

Site Implementation and Assessment of Lean Construction Techniques

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Abstract

The goal of this paper is to test the effectiveness of some lean construction tools, in particular, those tools that can be applied in medium size construction firms. Due to the success of the lean production system in manufacturing, the construction industry has adapted lean techniques to eliminate waste and increase profit. A field study was conducted to evaluate the effectiveness of some lean construction techniques including last planner, increased visualization, daily huddle meetings, first run studies, the 5s process, and fail safe for quality. The data collection methods included direct observations, interviews, questionnaires, and documentary analysis. The effectiveness of the lean construction tools was evaluated through the lean implementation measurement standard and performance criteria. It was found that last planner, increased visualization, daily huddle meetings, and first run studies achieved more effective outcomes than expected. However, the results of implementation of 5s process and fail safe for quality did not meet the expectations of the tool champions and the research team. It was found that there is need for behavioral changes and training for effective use of lean tools. Most of the lean construction tools selected for the project are either ready to use, or are recommended with some modifications. A summary of the results is provided, and future research needs are outlined.

Keywords: Lean Construction, Last Planner

Introduction

With the continuous decline in profit margins and increased competition in construction projects, construction contractors are continuing to search for ways of eliminating waste and increasing profit (Mastroianni and Abdelhamid 2003). Although numerous approaches have been developed to improve efficiency and effectiveness of construction processes, lean construction techniques offer the promise to minimize, if not completely eliminate, non value-adding work. Since the early 1990's, the construction research community has been analyzing the possibility of applying the

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principles of lean production to construction. Koskela (1992) introduced the idea of understanding construction as production. The International Group for Lean Construction (IGLC) has made significant contributions to the formulation of theoretical foundation for lean construction by abstracting the core concepts of lean production and applying them to the management of construction processes. Paez et al. (2005) indicated that the nature of the operation, planning, and execution are the key categories that emphasize the differences between manufacturing and construction. Due to these fundamental differences between construction and production processes, the tools of lean production can't be directly used to manage construction processes and a new set of tools is required. The Last Planner system of production control, introduced in 1992, which emphasizes the relationship between scheduling and production control, is the most completely developed lean construction tool (Ballard 2000).

Howell (1999) indicated that lean construction is similar to the current practices in the construction industry; both practices pursue better meeting customer needs while reducing waste of every resource. However, the difference between the current practices and lean construction is that lean construction is based on production management principles, and it has better results in complex, uncertain, and quick projects. One limitation to implementation of lean construction tools in the United States is the lack of investment in research from the construction industry. Banik (1999) stated that the construction industry is hesitant to invest in research and development to improve productivity. Lean construction currently is still in early stage of development. Tools such as Last Planner have been tested in the field and refined over last decade. However, tools such as Visualization, daily huddle meetings, 5S have not been extensively tested and concrete procedures for their implementation are being developed.

This study fills some of the gap in the literature by testing the effectiveness of lean construction tools. The following tools were evaluated: Last Planner, increased visualization, daily huddle meetings, first run studies, 5s process, and fail safe for quality and safety.

The first part of this paper reviews and discusses lean construction techniques and the second part presents a case study of "lean tools implementation and assessment". The effectiveness of the implemented lean tools in the field case study was evaluated, and future research needs were outlined.

Last Planner System[®]

Ballard (2000) indicates that *Last Planner System[®] (LPS)* is a technique that shapes workflow and addresses project variability in construction. The Last Planner is the person or group accountable for *operational planning*, that is, the structuring of product design to facilitate improved work flow, and *production unit control*, that is, the completion of individual assignments at the operational level. In the last planner system, the sequences of implementation (master schedule, reverse phase schedules (RPS), six-week lookahead, weekly work plan (WWP), percent plan complete (PPC), Constraint analysis and Variances analysis) sets up an efficient schedule planning framework through a pull technique, which shapes work flow, sequence, and rate; matches work flow and capacity; develops methods for executing work; and improves communication between trades. It will achieve *Should Can Will* which is the key term in WWP (Ballard 2000). "Should" indicates the work that is required to be done according to schedule requirements. "Can" indicates the work with can actually be accomplished on account of various constraints on the field. "Will" reflects the work commitment

which will be made after all the constraints are taken into account. Various key contributions to improve the work flow are included: two-way communication, the constraints analysis process in six- week lookahead before assignments are executed, the analysis of reasons for variance after assignments are completed, the efforts of each planner, and the training of the project team. Traditional practices do not consider a difference between what *should*, *can*, and *will* be done, the assumption being that pushing more tasks will result in better results.

The important role of the Last Planner tool is to replace optimistic planning with realistic planning by evaluating the performance of workers based on their ability to reliably achieve their commitments. The goals of Last Planner are to pull activities by reverse phase scheduling through team planning and optimize resources in the long-term. This tool is similar to the *Kanban system* and production leveling tools in Lean manufacturing.

Master Schedule

The master schedule is an overall project schedule, with milestones, that is usually generated for use in the bid package. Reverse Phase Scheduling (RPS) is produced based on this master schedule.

Reverse Phase Scheduling (RPS)

Ballard and Howell (2003) indicated that a pull technique is used to develop a schedule that works backwards from the completion date by team planning; it is also called Reverse Phase Scheduling (RPS). They also state that phase scheduling is the link between work structuring and production control, and the purpose of the phase schedule is to produce a plan for the integration and coordination of various specialists' operations.

The reverse phase schedule is developed by a team consisting of all the last planners. It is closer to reality than the preliminary optimal schedule which is the master schedule. However, without considering actual field factors in the RPS, the RPS is less accurate than the WWP.

