APPLYING LEAN CONSTRUCTION TO CONCRETE CONSTRUCTION PROJECTS

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ABSTRACT

The construction industry has demonstrated a decline in productivity when compared to other industries over the past twenty years. Lean concepts have caused a revolution in manufacturing design, supply, and assembly. Applied to construction, lean concepts can change the way work is done throughout the facility delivery process. This project studies the lean construction concepts and its application in concrete construction projects at both 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, lack of coordination among contractors was cited as one of the major factors contributing to project delays. This paper proposes the use of the Last Planner concept and Linear Scheduling Method (LSM) to improve communication and short-term scheduling effort. Related software was developed for implementing the proposed scheduling method. At the operation level, a systematic approach of waste identification, operation re-design, and employee training was applied to eliminate wastes in the field operation. A case study on bulkhead installation was used to demonstrate this approach. A 3D animation was created for employee training.

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Chapter 1: Introduction

1.1 Background

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 compared to many other industries. The lack of improvement in the industry can be contributed to a number of factors, including industry fragmentation, lack of trust between key participants, the traditional contracting environment, craft-oriented culture, increased regulations, safety issues, and lack of process innovation. Contractors are under enormous pressure for continuous improvement to enhance their productivity and competitiveness locally and internationally. To achieve this goal, construction companies are looking to other industries such as manufacturing to examine the effectiveness of their measuring, monitoring, and improvement techniques. Lean 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 et al. 1996). Lean concepts have resulted in dramatic performance improvements in manufacturing, the principles behind lean concepts have been effectively applied to construction, as shown in many previous studies, such as those published in the annual conferences of Lean Construction Institute.

1.2 Project Scope and Objectives

The primary objective of this project is to observe barriers in implementing Lean Construction concepts through an empirical study of a concrete construction project and develop practical solutions to facilitate the implementation process. With supports from a concrete contractor, a concrete construction project was monitored during summer 2006. This project involves the construction of a 788 unit mixed-use high-rise residential tower. It consists of two towers, each 23 stories, atop a 6-story parking structure and 22,500 square feet of street level retail space. Construction was started in December 2006. The first phase of the project, Tower One, is scheduled to top out in February 2007. During summer 2006, the concrete contractor along with several other subcontractors was working on concrete structures of the second to the fifth floor and a retaining wall. The study was focused on waste identification and elimination on job site performance. In the context of lean principles, waste is any resources consumed by activities that do not add value to meet a client's needs. At the project level, waste due to the lack coordination of subcontractors is identified. Effective short-interval scheduling and management of handoff points between different disciplines are the keys to eliminate this waste. This project reviews the current industry practice and proposes a scheduling approach that utilizes the Last Planner concept and Linear Scheduling Method (LSM). At the operation level, sequencing of work procedures and allocation and movement of labors and other resources contribute to schedule delays. This project follows a systematic approach of waste identification, work procedure re-design, and employee training to eliminate wastes in the field operation. A major obstacle in applying lean concepts at the operation level is the resistance to changes. This project uses a 3D computer training program to improve site personnel's understanding of the re-designed work procedure in order to reduce the resistance.

The following section provides a literature review on current industry practices and current development in short-interval scheduling and barriers in applying lean principles at the operation level. The two subsequent sections describe the observations obtained from the abovementioned concrete construction project and solutions developed to facilitate implementation of lean principles at the project level and the operation level respectively. The proposed LSM-based short-interval scheduling method and an employee training program using 3D work procedure visualization are described in details.

Chapter 2: Literature review

2.1 Lean Theory and Construction Industry

In 1950's after World War II, the ideas of new production philosophy were originated in Japan. Toyota Production System was the most prominent in enforcing this philosophy. The fundamental idea of the Toyota Production System is the elimination of inventories and other wastes through small lot production, reduced set-up times, semiautonomous machines, co-operation with suppliers, and other techniques (Monden 1983, Ohno 1988, Shingo 1984, and Shingo 1988). At the same time, quality concerns were introduced to Japanese industry by American specialists like Deming, Juran and Feigenbaum.

The thought process of lean was thoroughly described in the book The Machine That Changed the World by Womack, Roos, and Jones (1990). In a consequent volume, Lean Thinking by the same authors distilled these lean principles even further to five components: specify value, identify all the steps in the value stream, flow, and pull and pursue perfection (Womack et al. 1996). World leaders adapted the tools and principles beyond manufacturing to logistics and distribution, services, retail, healthcare, construction, maintenance, and even government as lean thinking continued to spread to every country in the world.

Lean Construction Organization pointed out that the reliable release of work between specialists in design, supply and assembly assures value is delivered to the customer and waste is reduced (2006). Lean Construction is believed to be particularly useful on complex, uncertain and quick projects. There are substantial researches that have been focused on Lean Construction theory. Some of the lean principles that are related to the construction industry are such improvements as the construction planning process, eliminating waste, construction supply chain, and downstream performance. An attempt has also been made to apply lean principles on the entire project management processes. Some of the main focused areas are lean project delivery system, production control, work structuring, design, lean supply, project controls, and project management in the construction industry (Lean Construction Organization 2006).

Construction industry has discarded many thoughts from manufacturing for the reason that construction comprises of unique and complex projects in highly uncertain environments under great time and schedule pressure that is fundamentally different from manufacturing. However, according to Howell (1999) construction Industry needs to take a closer look at Lean Production theory as waste in construction and manufacturing take place from the same activity-centered thinking, Reducing the cost and duration of each construction activity is the key to improvement.

Waste is defined by the performance standard for the production system. Numerous processes in the construction industry that generates waste are well documented in many studies in different countries. For example, the cost of poor quality has turned out to be between 10 to 20 % of the total project costs (Cnudde 1991). In another similar study in Sweden, the costs of quality failures in a design-build project of a construction company were found to be 6 % (Hammarlund and Josephson 1991). In an American study of numerous industrial projects, variation costs an average of 12.4% of the total installed project cost. However, “this value is only the tip of the iceberg” (Burati et al. 1992).

Average allocation of working time used in value-adding activities is estimated at about 31.9 % or 36 % (Oglesby et al. 1989; Levy 1990). Thus, there is strong evidence showing that a considerable amount of waste and loss of value exists in construction.

2.2 Project Coordination and Scheduling

The Last Planner, based on principles of lean concepts was developed by Glenn Ballard (Ballard 1996). The Last Planner system maximizes the value and minimizes the waste in a system. It heavily emphasizes on the 'assignment level' planning or the short-term schedule. This schedule provides a link between the high level project schedule and the actual execution schedule for day to day work. The Last Planner approach is a very proactive approach as it provides forward information for control and forces \problems to the surface at the planning stage and can facilitate project coordination. When reliable workflow is generated, simultaneous improvement in all key criteria, including time, cost, quality, and safety, will be achieve.

