THE PATH FROM LEAN MANUFACTURING TO LEAN CONSTRUCTION: IMPLEMENTATION AND EVALUATION OF LEAN ASSEMBLY

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ABSTRACT

Since the early 1990's, the US construction industry has taken interest in the application of lean production as a new theoretical framework. The IGLC has provided a new set of tools to improve project performance measures (e.g., productivity, quality, and safety). This article compares the techniques developed for lean assembly with those of lean manufacturing. It also introduces an assessment tool implemented by a general construction project in Ohio, USA. This assessment tool comprises six elements: Last Planner, Increased Visualization, Huddle Meetings, First Run Studies, Five S's, and Fail-Safe for Quality. The successful understanding and impact of this tool emphasizes the need for a simple and comprehensive approach that is transferable to any construction project.

KEY WORDS

Lean assessment, performance tracking, construction tools, manufacturing tools.

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INTRODUCTION

Japanese manufacturing techniques have been benchmarked by Western manufacturers for more than three decades (Druker, 1971; Schonberger, 1982). After the results of the study conducted by the International Motor Vehicle Program (IMPV), those techniques were seen as part of a new production system known as lean production (Krafick, 1988; Bartezzaghi, 1999). The scope of those techniques was not limited to manufacturing. In fact, Bowen and Youngdahl (1998) present cases of process-based services applying lean production practices.

Having the characteristics of production and service systems, the construction industry has also taken some steps toward the application of the lean production concept (Howell, 1999). Lean construction, however, presents additional challenges as a case of project-based production. The concept of Lean Enterprise (Murman et al., 2002) comprises a variety of production systems that share common principles: Waste minimization, responsiveness to change, just-in-time, effective relationships within the value stream, continuous improvement and quality from the beginning constitute the core goals of the Lean Enterprise.

Lean construction has sought a new foundation for project management (Koskela, 2002). The International Group for Lean Construction (IGLC) has led research on the application of lean techniques in the construction industry. The IGLC has provided tools for operational planning and control, supply, visualization, and continuous improvement. Emerging techniques have started to change the way constructors manage their own operations.

The extension of specific manufacturing techniques to lean construction is still an open question. It is clear that both contexts conform to a socio-technological construct (Niepce & Molleman, 1998) where the combination of human and technical elements ensures higher performance outcomes (Moore, 2002). In practice, however, it is important to determine a set of tools that can be applied to achieve higher performance outcomes in construction projects.

This paper presents a study that was conducted on a construction project in which specific lean construction elements were tested. Each technique was evaluated in terms of its impact on the performance of the project. Based on the findings of the study, a new 'lean assessment tool' is proposed to quantify the results of lean implementations.

MOVING FROM LEAN MANUFACTURING TECHNIQUES TO LEAN ASSEMBLY TECHNIQUES

Ballard (LCI, 2000) divides the Lean Project Delivery System into four interconnected phases: project definition, lean design, lean supply and lean assembly. This study focuses on Lean Assembly, starting from the first delivery of resources to the site and ending with the project turnover. Lean assembly is particularly important to General Contractors (GC) since they develop a human and technical structure for this activity.

By definition, techniques follow a heuristic approach; practices are designed and test through trial and errors until they can be implemented across companies. In lean production, techniques are linked through a common framework (Monden, 1993, Feld, 2001).

Accordingly, Dos Santos (1999) has linked heuristic approaches with the theoretical framework of lean construction. The following approaches apply to Lean Assembly:

FLOW VARIABILITY

In lean manufacturing production leveling addresses the impact of flow variability (*Heijunka*). In production leveling, the impact of fluctuating demand levels is controlled by optimizing the sequence of products with minimum batch-sizes. If batches are reduced, demand fluctuations can be managed by making small adjustments to the production volume and resources allocated. Techniques associated with production leveling are: product sequence scheduling, flexible standard operations, multifunctional layout design, and total preventive maintenance.