Six-Week Lookahead (SWLA)

Ballard (2000) indicated that the tool for work flow control is lookahead schedules. SWLA shows what kinds of work a supposed to be done in the future. In the lookahead window, week 1 is next week, the week after the WWP meeting. The number of weeks of lookahead varies. For the design process, the lookahead window could be 3 to 12 weeks (Ballard 2000). All six-week-lookahead durations and schedules were estimated based on the results of the RPS, and constraints are indicated in order to solve the problems before the actual production takes place. SWLA is distributed to all last planners at WWP meetings. Lean lookahead planning is the process to reduce uncertainty to achieve possible constraint free assignments (Koskela et al. 2000).

Weekly Work Plan (WWP)

Should, Can, and Will are the key terms in WWP (Ballard 2000). Weekly Work Plan (WWP) is produced based on SWLA, the actual schedule, and the field condition before the weekly meeting. Along with this plan, manpower from each trade will be adjusted to the need. The WWP meeting covers the weekly schedule, safety issues, quality issues, material needs, manpower, construction methods, backlog of ready work, and any problems that can occur in the field. It promotes two-way communication and team planning to share information on a project in an efficient and accurate way. It can improve safety, quality, the work flow, material flow, productivity, and the relationship

among team members. Ballard and Howell (2003) indicates that WWP should emphasize the learning process more by investigating the causes of delays on the WWP instead of assigning blames and only focusing on PPC values. Variance analysis is conducted based on the work performance plan from the previous week. The causes of variance should be documented within the WWP schedule.

Percent Plan Complete (PPC)

The measurement metric of Last Planner is the percent plan complete (PPC) values. It is calculated as the number of activities that are completed as planned divided by the total number of planned activities (Ballard 2000). The positive (upward) slope between two PPC values means that production planning was reliable and vice versa. According to Ballard (1999), PPC values are highly variable and usually range from 30% to 70% without lean implementation. To achieve higher values (i.e., 70% and above), additional lean construction tools such as first run studies have to be implemented.

Increased Visualization

The increased visualization lean tool is about communicating key information effectively to the workforce through posting various signs and labels around the construction site. Workers can remember elements such as workflow, performance targets, and specific required actions if they visualize them (Moser and Dos Santos 2003). This includes signs related to safety, schedule, and quality. This tool is similar to the lean manufacturing tool, Visual Controls, which is a continuous improvement activity that relates to the process control

Daily Huddle Meetings (Tool-box Meetings)

Two-way communication is the key of the daily huddle meeting process in order to achieve employee involvement. With awareness of the project and problem solving involvement along with some training that is provided by other tools, employee satisfaction (job meaningfulness, self-esteem, sense of growth) will increase. As part of the improvement cycle, a brief daily start-up meeting was conducted where team members quickly give the status of what they had been working on since the previous day's meeting, especially if an issue might prevent the completion of an assignment (Schwaber 1995). This tool is similar to the lean manufacturing concept of employee involvement, which ensures rapid response to problems through empowerment of workers, and continuous open communication through the tool box meetings.

First Run Studies

First Run Studies are used to redesign critical assignments (Ballard and Howell 1977), part of continuous improvement effort; and include productivity studies and review work methods by redesigning and streamlining the different functions involved. The studies commonly use video files, photos, or graphics to show the process or illustrate the work instruction. The first run of a selected craft operation should be examined in detail, bringing ideas and suggestions to explore alternative ways of doing the work. A PDCA cycle (plan, do, check, act) is suggested to develop the study: Plan refers to select work process to study, assemble people, analyze process steps, brainstorm how to eliminate steps, check for safety, quality and productivity. Do means to try out ideas on the first run. Check is to describe and measure what actually happens. Act refers to reconvene the team, and communicate the improved method and performance as the standard to meet.

This tool is similar to the combination of the lean production tool, graphic work instructions, and the traditional manufacturing technique, time and motion study.

The 5s Process (Visual Work Place)

Lean construction visualizes the project as a flow of activities that must generate value to the customer (Dos Santos et al. 1998). The 5s process (sometimes referred to as the Visual Work Place) is about "a place for everything and everything in its place". It has five levels of housekeeping that can help in eliminating wasteful resources (Kobayashi 1995; Hirano 1996): Seiri (Sort) refers to separate needed tools / parts and remove unneeded materials (trash). Seiton (Straighten or set in order) is to neatly arrange tools and materials for ease of use (stacks/bundles). Seiso (shine) means to clean up. Seiketsu (standardize) is to maintain the first 3Ss. Develop a standard 5S's work process with expectation for the system improvement. Shitsuke (sustain) refers to create the habit of conforming to the rules.

This tool is similar to the 5S housekeeping system from lean manufacturing. The material layout is commonly used for acceleration of 5S implementation on the construction site. Spooore (2003) indicates that 5S is an area-based system of control and improvement. The benefits from implementation of 5S include improved safety, productivity, quality, and set-up-times improvement, creation of space, reduced lead times, cycle times, increased machine uptime, improved morale, teamwork, and continuous improvement (kaizen activities).

Fail Safe for Quality and Safety

Shingo (1986) introduced Poka-yoke devices as new elements that prevent defective parts from flowing through the process. Fail safe for quality relies on the generation of ideas that alert for potential defects. This approach is opposed to the traditional concept of quality control, in which only a sample size is inspected and decisions are taken after defective parts have already been processed. This is similar to Visual inspection (Poka-Yoke devices) from lean manufacturing. Fail safe can be extended to safety but there are potential hazards instead of potential defects, and it is related to the safety risk assessment tool from traditional manufacturing practice. Both elements require action plans that prevent bad outcomes.

Research Methodology

The field study was used as the research strategy in this project. Lean tools from IGLC were tested extensively in this research project. The study tested and evaluated six lean construction tools for possible improvements. They are last planner, increased visualization, daily huddle meetings, first run studies, the 5s process, and fail safe for quality. The data collection methods in this paper include direct observation, interviews and questions, and documentary analysis, and these three methods are applied to each of the tools. Observational data was collected directly from RPS, WWP, and huddle meetings, and the construction process. The Lean Construction tools or techniques and the methods that were used in the first run study and the productivity study were decided upon by the vice president of the general contractor (GC) and the Research Team (RT).