One of the major problems in the construction industry is lack of coordination. The construction industry is very fragmented as compared to other industries which have caused considerable low productivity, cost and time overruns, conflicts and disputes, resulting in claims and time consuming litigation (Latham 1994).

Higgin and Jessop (1965) argued that sufficient thought and time does not seem to be given to ensuring that all project participants understand the common objective similarly and fully. There is seldom a full awareness of all the steps necessary to realize an optimum overall outcome without loss of time, and the means of ensuring coordination is often not clear.

As mentioned earlier in this text about the waste in the construction industry, unforced idealness has been observed in repetitive projects when labors and equipments are waiting, being idle, because the preceding resources have not finished their jobs. Research conducted by I-Tung Yang and Photios G. Ioannou (2001) investigated the existence and influence of unforced idleness and proposed the pull-system scheduling system to eliminate unforced idleness in repetitive projects. They also compared both push approaches in the form of Critical Path Method (CPM) mainly for repetitive projects.

Barcala et al. (2003) proposed an information model to integrate different phases in construction operation and to increase interaction among the stakeholders. Due to the advancements in communication and Information Technology, it is possible to increase the level of integration among different construction processes by improving the presentation and flow of information.

Lean production philosophy is set up with the objective of avoiding waste (Shingo 1988). CPM has been attacked in lean construction, for its lack of ability 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 repeating activities represent significant amount of waste, and unforced idleness (Harris and Ioannou 1998). As proposed by authors 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 (Tommelein 1998), which pulls upstream material and off-site work to match the progress on site.

The author proposed a pull-system approach to achieve continuous work flow. The research pioneers in investigating the pulling effect of work continuity and explaining possible cyclic relationships.

2.3 Short-Interval Scheduling

Two different types of schedules are utilized in most construction projects, namely master schedule and short-interval schedule or look-ahead schedule. Short interval schedule is a form of more detail plan that is developed in order to bridge the gap from the overall project schedule to the tasks performed by crew level. Short-interval schedule is a link between the master schedule and the execution of tasks. For master schedules, bar chart is predominately used for its popularity and simplicity for the communication of schedule information in the construction industry. The use of bar chart in master schedules is many times compulsory and is the only acceptable format for project reporting purpose. For short-interval schedule, however, the industry uses a number of different formats ranging from calendar schedule, check list, to daily planning chart, punch list, daily work plan, daily schedule form, crew planning chart, and pre-task planning form. The success of a construction project relies heavily on proper use of the short interval schedules.

The objective of this project is to find a method that can ease the implementation of last planner concepts, i.e. a graphical scheduling method that emphasize repetitive construction operations, interactions among different disciplines in terms of time, space, and resources, and work continuity.

2.4 Achieving Changes in Construction

There is a general consensus on the need for change in construction industry and various programmes and initiatives have been undertaken to achieve the same. As the construction industry is fragmented, any kind of change cannot happen suddenly but will happen gradually. According to Koskela et al. in their paper on "Achieving change in Construction" change should be started in the operational process that create the end product, downstream thinking as opposed to the mainstream thinking that suggests starting change from upstream decisions and stages of construction, contractual and organizational forms (Koskela et al. 1992).

Chapter 3: Lean Construction at the Project Level

Close coordination of project participants during construction stage is critical to the overall project success. Traditionally, productivity study has been primarily 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 on individual operations but also their interaction and coordination.

3.1 Site Observations at the Project Level

The overall concrete construction process consists of formwork, reinforcing, electrical and plumbing rough-in, concrete pouring and curing, and formwork stripping. Several contractors are involved including a general contractor, an electrical subcontractor, a plumbing subcontractor, a rebar subcontractor, an insulation subcontractor, and the concrete contractor. Like many other construction projects, the general contractor maintains a master schedule showing the general flow of activities and milestones for overall project coordination. Look-ahead schedules were prepared by project managers for the upcoming three to five weeks in bar chart format in scheduling software. Two types of look-ahead schedule presentation were prepared for superintendents and foremen. The first one is presented in a calendar view by manually transferring information from the bar chart look-ahead schedule to the calendar schedule. A sample calendar schedule is show in Figure 1. In the second schedule, activities and their location are marked manually on a site layout drawing for each day for a period of three to five weeks. A sample of this daily work chart is shown in Figure 2B. These types of schedules were updated on a weekly basis and shared with other subcontractors during a weekly project meeting. They provide additional level of detail but still limits to major activities conducted by the concrete and the rebar subcontractors. This is due to the time-consuming manual preparation and update of these schedules.

