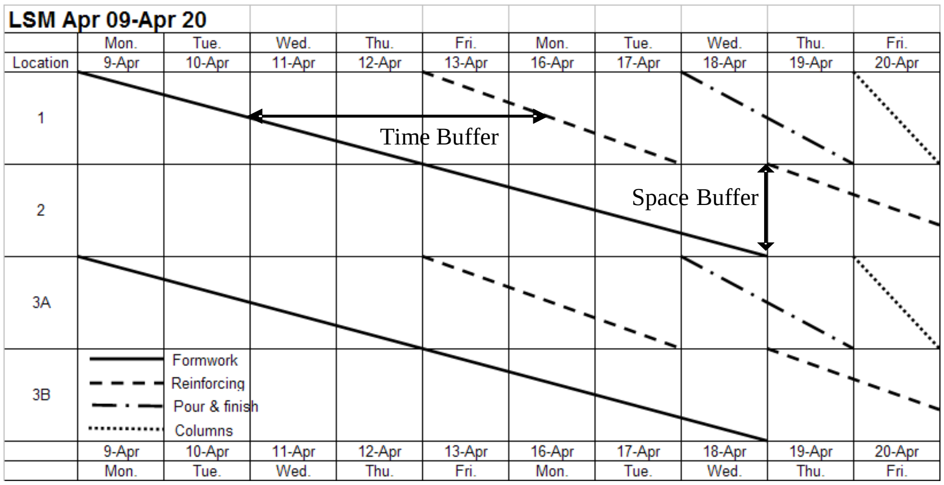


Figure 1: LSM schedule.

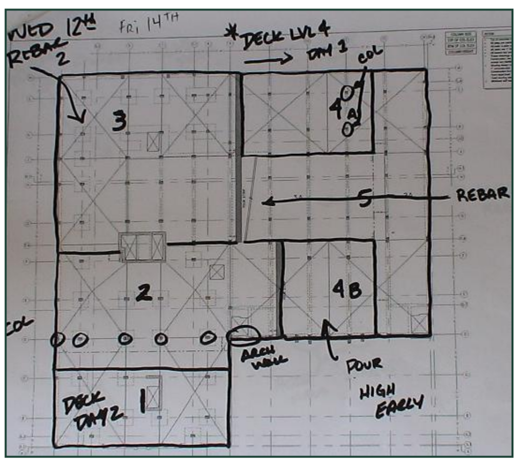


Figure 2: Sample graphic schedule.

Integration of the last planner concept, LSM, and the daily graphic schedule is proposed to improve communication and coordination among subcontractors. Although many construction projects are not repetitive linear projects as a whole, day-to-day operations performed by subcontractors are normally repetitive, such as concrete construction and steel erection. Thus, LSM provides a more effective communication tool for look-ahead scheduling than traditional bar charts or CPM schedules. Table 1 gives an overview of how last planner and other lean concepts can be effectively implemented using features provided by LSM and graphic scheduling.

- **Should-Can-Will Analysis**. In LSM, activities are positioned in a time and space coordinate system, along with their production rates. Time and space buffers among activities and activity productivity rates can be graphically evaluated to determine what can be done. Other constraints may also be recorded manually in a LSM chart or a graphic schedule for constraint analysis.

- **Work Continuity**. In LSM, activities performed by the same crew can be represented as line segments in the same style. The line segments that are not connected indicate interruptions in the crew's performance, which means that work continuity can be graphically examined and manipulated.
- **Pull-driven Scheduling**. LSM allows planners to pull activities to a later start time so that waiting can be eliminated. An activity and its predecessors can be grouped and moved together in LSM for pull-driven scheduling.
- **Team Approach for Scheduling**. A master schedule does not show detail assignments, for which the last planners are responsible. Look-ahead schedules must allow subcontractors, superintendents, and foremen, as last planners, to easily expand the master schedule and add their detailed assignments. In LSM, production lines that represent assignments can be easily added or deleted, and LSM and graphic scheduling can be used to analyze the overall impact of these assignments on the master schedule.
- **Simplicity**. LSM and graphic scheduling are easy to prepare and understand. Superintendents and foremen can schedule their work using either computers or pencil and paper.