The RT was part of the team in Last Planner, daily huddle meetings, and first run study; but for the rest of the tools, the RT only monitored the process and results. Leaders and participants of Last Planner and Daily Huddle meetings were interviewed on both

weekly basis and at the end of the project. The champion of each tool evaluated the implementation of each tool. Records collected included:

- Last Planner: meeting memos and minutes, various forms of schedules, action tasks with duration, actual completion dates, constraints in six-week lookahead, reasons for not completing assignments as planned, and the results of interviews.
- Increased Visualization: photos, and documentation of the implementation process.
- Daily Huddle Meetings: meeting minutes and the results of interviews.
- First Run Studies: videos, photos, recommendations for productivity improvement from workers and staff, field observation data for crew productivity study, working procedures, and estimated and actual unit costs for the studied items.
- The 5s Process: photos, meeting minutes and the results of interviews.
- Fail safe for quality: SPA, photos, recommendations for quality improvement, the counter measurement of specific items that apply to this project, and the results of interviews.

Background of the Field Study

The study focused on the first phase of a four-floor university garage project. This garage is a cast-in-place reinforced concrete structure; the structure to be built on top of the garage, a different bid package from the garage project, is a five story building that consists of a steel frame and reinforced masonry walls, designed for retail shops and dormitories. The size of the garage is about 133,500 sq. feet. Participating trades in the lean construction implementation study were limited to the general contractor (GC), the formwork subcontractor (SubA), and the rebar subcontractor (SubB). The GC is a mid size construction contractor with a substantial presence in Ohio, Kentucky and Tennessee. The top management of the GC firm has taken active interest in introducing innovative practices in the organization. They had introduced Last Planner as a planning tool prior to this study. The GC had, on an average seven staff and 26 workers each day on this project; SubA had 14 workers and SubB had 15 workers each day on the project. The Master Schedule of the project was divided into four levels: general conditions, underground utilities, phase I, and phase II. The durations were measured and based on five working days weeks. In the master schedule, the duration of the whole parking garage project was 171 days. The lean implementation focused only on phase I. The Master schedule for phase I had 105 working days, Reverse Phase Schedule (RPS) had 89 days, and phase I was completed in 81 days.

GC has been utilizing Last Planner in most of its projects; however, this is the first time that extensive usage of lean techniques such as Visualization, 5S etc. was made. To ensure successful implementation, a champion (the person who is the leader of the tool) for each one of the tools was chosen. The responsibilities of the champion were to implement the guidelines and provide feedback to the researchers.

Although all the tools have an impact on the overall project, two different teams were involved with each of the tools. The planners' team, led by the project manager, was focused on operational planning and controlling, and included GC's superintendent, the foreman, and the project engineer who was in charge of safety on site, as well as SubA and SubB. All members of the planners' team are called last planners. The workers' team, led by the carpenter foreman, was focused on the daily huddle meetings and included laborers and carpenters as well.

Constraints and Solutions

Lean Construction is not widely implemented in the US construction industry yet, and lean concepts are relatively unfamiliar. For both GC's staff and subcontractors, this project was the first opportunity to use lean techniques for operational purposes. Changing mind sets and behavior with lean thinking became a challenge initially in this project, and these also had a great impact on the *5s process* implementation. To eliminate this barrier, the GC offered training classes, provided recognition to promote behavioral change, encouraged employee involvement and rewarded real improvement. As a result, the workforce showed a tremendous amount of learning and improving curves on lean thinking and implementation.

Initially monitoring and documenting this project was a tremendous challenge for the RT because the field personnel from GC, sub A and sub B showed little or no interest in the study. At the end of the first week, the researchers were told that they were prohibited from visiting GC staff's trailer and the job site for the duration of the project; the reasons given were that researchers were asking too many questions and were congesting the working area in the trailer. The RT was not introduced to the members of the project initially.

The unfamiliarity with or misunderstanding of lean concepts and implementation were the greatest barriers at the beginning of the project. The project manager reacted strongly, and wondered whether his management ability was being questioned. He frequently expressed to researchers that these additional management tools were not needed. Most of the Last Planners thought that additional management tools, which came from lean manufacturing, were not applicable to the construction industry. They also felt that the tools were unnecessary and had added too much to their work load. This resulted in initial incomplete implementation of all tools, and no constraints were indicated, low accuracy of constraints and variances were provided, no daily huddle meetings took place, and RPS was made for Phase I only.

This was overcome by offering training, providing recognition to promote behavioral change, encouraging employee involvement, and rewarding real improvement. With an enormous metamorphosis, the same members of this project seemed to completely change into a new set of active people. GC and its subcontractors all put in a great amount of effort to pursue good results and new management of this project, and they gradually improved and achieved higher accuracy in their own assignments.