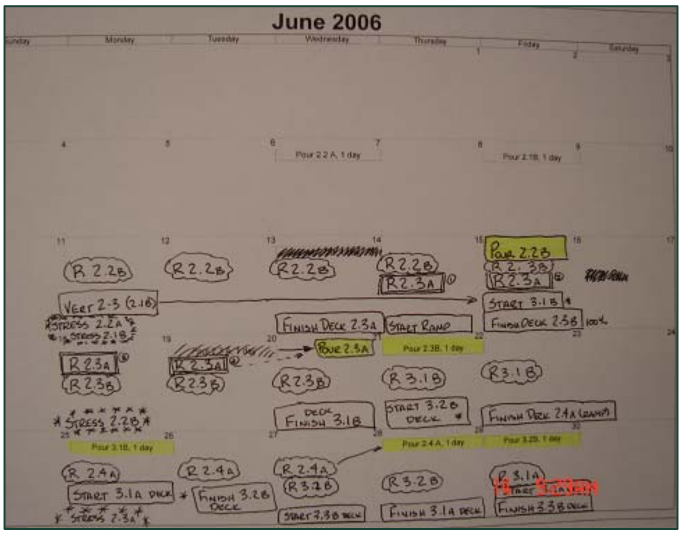

Figure 1: Calendar schedule for upcoming four weeks

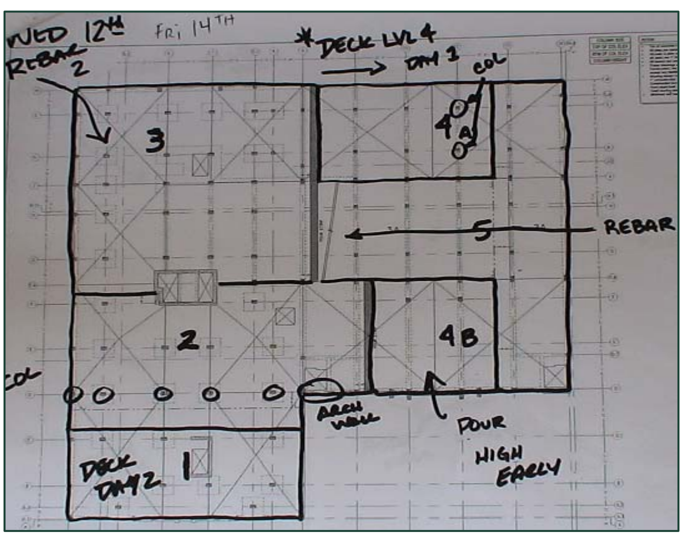

Figure 2: Daily work chart on a particular day

Several issues regarding coordination between different subcontractors were observed to cause schedule delay. First, it was perceived that 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 manpower loading, material and equipment delivery. However, technical engineering review on work in the upcoming weeks received much less attention. When design problems are identified on the site, delays are almost inevitable. For example, the rebar subcontractor changed the direction of post-tensioning cable run to ease concreting work but didn't get appropriate approval from the design engineer and the general contractor. The general contractor spotted this change, halted the construction, and called for an engineering review to evaluate its impact. Although the change was eventually approved, delay was incurred. If design issues had been identified and solved during look-ahead scheduling, the delay would have been avoided. Secondly, although look-ahead schedules provided more details than the project master schedule, they didn't contain enough details for coordinating crews in terms of their productivity rate, time and space constrains. For example, concrete work on columns and walls must complete before the formwork of the next floor can start, and the two activities must maintain proper space buffer. When time and space buffers are not considered properly, stacking of these activities could happen and the overall productivity of the operation will suffer. In other cases, because electrical and plumbing activities were not formally included in the look-ahead schedule, potential conflicts between their activities and concreting related activities may not be identified properly. Thirdly, all subcontractors should be actively involved in the look-ahead scheduling process so that they are clear about their responsibility and willing to buy into the schedule. For example, a crew of the insulation subcontractor was sent on site at the right time but without enough instruction to start their work.

These performance issues are all directly or indirectly related to the current look-ahead scheduling practice and suggest the need for a more effective short-interval scheduling procedure. This project proposed a computerized solution that integrates the Last Planner concepts and LSM. The last planner concept is aimed at improving productivity by eliminating bottlenecks and implementing short-term planning by the people at the work-face. LSM is a graphical scheduling tool originally designed for repetitive linear construction projects. Both concepts are described and the computerized solution is presented in the following sections.

3.2 Last Planer

The Last Planner based on principles of Lean Construction was developed by Glenn Ballard (1996). It is based on a "Should, Can and Will" approach. The last planners are the individuals, who decide the work that is to be done tomorrow. They are typically superintendents, foremen, and site supervisors.

A planner should create reliable weekly work plans based on the master schedule and then finally 'assignment level' planning. The work that is to be done tomorrow is called assignment. Last planner focuses on assignment level planning for which the last planner has input from project plans which state the amount of work that should be done. The constraints are associated with "Can". Based on the available information, the last planner then evaluates the work that will be done.

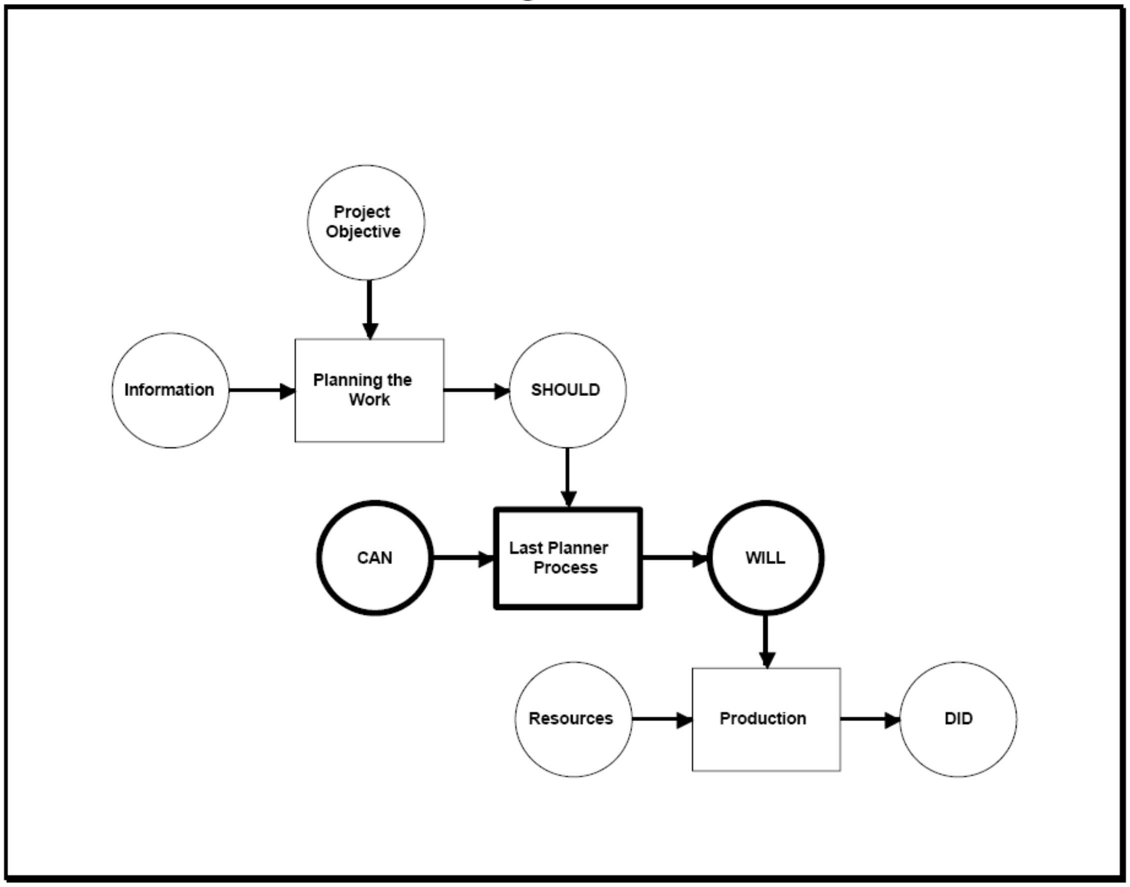

Figure 3: Last planner systems

For maximum project benefits and assignment planning, a planner should create reliable weekly work plans, by maintaining look-ahead schedules. Ballard suggests maintaining 5 week look-ahead schedule. The master schedule is broken down into a level of detail as appropriate for assignment on weekly work plans, which typically yields multiple assignments for each activity. For an assignment, to make it ready to be executed, it undergoes constraint analysis. Constraints could be technical issues like drawings, contract documents or processes like inspections and approvals. It reinforces the practice of being proactive rather than reactive. The assignments advance to the next week look-ahead or for execution once all the constraints are removed. Thus this procedure allows material or information into a production process only if the process is capable of doing that work which explains the concept of pulling.