Lean Construction is largely influenced by flow variability as the late completion of one trade can affect the overall completion time. Last Planner is as a technique that supports the realization of plans (Ballard, The Last Planner, 2000). Last planners are the people accountable for the completion of individual assignments at the operational level. The process starts with the Reverse Phase Schedule (RPS), i.e., a detailed work plan specifying handoffs between trades for each phase (Ballard and Howell, 2003). Based on the RPS, the lookahead schedule provides the activities to be completed during the next weeks and a backlog of ready work. The workflow is controlled by weekly work plans prepared by each planner. If assignments are not completed on time, the planer has to determine the root cause of variance and develop an action plan to prevent future recurrences of the problem.

PROCESS VARIABILITY

Autonomation (*Jikoda*) is the notion that defects should not be allowed to flow through the process and immediate action should be taken to prevent those defects at the source. In lean manufacturing, Visual Inspection is a technique that gives back to the workers the autonomy to control their own machines. Whenever they identify defective parts they are allowed to stop the process and identify the root cause. Fail safe (*Poka-yoke*) devices are used to automatically prevent defects from going to the next process (Shingo, 1985).

Because defects are difficult to find before installation, quality in construction has traditionally been focused on conformance. Lean construction concentrates efforts on defect prevention. Fail-safe actions can be implemented on the job site to ensure first-time quality and optimum toleracing on all assignments (Milberg and Tommelein, 2003).

TRANSPARENCY

In lean manufacturing, any resource that is not contributing to better performance is regarded as waste and, it should be eliminated from the system. The Five S's are a method to identify hidden wastes in plants. Different degrees of housekeeping: sort (*Seiri),s*traighten (*seition), s*tandardize (*sieso), shine (seiketsu) and sustain (shisuke*) contribute to eliminate slack in the workplace.

The Five S's in construction seek a transparent jobsite where materials flow efficiently between warehouses and specific jobs in the field (dos Santos, 1998). Since construction has mobile workstations, 'Increased visualization' helps identify the work flow on the jobsite and create awareness of action plans on the jobsite (Moser and Dos Santos, 2003).

Continuous Improvement

Continuous improvement (*Kaizen*) cannot be associated with a specific technique. In fact, all techniques are set to drive continuous improvement by problem-solving focus and creative thinking. However in lean manufacturing, quality circles are an opportunity for workers to actively participate into process improvement. These teams meet periodically to propose ideas for the most relevant problems in the workplace. Quality, maintenance, cost reduction, and safety issues can be worked out by the teams to provide potential solutions for future activities. The benefits of the quality circles are not only the implemented ideas but also the learning process that workers experience.

Daily huddle meetings are used in construction to develop and improve assignments. Based on a set of targets, during daily 'huddle meetings', people give their input on their progress (Mastroianni and Abdelhamid, 2003). At the end of the month new targets are established (Schwaber, 2002). First Run Studies are used to redesign critical assignments (Ballard and Howell, 1997). An operation is examined in detail, bringing ideas and suggestions to explore alternative ways of doing the work. The PDCA cycle (plan, do, check, act) is used to develop the study. *Plan* refers to select work process to study, analyze process steps, and brainstorm how to eliminate steps. *Do* means to try out your 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 as the standard to meet. Continuous improvement relies in the best use of the capabilities of the team to develop both individual and joint contributions (West, 1998).

OBJECTIVES AND SCOPE OF THE STUDY

The purpose of this study is to assess the value of different techniques for a general contractor (GC) in Ohio, USA. The General Contractor pursues human and technical learning through the implementation of lean construction. The GC management decided to test six techniques based on previous knowledge of tools implemented in lean construction and lean manufacturing. Those technique are Last planner, Increased Visualization, First Run Studies, Huddle Meetings, The Five S's, and Fail-safe for Quality .A Research Team (RT) monitored the implementation of those techniques in a parking-garage project during a six-month period. Based on the results and the feedback provided by all participants, an overall assessment was prepared and a modification of for future implementations was proposed.

The RT worked with two different teams in the project. The planners team, led by the project manager, was focused on operational planning and included subcontractors as well as the staff. The workers team, led by the foreman, was focused on the improvement activities and included laborers and carpenters as well. One champion for each tool was selected from the GC staff to lead the implementation of one technique. The research team provided reference materials and gather information to monitor the progress on the implementation of the tools.