A Field Study - The Parking Garage Project

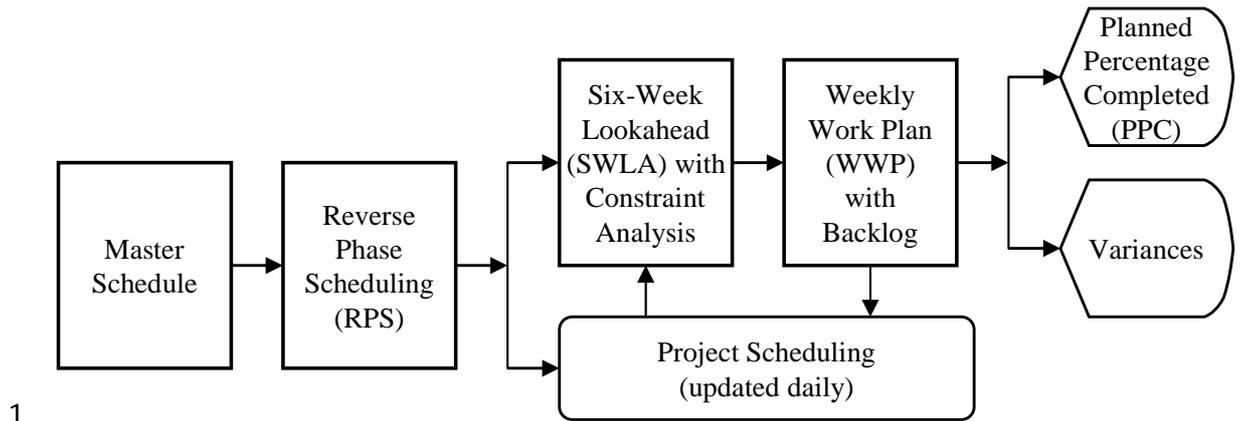
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In order to eliminate waste and achieve two-way communication, the traditional push-system scheduling technique was replaced by pull-system scheduling techniques and team planning. Figure 1 maps the sequence of the Last Planner process for this project.

Insert Figure 1

The process involved the following steps:

1. A master schedule was developed by the project manager which utilized a push-system approach and cumulative experience from similar projects; it included an overall schedule with all phases. The master schedule and drawings with pouring sequences were distributed to all planners and the rebar supplier before the Reverse Phase Scheduling meeting.



1. Figure 1: The Sequence of Last Planner Process

2. Before the Reverse Phase Scheduling (RPS) meeting, lean concept and Last Planner procedures were explained to all Last Planners. All Last Planners and the rebar supplier participated in team planning, and developed network of detailed activities for Phase I of RPS. One RPS meeting was conducted at the start of the project. Using a long sheet of paper on the wall and post-its, Phase I was split into activities with the feedback of all Last Planners. First, the planners wrote down activities, with their durations, on the post-its, one activity per sheet, and stuck those sheets on a long sheet of paper that was posted on the wall forming a timeline, from a target completion date backward. Next, all planners identified the logic between these activities and adjusted the sequences if needed by moving the sheets, and they discussed and decided which activities would dominate the critical path. Then, float, used as the schedule contingency, was added to the activities that were on the critical path and contained some uncertainty. The milestone of the master schedule was an important guideline for RPS production. Finally, the final schedule adjustment was taking the place. A detailed schedule was prepared and some constraints appeared. The RT observed the whole process and then produced an electronic RPS file from this new set of detailed schedule.
3. Six-week look-ahead (SWLA) is a six-week rolling schedule with constraints indicated. The project schedule updated daily which was adjusted from the actual project schedule. SWLA was produced by the project manager based on the results of the RPS and the project schedule. RT documented constraints with indication by the project manager, and performed the constraints analysis. SWLA was distributed to all last planners at WWP meetings.
4. The participants in the WWP meeting included all Last Planners and the RT. The meetings were held each Thursday. Each trade submitted its own upcoming week's schedule to the project manager on the day before the Weekly Work Plan (WWP) meeting. The WWP schedule, manpower, safety, 5S (clean-up and material lay down area issues especially), construction methods, delivery schedules, and any problems from the job site were discussed as part of the planning process during the meeting. Open and two-way communication was the key to the success of this meeting.
5. At the end of each week or on the following Monday, the researcher interviewed the project manager and documented the actual schedule for each activity that was performed. They then reproduced an electronically updated WWP schedule

and variance control table, and analyzed them. PPC charts and PPC calculations were also prepared by the researcher. The PCC calculation is based on the actual start and finish dates of activities. In addition to the overall Percent Plan Complete (PPC) of the project, individual PPC Charts for each trade were prepared to compare their individual progress. Each planner received both PPC charts during the WWP meeting.

Increased Visualization

Combinations of visual signs were tested throughout the project, which are described below:

Safety commitment

- A safety meeting was held on the job site at the beginning of the project for staff and workers. The importance of safe practices for the company was emphasized and people gave feedback on different safe practices on the job site. A commitment to safety was signed by all attendants. The commitment was placed on the trailer where safety training is conducted for new workers.

Safety signs

- Workers provided new ideas and created safety signs in order to increase their involvement in the process. Workers brought forth creative slogans including "Keep an Eye on Safety", "GC Races for Safety". Signs were placed on different spots of Phase I/II, and at the gates of entry and exit.

Completion dates

- Milestones for Phase I and II were identified as results of the RPS, and the expected pouring dates were the results of the WWP meetings. The signs included the phase, pouring sequence, and the completion date for each floor. Drawings with pouring sequences were prepared for the workers and placed on their gang boxes. Signs were posted on the pouring pots for each floor of Phase I and II and were also placed on the retaining wall.

PPC Charts

- PPC Charts were prepared based on the actual schedules of WWP and the variances analyzed by the Project Manager. In addition to the PPC Charts for the overall project, separate charts by each trade were posted.
- Daily Huddle Meetings (Tool Box Meetings)

At the beginning of the project, a weekly informal setting for all foremen was conducted on the site and people gathered at the start of the day to review the work to be done. Throughout the project, two meetings were formally conducted: last planner for all foremen (GC and subcontractors) and the start of the day, a 5 to 10 minute meeting, for laborers and carpenters (this meeting was started the third week of this project). On a weekly basis, interviews were conducted with the leaders and participants of those meetings to identify potential benefits. The reliability of the questions was measured based on a test-retest (i.e., conducting the survey two times for validation) of 33 respondents. The correlation coefficient r^2 averages were 76%.