The last planner must select assignments from a workable backlog comprising of activities that meet three quality criteria: (1) work must be assigned in the right sequence, (2) work must be assigned in an amount that matches labor and equipment capacity, and (3) the work must possible, i.e., design documents and materials must be on hand or in control, prerequisite work must be finished in time for the assignment to be carried out, and necessary coordination must be identified and arranged. The Last Planner approach provides forward information for control because it forces problems to the surface at the planning stage and can facilitate coordination.

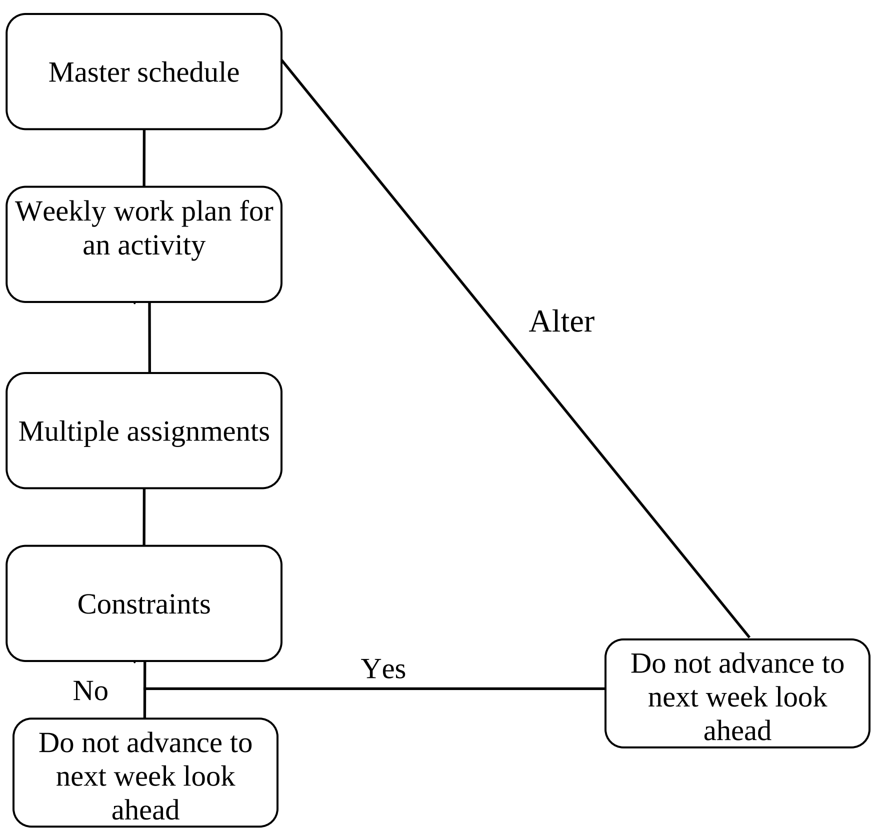

Figure 4: Schematic functioning of look-ahead process.

3.3 LSM

Linear Scheduling Method (LSM) was developed for better representation of repetitive projects that contain identical or similar units which are the essential characteristics of most construction projects. Early representation of LSM was ‘Time versus distance diagram’ (Gorman 1972). This technique allows better representation of information than the conventional CPM. The production rate of an activity is the slope of the plotted line. A location and time along with which certain number of crew members would be working for the entire project is diagrammatically represented by LSM. The activities are positioned in a time and space format, along with the production rates for the activities also included in the schedule in the form of the slope of the lines that represent them.

A research conducted by Charzanowski and Johnston (1986) presented an application to road project and stated that the use of LSM should be used as a compliment to CPM and can be employed by itself on simple projects. Also from the LSM diagrams, one can determine the resource requirements and entered into the tables where cumulative quantities can be easily found.

Three essential factors were described by Voster and Parvin (1990) to successfully plan the linear construction job, which are crew must be given time and space to do their work, work must be performed in an ordered sequence, delays and changes must be minimized. The advantage of using LSM in dispute resolution was also described.

Below is a brief summary of the comparison of LSM to bar char schedule:

1. LSM schedule accurately represents the inherent space time relationships of activities.
2. Due to the layout of space-time, LSM represents the relationship of the activities that can not be easily determined by CPM and also it allows the changes in start and end time of activities and productivity in ways that will guarantee work continuity.
3. .LSM provides better visualization features than CPM and it eases communication for repetitive activities or projects.
4. CPM is appropriate when time-space relationship occur in different dimensions that can not be represented in two dimensional formats.

Application of LSM is proposed for concrete construction as although a project at a whole is not repetitive, but subcontractor's works are highly repetitive.

3.4 The integration of Last Planer and LSM

Integration of the Last Planner concept and LSM can improve the coordination problem between subcontractors. The following table gives a brief overview of how last planner concepts can be effectively implemented using features provided by LSM , as shown in Table 1.

Table 1: Integration of Last Planner and LSM

LSM features	**Last planner concept**
LSM time/space buffer	Should/can analysis
Activity continuity	Work continuity
Easily represent pulling of activities	Pull driven scheduling
Easy to add/delete assignments by different users	Involvement of many levels of participants in developing schedules
Easy to prepare	Last planners are superintendents and foremen

LSM time/ space buffers and Should/can analysis

In LSM the activities are positioned in a time and space format, along with the production rates for the activities also included in the schedule in the form of the slope of the lines that represent them. This representation can facilitate the "should-can" analysis. For example, time and space buffers among activities, activity productivity rate can be checked during constrain analysis.

Activity continuity and work continuity

In LSM, repetitive activities are represented as the same line segments. Work continuity suggested by Last Planer can be visually verified and manipulated.

Pulling of activities

A pull-system approach automatically pulls activities and/or activity segments to later start times so that unforced idleness can be eliminated. Yang (2001)et al. suggested that a pull-system approach for continuous work flow can be modeled by LSM. Activities and their predecessors can be grouped together easily in LSM for pull-driven scheduling.

Easy to add/delete assignments

The last planner concept focuses on the assignment level. Master schedules normally do not show the detail assignments which the last planners are responsible for. The look-ahead scheduling method should allow superintendent and foremen as last planners to easily expand the master schedule and add their detail assignments. Production lines that represent assignments can be easily added and their time and space relationships can be directly analyzed.

Easy to prepare

The LSM chart also provides a basis for superintendents and foremen to either schedule their work using computers or using pencil and paper. As weekly work plans need more detail decomposition of the activities from the master schedule, detail assignments need to be added. LSM can assist in analyzing the overall impacts of these detail assignments and the amount of flexibility they have with respect to the master schedule. Detail assignments can be added or deleted easily in LSM along with the location and time details.