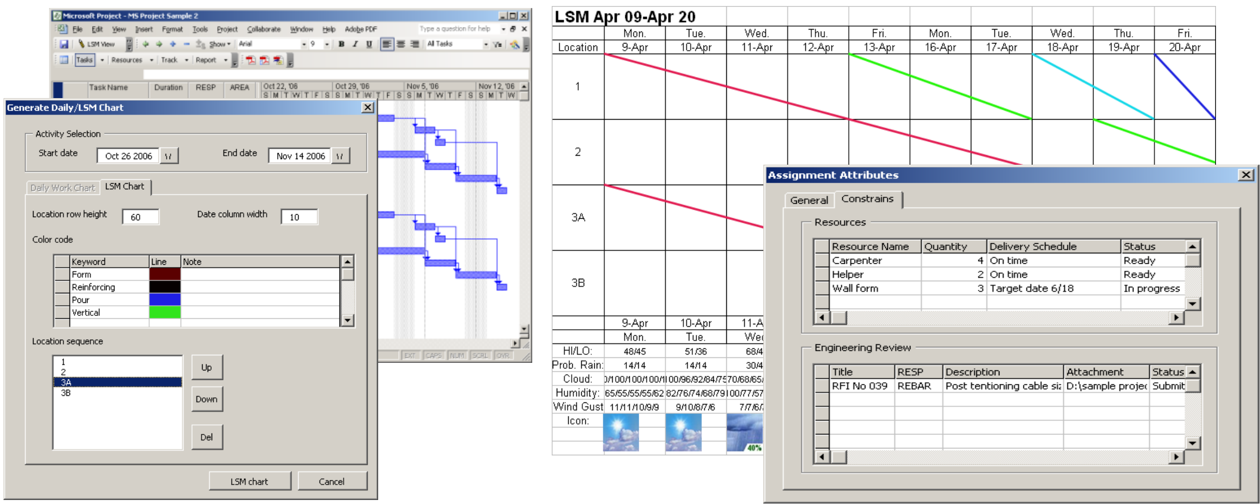
Table 1: Integration of Last Planner and LSM

Last Planner and Lean Concepts	**LSM and Graphic Schedule Features**
Should-can-will analysis	LSM time/space buffer and productivity rate
Work continuity	Production line continuity
Pull-driven scheduling	Easily represents pulling of activities
Involvement of all participants in developing look-ahead schedules	Easy to add/delete assignments by different users and show the impacts
Superintendents and foremen, the last planners, need an easy-to-use graphical scheduling tool	Easy to prepare and understand, and can be computerized

Software Development

Bar chart schedule is currently the most standard and widely used format for schedule development and reporting. Although look-ahead schedules can be directly developed in the LSM and graphic schedule format, most users still use bar charts because of their popularity, or, in other cases, simply because bar charts are the only accepted format for progress reporting. Furthermore, preparing LSM and graphic schedules is very time consuming. Schedulers are reluctant to duplicate their efforts by manually translating the same scheduling information to a different format—i.e., to LSM and graphic scheduling. The goal of the software development is to develop a computer application to automatically convert a bar chart schedule to the LSM and graphic schedule format.

This computer application was developed using Visual Basic for Application (VBA), and two similar versions of the program were developed to work with two popular scheduling software packages—Primavera Project Planner and Microsoft Project. The program allows users, before conversion, to define repetitive activities, production line colors, activity filters, look-ahead time periods, and location sequences. A screen shot of this program is shown in Figure 3, and the original schedule in a bar chart format and the conversion options are shown in Figure 3(a). A converted LSM chart is shown in Figure 3(b), along with a dialog box showing an assignment's attributes.



(a) (b)

Figure 3: Bar chart and converted LSM schedule.

In addition to the time and space constraints shown in LSM, other types of constraints can also be captured for the should-can-will analysis. Activity attribute data can be either manually recorded or transferred from a bar chart schedule to a LSM chart, such as precedence relationship and resource allocation. The attribute data allow project managers to monitor resource commitment and keep track of outstanding issues, and new constraints can be added to the chart to facilitate analysis. For example, weather forecasting information for an upcoming week can be automatically provided by pulling data from a dedicated weather forecast Web service when a LSM chart is generated, which can allow a scheduler to easily factor weather conditions into the should-can-will analysis. Project participants can also easily insert additional assignments into the LSM schedule, and assignments and their predecessors can be grouped and moved together for pull-driven scheduling.

Another function of the program is to automatically generate daily graphic schedules based on data in the look-ahead schedules. Planners must first define the job site layout, and this can be done with drawing tools provided in Microsoft Excel or by importing layout drawings from CAD programs. Users can control the format of the graphic schedule using the conversion configuration dialog box, as shown in Figure 4. These charts describe activities and their locations on the site layout drawing, and they can be transferred to a Tablet PC or a handheld PC for easier commenting and sharing. Similar charts are generated for each working day within a user-specified time frame.