First Run Studies

Two first run studies were conducted. The first study was on bumper walls and the second one was on construction joints. RT followed the PDCA cycle (plan, do, check, and act) proposed as follows:

Plan: The activities were selected by GC based on target costs and variability. Drawings and specifications of each element were reviewed, and the foreman set the dates for the study based on scheduled activities. The foreman then reviewed the procedures with the RT before the actual action took place.

Do the work: Documenting the process was a stepwise activity because weather conditions and time constraints affected the schedule of activities; hence, at least two repetitions of the same elements were included for continuity. The video file helped to ensure all elements of the operation were included.

Check: Two meetings were held to describe and brainstorm the activities. During the meeting short portions of the video were introduced. The foreman, the project manager, and the workers who were involved with the study gave some ideas for improvement. The manager and foremen evaluated the feasibility of their ideas. A key component was the setting of the meeting which allowed workers to speak freely on how the work could be done better.

Act: Suggestions and potential improvements were added to the subsequent activities. Not all ideas came from the meetings, but the meetings helped formalize them and put them into action.

Productivity Studies: In addition to the video files, productivity estimations for the two activities were performed (Oglesby et al 1989, Mohamed 1996). The field data for the productivity study was recorded and divided into three categories: effective work (E), contributory work (C), and idle time (A). Productivity calculations were conducted by using productivity rating analysis, and labor-utilization factor (LUF), based on the crew balance chart which is the result of one-minute interval field observation data. The productivity rating LUF and field rating can be calculated as follows:

$$\text{Labor - utilization factor (LUF)} = \frac{\text{effective work} + \frac{1}{4}\text{essential work}}{\text{Total observed}} = \frac{(E + \frac{1}{4}C)}{(E + C + A)}$$

$$\text{Field Rating} = \frac{\text{Work}}{\text{Total observed}} = \frac{(E + C)}{(E + C + A)}$$

With recommendation for productivity improvement, a modified LUF was made based on a modified crew balance chart. For the bumper walls, a standard crew and the sequence of activities were established but some downtime was not documented and the estimations were biased

The 5s Process

The superintendent determined the main housekeeping items, and actions that could be implemented. A material layout was made once at the beginning of the project, and was implemented as part of jobsite standardization. It helped to identify the location of material, equipment, and access, which reduced waste, such as search time for material and lay down spaces, and waiting time. All planners repeatedly emphasized the importance and implementation of 5S in all meetings. Foremen from each trade demanded all their members clean up and locate tools and material at the proper places daily. The 5s Process had a successful result initially due to enforcement of

discipline. GC and subcontractors made joint efforts to improve conditions at the jobsite; a housekeeping crew, made up of one worker and one staff member from each trade picked up trash from the whole job site once a week. This additional cost increased the project budget burden.

Fail Safe for Quality and Safety

The project superintendent selected the activity that had potential quality defect problems to further study for prevention purposes. For instance, uneven aggregate distribution occurred around the circular openings and on the sides of the shear wall during the concrete pour. Initial suspicion was that workers did not vibrate the concrete properly. Different vibrators and quality control were carried out, but the condition did not show any improvement. The superintendent found that the problem was not the workers, but rebar sizes and density. Three alternatives were considered: (1) change to smaller aggregate, (2) use self-consolidated concrete or (3) pre-insert extra-vibrators inside the wall and between the circle areas. The study showed that smaller aggregate could not meet the strength of the shear wall, and self-consolidated concrete was not applicable due to the step shape of the shear wall where beams and slab met. Extra vibrating was determined to be the most efficient alternative. Three or four vibrators were used simultaneously and workers hammered the bottom of the circle area manually.

The RT prepared a risk assessment of quality and safety issues (Arditi & Gunaydin 1997). Risk assessment is obtained from the severity times the probability of each evaluated item. The superintendent and safety staff reviewed the most relevant items.

Results and Discussions

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Constraint Analysis

The constraint analysis was limited to the material category, and it focused more on verifying that the duration of the activities would meet the schedule and that those resources were available. Even though constraints were indicated after the initial stage of the project, they failed to anticipate potential variances. One finding from the observation of the researchers was that six weeks could be a good lookahead period for material flow.

PPC

WWP meetings were held regularly and the meeting time was adjusted according to concrete pouring schedules. Phase I was completed eight days ahead of RPS and 16 days ahead of the master schedule. Twenty percent of PPC values were between 60% and 70%, forty-five percent of PPC values were between 70% and 90%, and fifteen percent of PPC values were above 90%. Figure 2 shows the overall Percent Plan Complete (PPC) for the project.

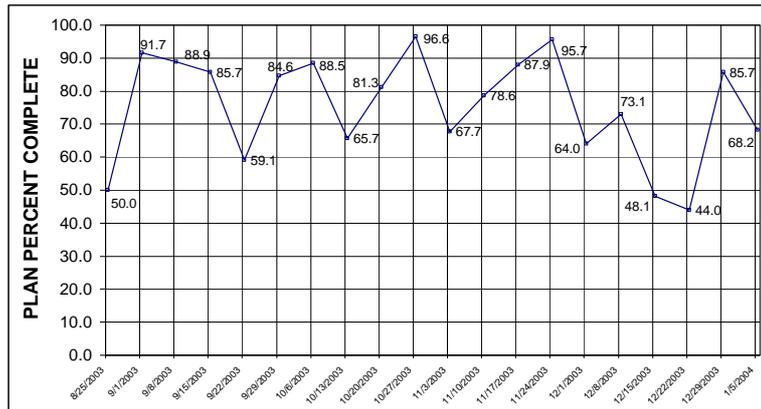


Figure 2: the overall Percent Plan Complete (PPC) of the project

The major reasons that caused downward slopes of PPC values are weather, scheduling\coordination, and prerequisite work. The main reasons for the high PPC values achieved in this project were:

- The project manager approached a new set of pouring sequences to accelerate and shape the workflow rate and optimize the workflow capacity.
- All last planners made a commitment to contribute their best efforts to achieve high reliability.
- All last planners respected each other, established open and two-way communication, and solved most of the problems at the WWP meeting.
- This garage project consisted of repetitive activities which were simpler and had less overlapping work compared with more complex construction projects.