3.5 Software Development

Currently, bar chart is still the most understood and standard way for schedule development and reporting. Although the six-week look-ahead schedule can be directly developed in the LSM format, it is anticipated that most users will still use bar chart for its simplicity and popularity. Furthermore, although LSM presents many benefits as already discussed, project managers are reluctant to duplicated their efforts and translate the same bar chart schedule into the LSM format manually. The goal of this part of the project is to develop a computer application to automatically convert look-ahead bar chart schedule to LSM schedule and allows user to following last planner procedure to plan their assignments. Furthermore, although the daily work chart, as described earlier, is very intuitive for site personnel, preparing and updating daily work charts are extremely time-consuming. The computer application is also designed to automatically present schedule information in site layout drawing format.

This computer application was developed using Visual Basic for Application (VBA). Two similar versions of this program were developed to work with two popular scheduling software packages, Primavera Project Planner and Microsoft Project. For demonstration purpose, only the version developed for Microsoft Project is presented. The program allows users to define repetitive activities, production line color, activity filtering, look-ahead time period, and location sequence and filtering activities before conversion. A screenshot of the conversion dialogue box is shown in Figure 5. Figure 6 is a sample project bar chart schedule.

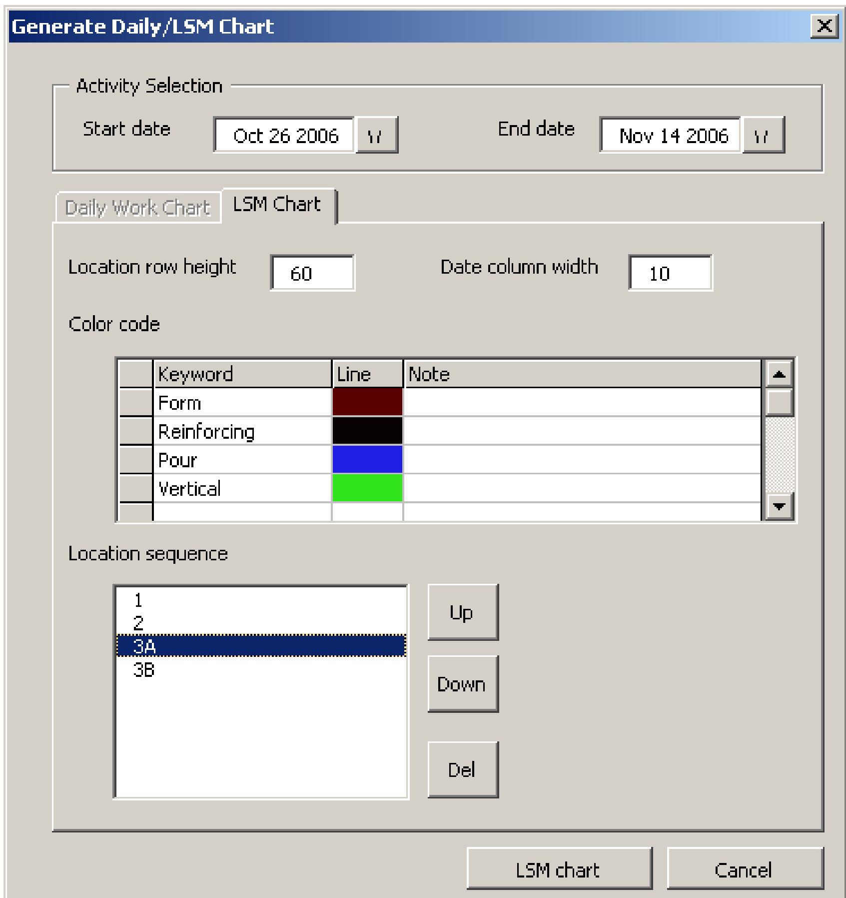

Figure 5: Conversion to LSM chart dialog box

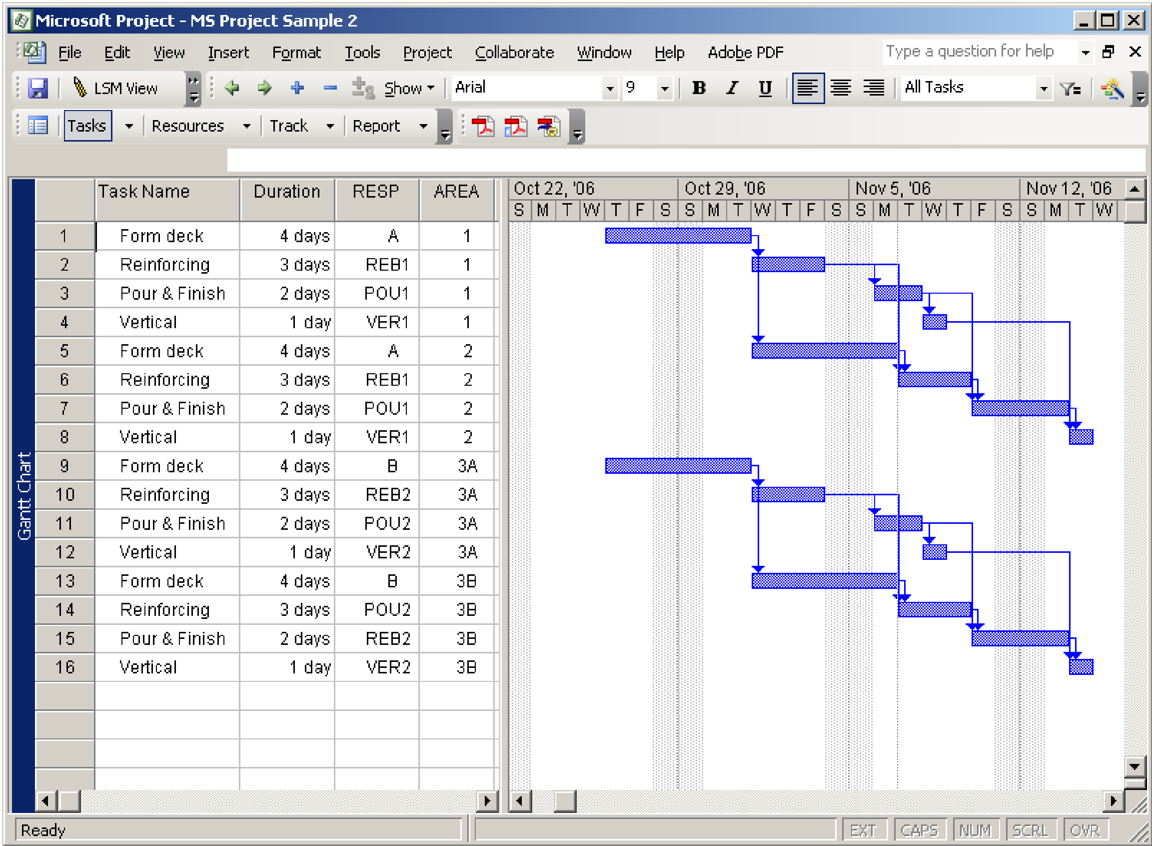

Figure 6: Sample project bar chart schedule

Figure 7 is a screenshot of the converted LSM Chart in Microsoft Excel. Activity attribute data are transferred from bar chart schedule to LSM chart, such as activity float, precedence relationship, and resource allocation. The LSM program allows schedulers to perform constraints analysis. Figure 8 shows the assignment attributes form that allows project managers to monitor resource commitment and keep track engineering issues. The LSM chart also provides a basis for superintendents and foremen to either schedule their work using computers or using pencil and paper. Detail assignments can be added or deleted easily. Activities and their predecessors can be grouped together for pull-driven scheduling.