FINDINGS OF THE STUDY

LAST PLANNER

Reverse Phase Scheduling

All subcontractors were encouraged to chart their schedule on wall display using post-it notes Subcontractors could see how their estimations affect the completion time of a particular phase of the project. Within few weeks, last planners started to rely on reverse phase scheduling to estimate activity durations instead of going back to the original master schedule. This setting could not be prepared for all phases; thus, some phases were prepared based on information gathered from previous phases.

Six-week lookahead

The project manager was not familiar with the lookahead schedule, so the RT prepared the first lookahead schedules. Once the project manager realized that the lookahead schedule provides an updated picture of to the assignments to be completed, he started to prepare it regularly. The project manager focused the constraint analysis in material problems. A more inquisitive look at potential constraints would have anticipated some variances during the execution as shown in Figure 1.

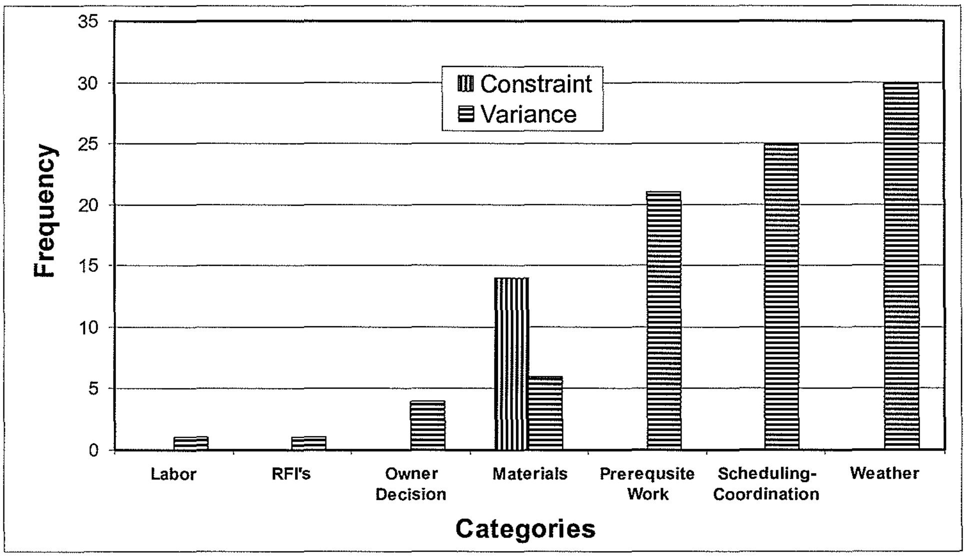

Figure 1- Constraints and Variances by Category

Variance Analysis

Cost variance was the only performance indicator at the start of the project, so it was difficult to introduce the variance of assignments as a meaningful performance measure. When assignments were not completed on time, the project manager provided the immediate cause, e.g., weather conditions or scheduling. By the end of the study, the project manager was able to identify the root causes of variances and set action plans.

PPC CHARTS

The research team prepared the Percentage Plan Completed (PPC) Charts at two levels: Project and Subcontractor PPC Charts. Subcontractors were concerned about their weekly PPC value, so they tried to improve the quality of their own assignments. By the end of the study, the project staff prepared the PPC Charts and posted them in the trailer.

INCREASED VISUALIZATION

Commitment charts

The GC's Vice President addressed the project personnel to emphasize the importance of their safety to the company. The attendees were asked to give examples on how to maintain safety practices on the jobsite. The end result was a commitment pledge that was signed by all employees and posted in the trailer throughout the project.

Mobile signs

The project personnel provided their input on the design of the safety signs. After a brainstorming session, mobile signs were designed and later posted on various areas of the site. Most of them used colorful and funny expressions to attract the attention of all people on the jobsite.

Project milestones

The project personnel were not regularly informed on completion dates at the beginning of study. Once the signs were designed, completion dates were plotted and posted floor by floor throughout the project. At the end of the study, most workers stated that they were more involved in the execution of the project.