The goal PPC value for GC's Last Planners was between 90% and 100%, which demonstrated that they didn't fully understand the purpose of PPC. Training becomes an important issue here. Towards the end of the project, during a severe winter with a heavy snow fall and wind chill, each trade only had one or two activities on the schedule each week, which meant, if one trade did not finish one activity on time as planned, the individual PPC value for that week would either be 0% or 50%. This happened to GC and SubB for consecutive weeks. These low PPC values had a great impact on their morale. Some Last Planners started to complain that SubA could maintain high PPC values due to their conservative estimations. The RT decided to conduct a calculation and a comparison for the accuracy of scheduling of each trade.

Since GC had a total of 84 tasks, most of them were one- or two-day short duration activities; SubB had a total of 32 tasks with mixed durations; SubA had a total of 16 tasks, most of them were activities of five- to ten-day long duration. Regarding the accuracy of schedule estimation calculations, one day over- or under-estimation was significant to GC. In contrast, it was only of minor significance to SubA. Therefore, in order to evaluate the accuracy of estimations equally, the RT made three different comparisons. In the first two parts of the table, the category is the difference in days between RPS, WWP, and actual duration of activities, versus numbers of tasks from each trade, and proportion to total tasks of each trade. In the third part of the table is the accuracy of estimations between RPS, WWP, and the actual duration of activities, versus the number of tasks from each trade. The results of these three comparisons are summarized as follows: GC had the most accurate and consistent estimations on both RPS and WWP, SubB was placed at second. SubA had the largest margin on his estimations. At the end of the study, questions were raised: (1) how to distinguish

between conservative estimation and improving productivity that had achieved right-on schedule or ahead of schedule, (2) how to prevent conservative estimation in RPS and WWP, (3) will PPC values be used in a normal way to interpolate at the end of the project or during the severe winter weather; these questions will need to be explored in further study.

Variance Analysis

The performance of the previous week was not reviewed during the WWP meetings. Instead, the project manager provided reasons why the work was not completed (variances) to the RT. Most of the problems were tracked on the spot; therefore, no action plans based on variance analysis were formally conducted. Constraints and variance analysis are summarized in Figure 3.

For variance analysis, weather, scheduling/coordination, and prerequisite work, were the key categories that influenced activities from being completed on time. Most were not accurately indicated. For example, alignments of structural elements were misplaced and one column was missing during the column casting and concrete pouring process. These great defects were caused by human error on site or unclear indication of the drawings that were provided by the architects/engineers, such as not enough information, lack of sections and details to show the connections, too much information shown in a small scale, or not enough dimensions. This caused schedule delays which were not indicated in variances of the project. Because of these defects, workers needed to stop working and wait for the decisions from the engineers. Usually rework was performed. Constraint analysis is limited to material only. The data show that either Last Planners have overcome material problems, or the truthfulness of the indications should be questioned. Without accurate data collection, constraint and variance analysis could not be done further in depth.

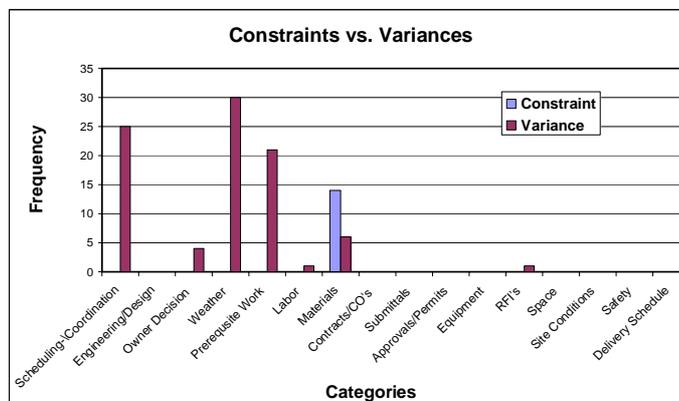


Figure 3: Comparison of constraints and variances

Increased Visualization

Visual signs were posted at the various locations, but some project milestones were hidden or in dark places. Most of the signs were posted at the beginning of the project except pouring milestones that were ongoing efforts. Workers viewed that safety was an important issue, as the company introduced it in a family perspective. They also were interested in being knowledgeable about the where and when of each pouring sequence. To pursue the best results in this category, financial budget and manpower availability for ongoing efforts are the important keys that need to be evaluated by the project manager.

Daily Huddle Meetings

Most of the workers and planners stated that their leaders reviewed performance during the meetings. Planners received information on successes and failures more than 73% of the time, and workers received information on performance more than 60% of the time. However, some people failed to remember issues during those meetings. The proportion of planners who remembered the issues ranges from 42% to 100% while the proportion of workers ranges from 17% to 86%. To assess the effectiveness of the meetings, some key categories of issues were selected: quality, scheduling, manpower, clean-up, lack of tools and safety. Both the leaders and the members were asked to suggest the main issues for the meetings each week. The effectiveness is quantified based on the correlation between the response of leaders and members. The results show that the effectiveness was high at the beginning of the project, but dropped during the last three months. The main reason is that new workers joined the jobsite and they received little information about lean construction. The second reason is that the project manager tried to push the issue of cleanup without any reaction from the workers. Most people were focused on safety and scheduling only. At the end of the project, the effectiveness of the foreman meeting was 75% and the start-of-the-day meeting was 29%.