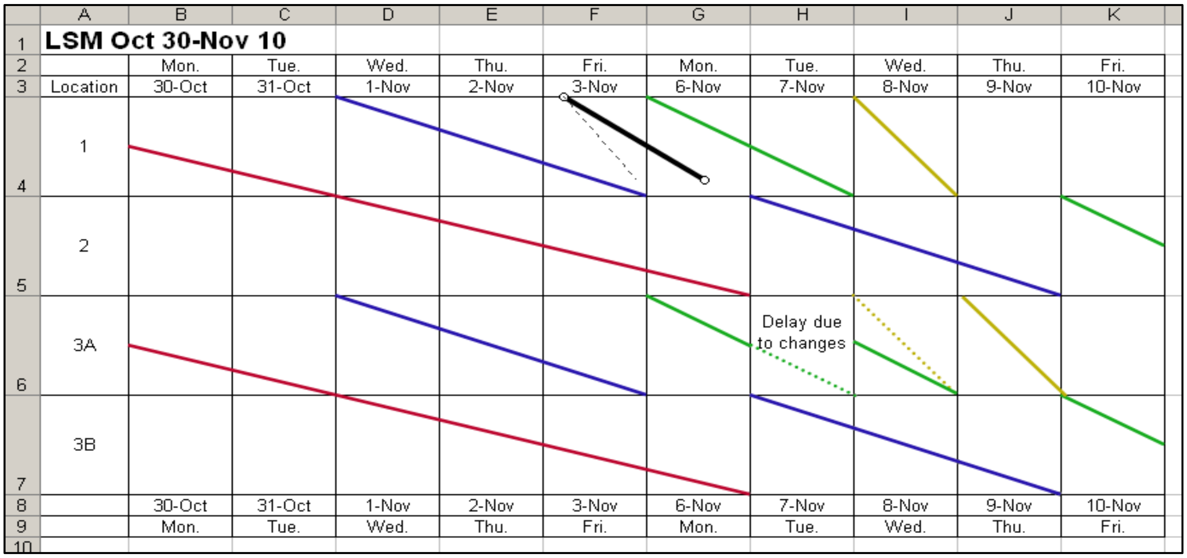

Figure 7: LSM Chart

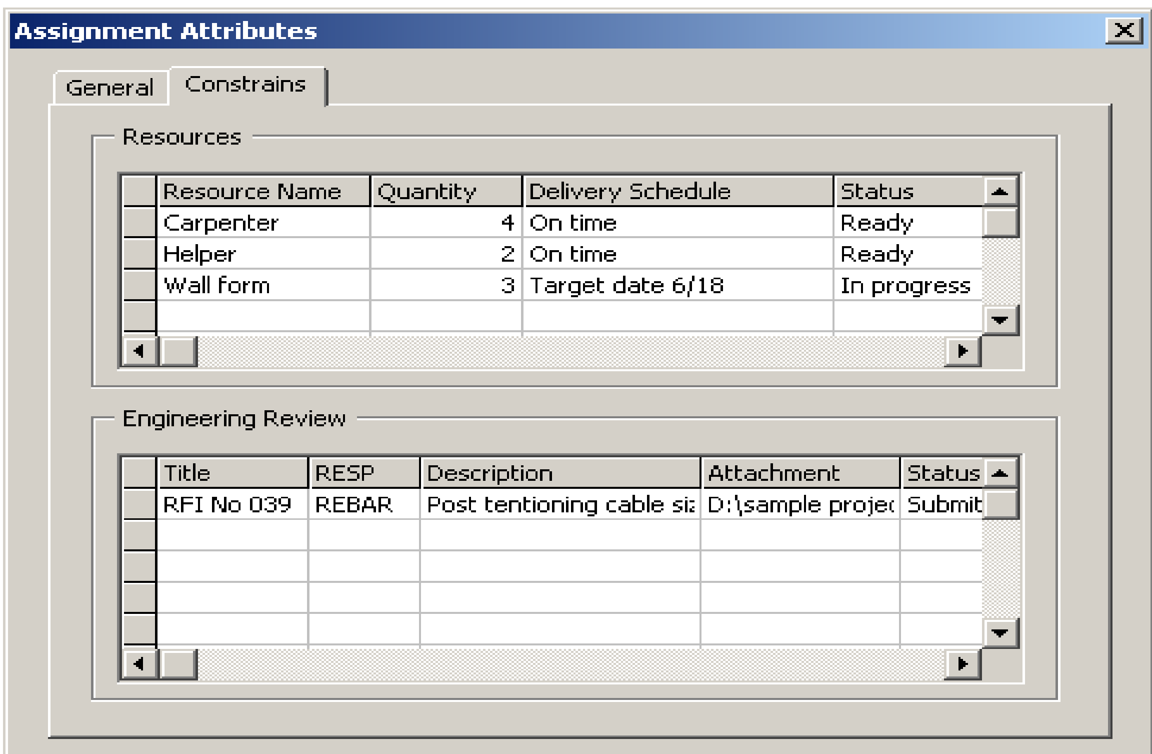

Figure 8: Assignment attributes

Another function of the program is to generate daily work chart based on look-ahead schedules in the bar chart format. Users must first define the job site layout in

Microsoft Excel. This can be done easily using drawing tools provided in Microsoft Excel. Users can control the format of the daily work chart using the conversion configuration dialog box, as shown in Figure 9. It allows users to select the time frame, define site layout and locations of the date label and activity description labels. Figure 10 shows a generated daily work chart for July 17 2006. The chart describes activities and their location on the site layout drawing. The same charts are generated for each working day within user specified time frame.