HUDDLE MEETINGS

All-foreman meeting

An informal meeting for all foremen was replaced with the Weekly Work Plan Meeting. The meeting focused on the completion of the assignments for the following week. The discussions during the meetings were essential to address overlapping activities and to identify potential problems on the jobsite. Actions agreed to at the meetings were recorded in minutes and reviewed the following week.

Start of the day meeting

Project personnel were meeting at the beginning of each workday for five to ten minutes to review the work to be done. Scheduling, safety and housekeeping were the most common issues during these meetings Based on surveys, at least 67% of the workers found value in the meetings. Not more than 42% of the workers provide some feedback during the meetings. Most of them stated that they are more likely to talk directly to their foremen during the day.

First Run Studies (Plan, Do, Check, Act)

Plan

Two assignments were selected with input from the foreman, superintendent, and project manager. The first study was on bumper walls and the second on construction joints. Bumper walls were chosen due to the high cost of the activity, and construction joints were selected because of the high variability of the activity.

Do

Assignments were documented with video shooting and productivity studies. One flaw in the documentation was that most of the input came from the foreman and not from the crew. The crew was focused exclusively on the completion of the task. The description of the activities could have been more detailed with input from the crew.

Check

The work performed was checked in a formal meeting attended by the project manager, the foreman, and the crew. The research team led the meetings, looking for potential improvements and learning opportunities. Most of the participants tried to give their best suggestions on what can be improved for the next repetition of the assignment.

Act

Ideas suggested during the meetings were tested by the same crew, with support from the project manager and the foreman. The results showed more than 38% reduction in the cost of crash walls and 73% reduction in the cost of construction joints after the studies were completed. The actions implemented included new methods, changes in the composition of the crew, and a better sequence of activities.

FIVE S'S

Sort

The first level of housekeeping consisted of separating material by reference and placing materials and tools close to the work areas with consideration of safety and crane movements.

Straighten

The next step required to pile materials with a regular pattern and place tools in gangboxes. Each subcontractor took responsibility for specific work areas on the jobsite.

Standardize

The next level included the preparation of a material layout design. The layout contained key information of each work activity on the jobsite. The visual workplace helped locate incoming material, reduce crane movements and reduce walking distance for the crews.

Shine

The next step consisted of keeping a clean jobsite. Workers were encouraged to clean workplaces once the activity had been completed. A housekeeping crew was set to check and clean hidden areas on the job site.

Sustain

The final level of housekeeping sought to maintain all previous practices throughout the project. At the end of the project, this level was not fully achieved, in part because the project personnel did not view housekeeping as a continuous effort, and they have to be reminded frequently of housekeeping practices.

FAIL SAFE FOR QUALITY

Check for quality

An overall quality assessment was completed at the beginning of the project. Most quality issues could be addressed by standard practices, and it seemed there was little room for improvement. During the execution of the project, however, some critical items appear. A new vibration method for shear walls was suggested and implemented by the superintendent of the project.

Check for safety

Safety was tracked with Safety Action Plans, i.e., a list of main risk items prepared by each crew. Potential hazards were studied and explored during the job. Most hazards such as eye injuries, falls and trips, and hearing loss have standard countermeasures; however, in practice, workers have to be reminded of safety practices.

LEAN ASSESSMENT TOOL FOR CONSTRUCTION PROJECTS

The Lean Assessment Tool was developed to compare the implementation of each technique Similar assessment tools have been developed in lean manufacturing (Soriano-Meier and Forrester, 2002; Sánchez and Pérez, 2001) as well as in lean construction (Diekmann et al., 2003). The assessment tool is based on a checklist of lean construction practices. This checklist is introduced in Table 1. Each tool is split by specific elements essential for a successful implementation. Instead of assigning a single score for each element, management defined some criteria (knowledge, communication, interaction with other tools) to quantify the implementation. The champion of each tool completed the checklist with the support of the research team.