To evaluate the value of the meetings, team members were asked whether they could solve the problems on the jobsite as a result of the meetings. More than 80% of the planners and 67% of the workers found value in the meetings and would like to talk more often to their leaders. This does not mean they contribute to the meetings in the same proportion. According to the last question, between 31% and 47% of the time planners offer some ideas or suggestions. Workers offer feedback between 19.8% and 42.2% of the time.

Throughout the project, the all-foremen meeting was regularly held and key topics were well covered. The main challenge for implementing this tool was the communication between foremen and workers throughout the day. Most of the workers state that they talked to their foremen between two and six times a day and the issue of success/failure on the job site is discussed directly with the crew involved. Therefore, there is little room for new issues during the daily meetings. Hence daily meetings with repetitive issues lead workers to adopt a robotic mode.

Two-way communication is the key to the daily huddle meeting process prior to workers experiencing involvement in the project; it was promoted well in the daily huddle meeting. People are used to not providing feedback or questioning any issues, therefore, commonly traditional one-way communication dominated the meetings. Statistics of the meetings and the instrument (survey) provided valuable management information for the project manager, planners, and foremen. It identified how much information the management level was given and how much information the workers absorbed.

First Run Studies

The study shows that productivity could be increased from 53% to 62% without additional investment. Placing the material closer to the operation and having a standard crew of two people will have an impact on its productivity. Several site factors that contributed to decreased productivity of construction joints in the study included severe weather, placing material too far from the work location, alignment problems from the prerequisite work that was performed by other trades.

At the beginning of the project, actual bumper wall productivity was far lower than normal. (30% of the expected productivity) The GC decided to select it as a test activity. Shortly after the first run study, productivity increased tremendously; with continuous improvement over time, the productivity increased to almost 3 times the expected value.

Besides the site factors, other physical factors could also contribute to the productivity variation, such as time of day and day of the shift work. The workers were excited to be a part of the video filming process. Furthermore, the company provided an open and friendly atmosphere, not focused on blaming for failure, and encouraged bringing ideas and suggestions. This played an important role in the success of this First Run Study. At the first study meeting, all participants stated that the fear of questioning the status quo was the main obstacle to providing more suggestions at the second First Run Study meeting, even though GC had encouraged the workers to speak openly. The project manager, the superintendent and foremen implemented actions based on the study.

With positive outcomes of the study, the superintendent recommended implementation of this study to activities that are involved with complex construction techniques, multi-trades work overlap, and potential quality problems.

The 5s Process

Construction is a dynamic production; lay down area change dramatically as production is moving forward, hence, the material layout plan should be a continuous effort that includes all trades' involvement. Throughout the project, Sort, Straighten, and Standardize are the winners in this category mainly due to management eagerly making efforts. Conversely, the traditional working behavior became an obstacle for the enforcement of shine (clean up) and sustain. Workers are used to being messy and throwing garbage on the ground, and they think that they were hired to do physical construction work, but not to clean up.

Housekeeping is a behavior that cannot be automatically enforced because workers are not used to it. Therefore, enforcement can't work directly. The foreman should create awareness in the basic principle of housekeeping: leave your work area as you receive it. Additional reasons why cleanup is difficult or not possible could be discussed with people who show little or no concern about housekeeping. Enforcement of the 5s Process is the responsibility of all members of the project. It seems easy to do but it is the most difficult tool to implement successfully. GC realized that behavior change, commitment, and discipline are the keys to the success of housekeeping.

Fail Safe for Quality and Safety

OSHA standards were followed throughout the project and showed that the management level seemed to input more into efforts than the workers. Planners went beyond standard practice and identified particular hazards for their work and some successful actions took place, such as tying off, keeping an eye on leading edge, use of safety glasses and hard hats. Saurin et al. (2002) advocate the introduction of health and safety plans into the project execution as Plan of Conditions and Work Environment. A Preliminary Hazard Analysis (PHA) should be implemented in the planning state. Safety actions are incorporated into the look-ahead planning. Next, planners review the safety requirements for the following assignments that might create additional constraints. Safety practices are integrated into the short-term planning through daily feedback with crew and subcontractors. Performance is tracked through safe work

packages, an indicator of the proportion of safe work. Based on the information collected, the overall percentage safe work improved 27.8%.

Marosszeky et al. (2002) state that quality analysis is affected by the poor detection of defects during the operation and the long cycle times from detection to correction. To address those issues, a lean manufacturing tool is proposed - quality at the source (QAS). In order to implement QAS, checklists were prepared and handed over to the workers so that they can do it right the first time and identify any quality issues as they arise. The % of quality points from the checklists done by the workers was recorded throughout the project. The % QAS improved by 14.0% for the items selected during the project.

People tend to confuse preventing potential defects, which is the purpose of this category, and meeting the quality specification. For this reason, most planners think this tool is unnecessary. However, the superintendent clearly indicated that he welcomed this tool for preventing quality defects. In order to achieve a better outcome more training and a concrete action plan with clear procedures were required.

Assessment

The tools such as daily huddle meeting, visualization, 5S process etc. are new to the construction industry and as there are no uniform construction industry standards for the implementation of these tools. It would have been erroneous to compare the results of their implementation to the standards in manufacturing industry. The RT designed an implementation measurement standard for the project and assigned the numbers to evaluate the progress. The tool such as Last Planner could be evaluated easily due to its quantitative nature. However, the evaluation of other tools such as daily huddle meetings, visualization, 5s process was based on many subjective criteria. These criteria are listed in the table 2.

Table 2: The criteria of assessments for each tool

Tools	Criteria for Assessment
Last Planner	Pull Approach, quality, knowledge, communication and relation with other tools
Visualization	Visualization, continuous improvement, knowledge, communication and relation with other tools
Daily Huddle Meetings	Time spent under control, review work to be done, issues covered, communication and relation with other tools
First Run Studies	Action Plan, continuous improvement, knowledge, communication and relation with other tools
The 5s Process	Action Plan, continuous improvement, knowledge, communication and relation with other tools
Fail Safe for Quality and Safety	Action Plan, continuous improvement, knowledge, communication and relation with other tools

The progress was assessed on a scale from 0 to 10 to compare the initial, expectation, and achieved status of each tool. The scale for evaluation of implementation of tools is shown below in Table 3. The tool champions were intimately involved in the implementation and they received feedback from the tool implementers at the site.