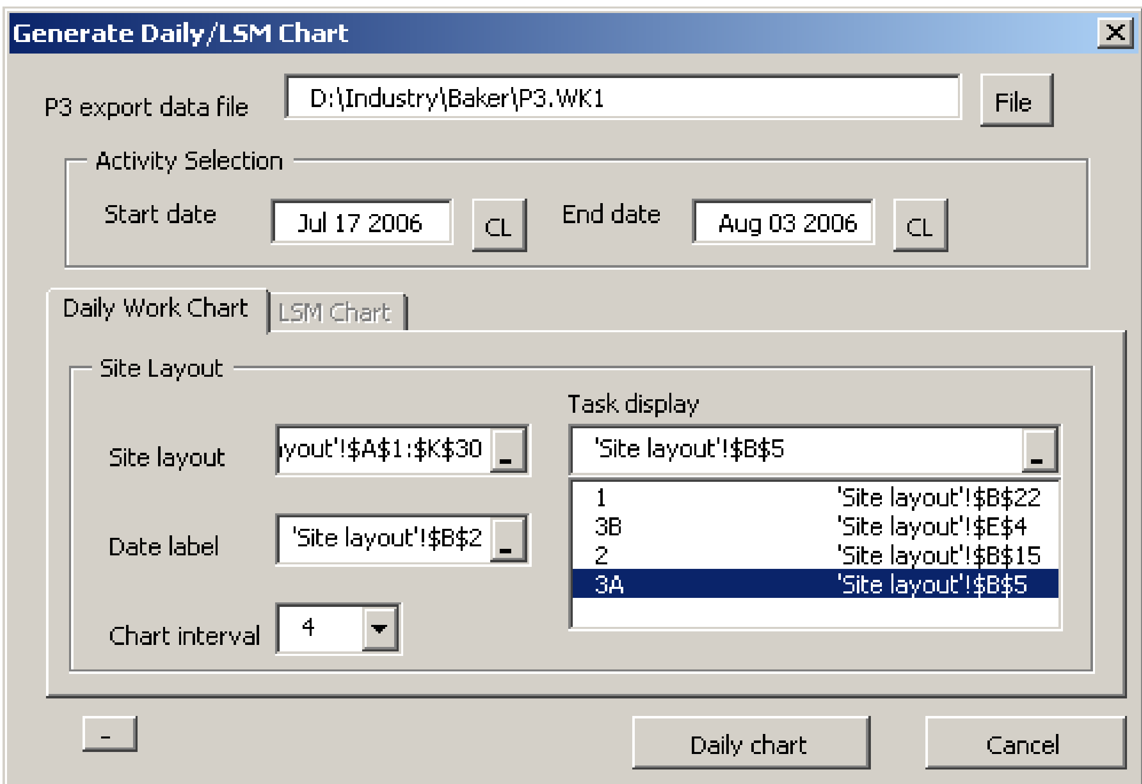

Figure 9: Generate daily work chart

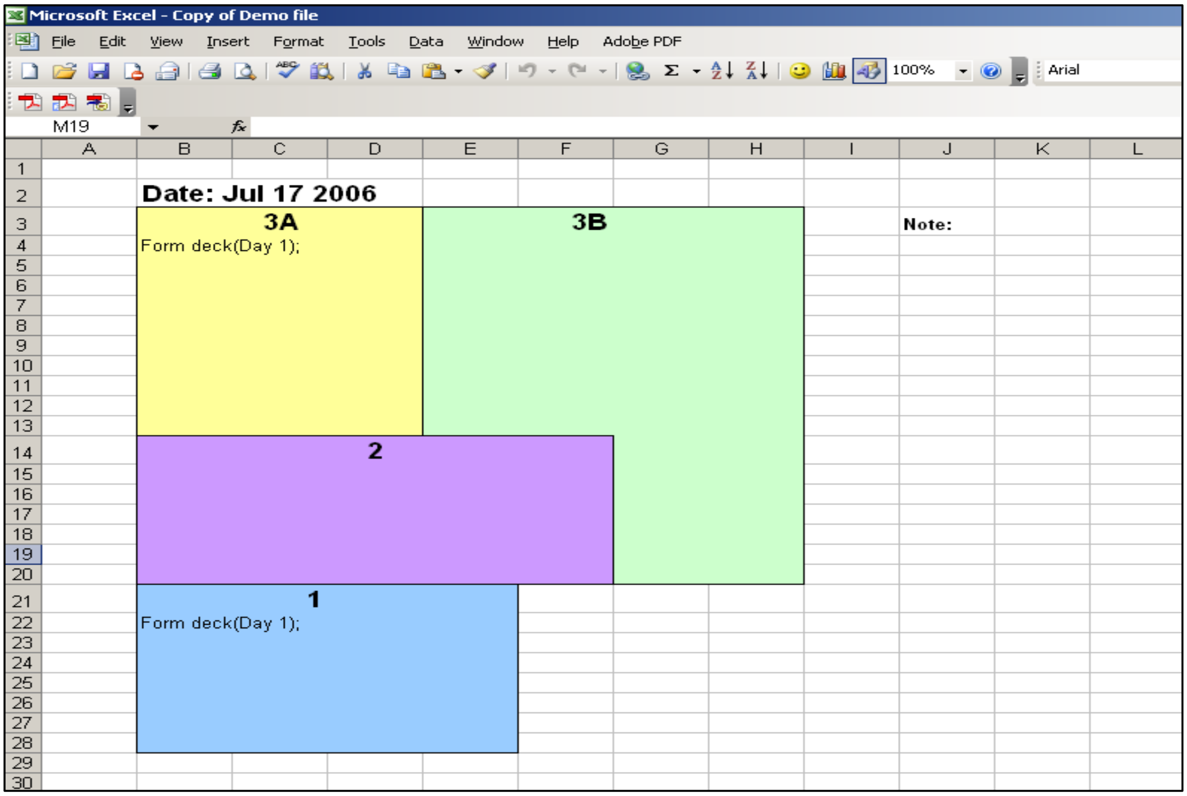

Figure 10: Daily work chart

Chapter 4: Lean Construction at the Operation Level

4.1 Site Observations at the Operation Level

Observations at the operation level involve monitoring work procedure, movement of resources and information on the job site. There are various types pf wastes observed in the sample project as what has been identified in many other similar studies, such as crane waiting, double handling of materials, and rework. Suggestions have been made to redesign work procedure and eliminate the wastes. During the course of this study, resistance to change is perceived to be the major obstacle in implementing lean concepts.

Effective training places an important role on reducing this resistance by improving employees' understanding of new work procedure. In this project, bulkhead installation is identified as a pilot study to demonstrate the process of identifying waste, redesigning work procedure, and training employees.