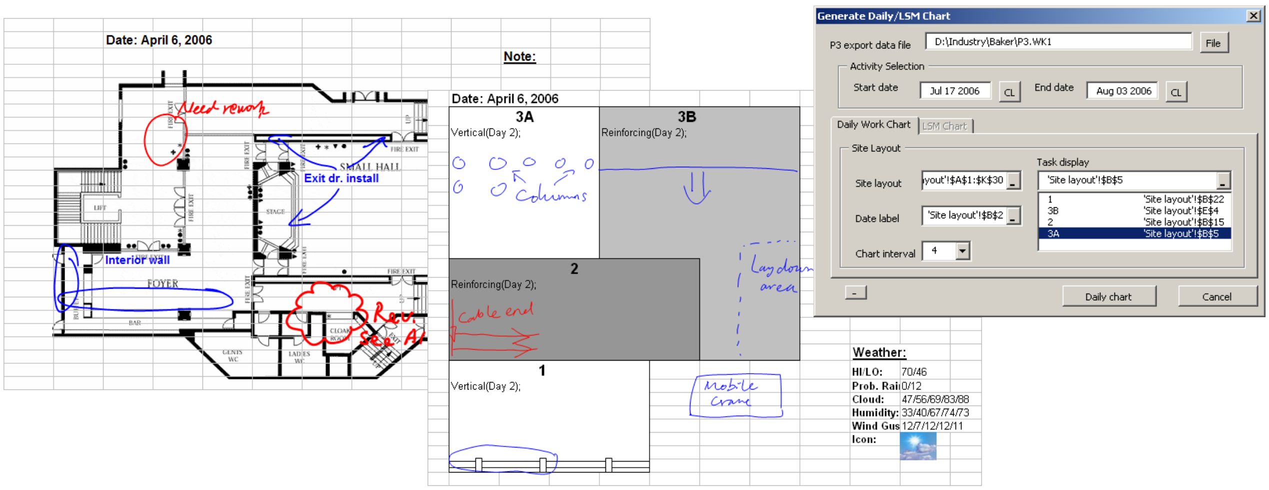


Figure 4: Daily graphic schedule.

Lean Construction at the Operation Level

Observations at the operation level involve monitoring work procedures, movement of resources, and information available on the job site. Various types of waste were observed in the sample project that are similar to those that have been identified in many other similar studies; they include crane waiting, double handling of materials, and rework. Suggestions have been made to redesign work procedures and to eliminate or reduce the different types of waste.

During the course of this study, resistance to change was perceived to be the major obstacle to implementing lean concepts at the operation level. A decision was made to use a simple operation as a pilot study to demonstrate to field personnel how the current process can be changed to reduce waste. In this project, bulkhead formwork installation and removal was identified as a case study to demonstrate the process of identifying waste, redesigning work procedures, and retraining employees. A bulkhead is a temporary formwork strip that blocks fresh concrete from a section of forms or closes the end of a form at a construction joint. The current bulkhead installation and removal activities are carried out by carpenters and general laborers, respectively. Bulkheads are first drilled and installed in place by carpenters, and then this is followed by the placing of rebar, cables, and conduits, and finally by concreting. After the concrete is cured, the bulkheads are removed by general laborers using prying tools.

Carpenters normally install the bulkhead as one piece in order to reduce their processing time. However, this makes bulkhead removal difficult and time consuming and may also cause concrete quality problems, especially when there are multiple conduits, rebar, and post-tensioning cables running through the concrete slab. In other words, there is a coordination issue between the two teams. Waste can be reduced by revising the process of the upstream team, which means that if carpenters take the extra step of cutting the bulkhead, the wastes in the downstream activity (i.e., bulkhead removal) can be reduced. This new procedure includes the additional step of cutting the bulkhead into two parts at the centerline, through which most of the rebar and cables run. The bottom piece of the bulkhead is installed first, followed by the routing of cables, conduits, and rebar through pre-drilled holes, and then the top piece of the bulkhead is installed. With the new procedure, the time for bulkhead installation is slightly increased, but the gains are that the time required for removing bulkhead is significantly decreased and damages to concrete are reduced.

Effective training is very important to reduce the resistance to change by improving employees' understanding of new work procedures. In this sample project, the majority of construction workers cannot communicate adequately in English. Also, due to the temporal nature of construction projects, employees frequently move from project to project, and so employees who are new to a particular project must be trained before they start work. Therefore, the training must be designed in a way that is highly graphical and easy to understand. Considering the above requirements, a 3D animation was developed for training purposes. The animation of the bulkhead installation process was developed using 3D Studio Max, and a flowchart of the installation process described above was developed before building the model. 3D objects were first created in three dimensions and then manually animated according to the process defined in the flow chart. Camera position was fixed, and the scene, consisting of about 3,000 frames, was then rendered. Figure 5 shows a screen shot of the process animation. The 3D animation was used to train construction workers on the new work procedure, and this training method proved to be very effective in explaining new ideas and encouraging changes.

Figure 5: 3D animation of bulkhead installation.

Conclusions

This project studied lean construction and its application in concrete construction projects at both the operation and project levels. In conjunction with a concrete contractor, an actual concrete construction project was observed, and problem areas contributing to delay and other wastes were identified. At the project level, lack of coordination among contractors was cited as one of the major factors contributing to project delays. The "last planner" concept and look-ahead scheduling were implemented in LSM and graphic schedule formats, which improved communication and coordination among subcontractors. The computerized solution greatly reduced the time required to produce LSM and daily graphic schedules, which, allowed contractors to prepare longer periods of look-ahead schedules and to communicate their schedules in electronic formats. At the operation level, a systematic approach to waste identification, operation re-design, and employee training was applied to eliminate waste in field operation, as shown in the bulkhead case study. 3D animation was shown to be a very effective training tool to improve understanding on the part of employees and to reduce resistance to change. This procedure can be applied to reduce or eliminate other wastes found in construction operation.

This project shows how lean principles can be applied at both project and operation levels of a construction project through an empirical study. Future research should quantify the benefits of lean applications by collecting and analyzing performance data from actual construction projects. The data analysis should objectively and quantitatively measure the effectiveness of lean applications and assist future decision making on investing in lean construction concepts.

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