Table 3: Assessment scale for lean implementation

Item	Description	Value
None	Not implemented	0 - 2
Low	Most of the items are not implemented	2 - 4
Moderate	Partially implemented	4 - 6
High	Most of the items are successfully implemented	6 - 8
Very High	Entirely implementation	8 - 10

An expectation value was set for each tool based on the expectations of each champion. The champions of the tool were representatives from the GC organization who had substantial experience on construction sites.

The final/current status was taken up to the end of Phase II construction, once all the tools had been properly tested. The performance is listed in Table 4.

Table 4: The performance, measure items, and average score of assessments for each tool

Tools	Measure Items	Average Score		
		Initial	Achieved	Expected /Target
Last Planner	Reverse Phase Scheduling, Six Week Look-ahead, Weekly work Plan, PPC Charts and reasons for variances	3.6	7.2	6.25
Visualization	Commitment Charts, Safety signs, Mobile signs, Project milestones and PPC Charts	3.4	7	6.75
Daily Huddle Meetings	All foreman meeting and start of the day meeting	4.6	7.4	4.75
First Run Studies	Plan, Do, Check, Act and Productivity Studies	3.1	6.6	4.25
The Process	5s Sort, Straighten, Standardize, Shine and Sustain (5 S's)	3.6	6.1	10
Fail Safe for quality and Safety	Quality, Safety and SPA	4.4	6.2	7.5

The signs required fro increased visualization didn't get adequate attention from the project management in the initial phase of the project. The PPC charts or project milestones were not posted, commitment charts were not posted on the trailer. A few safety signs were posted at the project site. Due to the continuous efforts taken by the

research team, the level of visualization increased significantly towards the end of the project. Commitment meetings took place and commitment charts were posted on the trailers. The project milestones and PPC charts were posted at various locations at the site. The average score of the state of visualization jumped from 3.4 (low) to 7.0 (high) by the end of the project Figure 4 shows the Spider Web Diagram; which is an overview of the assessment of implementation of the tools in this project. This diagram shows the initial, expectation and achieved status of *the lean construction tools implementation*, which are the results from the assessment of each tool.

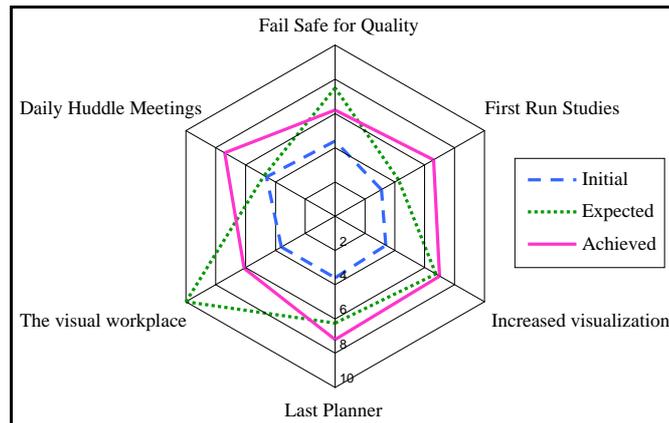


Figure 4: Assessment implementation of tools - Spider Web Diagram

The RT proposed the status of tools for future use based on the assessment implementation of each tool. However, with the experience gathered on the Garage project, it is possible to realize that not all tools show the results and compensate for the effort made by all GC employees. Table 7 summarizes the findings on these tools and the status for future projects.

Table 7: Tools recommended for future use

Enabler	Status	Recommendations
Last Planner	Ready to be implemented	1.Emphasis on Reverse Phase Scheduling 2.Emphasis on variance Analysis
Visualization	To be implemented with some modifications	1. Integrated approach 2. Safety-Quality-Housekeeping
Daily Huddle Meetings	To be implemented with some modifications	Change frequency of the meetings with smaller groups
First Run Studies	To be implemented with some modifications	1 Integrate with scrum meetings (Tool Box Meetings) 2 Document learning process
The 5s Process	To be implemented with some modifications	Housekeeping can be address with Increased Visualization
Fail Safe For Quality and Safety	To be re-examined	1 Use Plan Conditions and Work Environment 2 Use Quality at the Source

Conclusions and Recommendations

This paper reviewed and tested the effectiveness of lean construction tools that are suitable to apply in construction firms. The authors found that the lean manufacturing tools can be modified for use in construction projects and successfully implemented. The commitment of the top management for implementation of these tools may prove to be the most important factor in successful implementation of these tools. The authors observed a complete attitudinal shift in the project participants in this project. At the beginning of the project, the project manager questioned the applicability of these tools at the site. However, by the end of the project, everyone on the site participated in the implementation of these tools. The training classes offered by the GC, recognition provided to promote behavioral change, encouragement of employee involvement and rewarding real improvement proved to be critical factors in eliminating barriers to change. The workers enjoyed being a part of a structured planning and decision making process.

Training will be a key aspect of implementation and success of the Last Planner at the site. The staff and workers will need to be trained to use this tool effectively. This training may result in an increased burden in early stages of implementation but over the long haul, it will serve to increase the efficiency of construction companies and more than make up for the initial investment in training.

Further research is needed to investigate to find how to distinguish between conservative estimation and improving productivity that had achieved right-on schedule or ahead of schedule using the Last Planner tool. It is also important to develop new methods to prevent conservative estimation in RPS and WWP.

The authors are currently working with the GC to find ways to effectively implement lean construction.

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