Form work installation forms an important part of the concrete construction process. A simple bulkhead installation on construction site was observed and improved method for the installation based is proposed based on Lean principle. The current practice of installation procedure is marking and drilling the holes on bulkhead to allow the cables and conduits to pass through and place the bulkhead on the required position. After the concreting is complete, the next step is removing of the bulkheads. The bulkhead removal increases in complexity and becomes time consuming when there are multiple conduits, rebar, and post tensioning cables passing through. A new operation was designed for this process to ease the installation and reduce the time for dismantling the bulkhead after concrete operation. The new procedure includes an additional step of cutting the bulkhead into two parts at centre followed by the placement of the bottom part, run the cables, conduits and rebar and then place the top part of bulkhead. Due to the application of this process in the installation, time for the installation and dismantling of bulkhead is reduced. The following flowchart describes of the new installation process.

Process flow chart

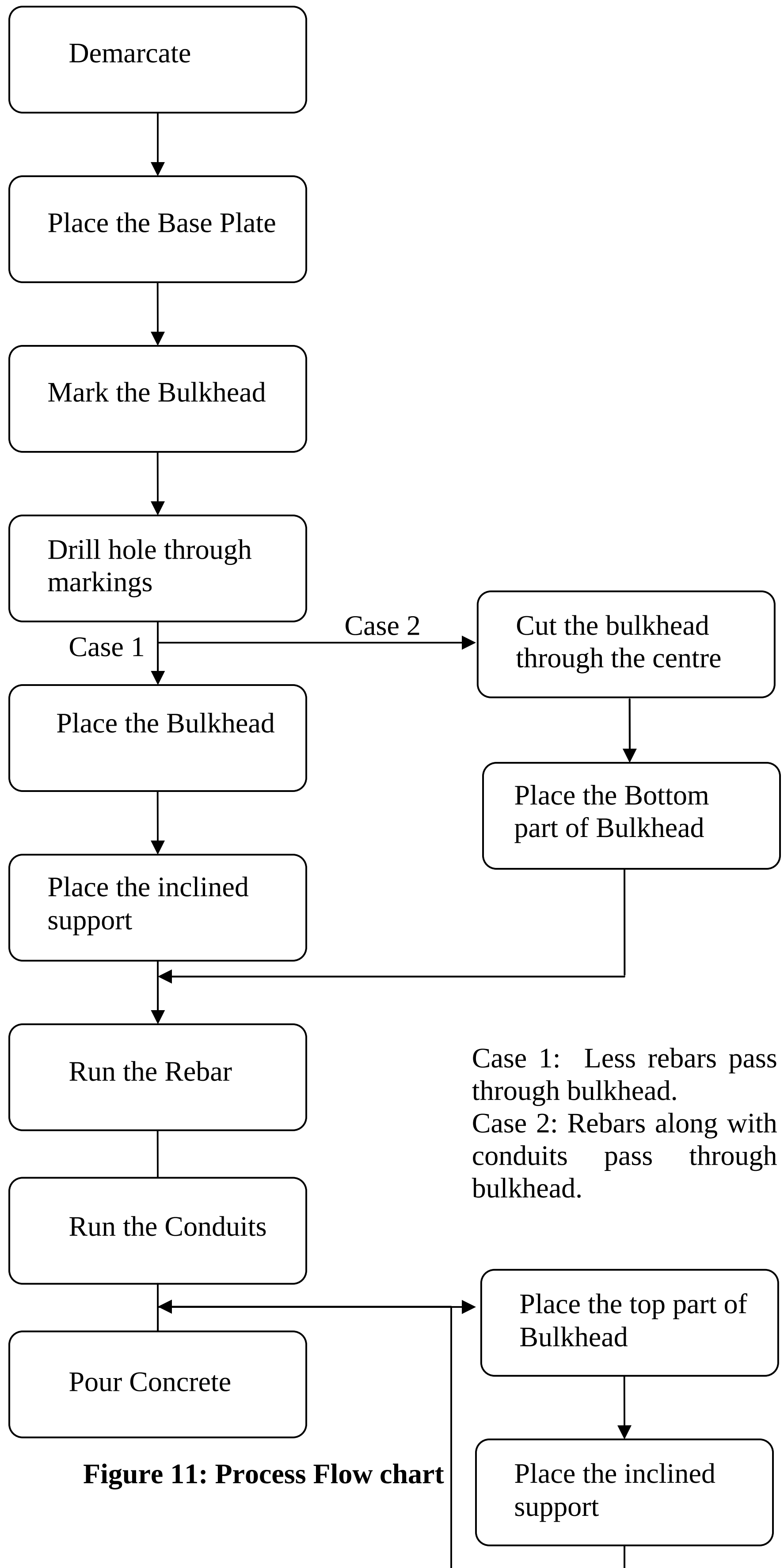

Figure 11: Process Flow chart

4.2 Employee Training

According to the change theory, human systems seek homeostasis and equilibrium, i.e. prefer a predictable, stable world so any kind of change is always met by resistance. Some of the reasons for resistance to change are fear to lose something which one values, not understanding the change along with its implications, and finding it difficult to cope with either the level or pace of the change (Baguley 2001). Effective training can overcome most of the problems of insecurity.

Construction workers lack formal education and therefore selection of effective training technique is a challenge. Also due to temporal nature of the construction jobsite, there is no stability or continuity of crew members. Hence the training technique should be selected considering the repetitiveness of the activity. As the crew could be from varied backgrounds, language should not be a barrier. It should also be less time consuming and effective. Considering the above requirements, a 3D visualization animation was developed for the training purposes.

4.3 3D Animation as a Training Tool

For effective training purposes, 3D animation of the bulkhead installation process was developed in 3D Studio Max. The output of the file is AVI, which can be played o any movie player application. A process flowchart was developed before building the model. The objects were first created in three dimensions and then animated according to the process in the flow chart, as shown in Figure 11. Camera position was fixed and the scene consisting of about 3000 frames was then rendered. Figure 12 to 17 shows several screenshots of the new installation process in 3D format.

Figure 12: The layout operation

Figure 13: The base plates in place

Figure 14: Bulkhead being marked for drilling holes for rebars

Figure 15: Bulkheads and the inclined supports in place

Figure 16: Bulkhead is shown splitting at the centre

Figure 17: The final completed installation

Chapter 5: Conclusion

This project studied the lean construction concepts and its application in concrete construction projects at both 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, lack of coordination among contractors was cited as one of the major factors contributing to project delays. An integration of the Last Planner concept and linear scheduling method to improve communication and short-term scheduling effort was achieved. 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 eliminate wastes in the field operation. A case study on bulkhead installation was used to demonstrate this approach. A 3D animation was created for effective employee training.

This project shows how lean principles can be applied to both project and operation level through an empirical study. Meanwhile, the efforts of applying lean concepts must be justified by its benefits to project performance. Future project should quantify the benefits of lean applications by collecting and analyzing performance data from actual construction projects. This data analysis will measure objectively the effectiveness of lean applications and assist future decision making on investing in lean concepts.

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