Table 1: Lean Implementation Tool

Scope	Technique	Requirements	Criteria / Change	
Flow variability	Last Planner	Reverse Phase Scheduling Six-week lookahead Weekly work Plan Reasons for Variance PPC Charts	Pull approach Quality Knowledge Communication Relation with other tools	↑ ↑ ↑ ↑ ↑
Process Variability	Fail Safe for Quality	Check for quality Check for safety	Actions on the jobsite Team effort Knowledge Communication Relation with other tools	↑ ↑ ↑ ↑ ↑
Transparency	Five S's	Sort Straighten Standardize Shine Sustain	Actions on the jobsite Team effort Knowledge Communication Relation with other tools	↑ ↑ ↑ ↑ ↑
	Increased visualization	Commitment charts Safety signs Mobile signs Project milestones PPC Charts	Visualization Team effort Knowledge Communication Relation with other tools	↑ ↑ ↑ ↑ ↑
Continuous improvement	Huddle Meetings	All foreman meeting Start of the day meeting	Time spent Review work to be done Issues Covered Communication Relation with other tools	↓ ↑ ↑ ↑ ↑
	First Run Studies	Plan Do Check Act	Actions on the jobsite Team effort Knowledge Communication Relation with other tools	↑ ↑ ↑ ↑ ↑

Each item is rated in a linguistic scale with six values: none (N), very low (VL), low (L), moderate (M), high (H) and very high (VH). A sample of the assessment format is shown in Figure 2.

Tool: Last Planner

Initial State							
Criteria	**1**	**2**	**3**	**4**	**5**	**Initial Date: 8/25/2003**	
Items	Pull approach	Quality	Knowledge	Communication	Relation with other tools	**Description**	**Score**
Reverse Phase Scheduling (RPS)	Low (4)	Low (4)	Very Low (2)	Moderate (6)	None (0)	Planners were not familiar with RPS.	4.0
Six-week lookahead (6WLA)	Low (4)	Low (4)	Very Low (2)	Moderate (6)	None (0)	The Project Manager was not familiar with 6WLA.	4.0
Weekly work Plan (WWP)	Low (4)	Low (4)	Very Low (2)	Moderate (6)	None (0)	A weekly meeting was conducted to review future work without any formal setting.	4.0
Analysis of reasons for variance (ARV)	Low (4)	Low (4)	None (0)	Moderate (6)	None (0)	Performance was measured in terms of cost at the project level. Variances were undocumented..	5.2
PPC Charts	Low (4)	Low (4)	Very Low (2)	Moderate (6)	None (0)	There were no Performance Charts posted in the trailer.	4.0
						Average Score	**4.2**

Current State							
Criteria	**1**	**2**	**3**	**4**	**5**	**Current Date: 1/15/2004**	
Items	Pull approach	Quality	Knowledge	Communication	Relation with other tools	**Description**	**Score**
Reverse Phase Scheduling (RPS)	Very High (10)	High (10)	Moderate (6)	High (10)	Moderate (6)	Each planner relies on RPS to estimate actual durations. However, the RPS was not conducted for all phases of the project.	7.6
Six-week lookahead (6WLA)	High (10)	High (10)	High (10)	High (10)	Moderate (6)	The project manager prepares the 6WLA regularly. The contraint analysis is limited to material problems.	7.6
Weekly work Plan (WWP)	High (10)	High (10)	High (10)	Very High (10)	Moderate (6)	Planners prepare the work for the following week, estimate the duration of each activity and communicate openly in the meeting	8.0
Analysis of reasons for variance (ARV)	Moderate (6)	Moderate (6)	Moderate (6)	Low (4)	Moderate (6)	The project manager reviews performance and identifies the main reasons for variance. ARV is not consistent with the constraint analysis at the 6WLA	5.6
PPC Charts	High (10)	High (10)	Moderate (6)	High (10)	Moderate (6)	The staff prepares the PPC Charts	7.2
						Average Score	**7.2**

Figure 2 - Lean assessment format

Three measures were taken during the project. The first measure was the initial state during the first week of the study. The second measure was a target value set by each champion. The third measure was the final level of implementation at the end of the study. An average score was calculated converting the linguistic scale to numbers from 0 to 10. Figure 3 shows a summary of the scores for each tool. The purpose of this figure is to provide management with a simplified way to assess the progress of implementation.

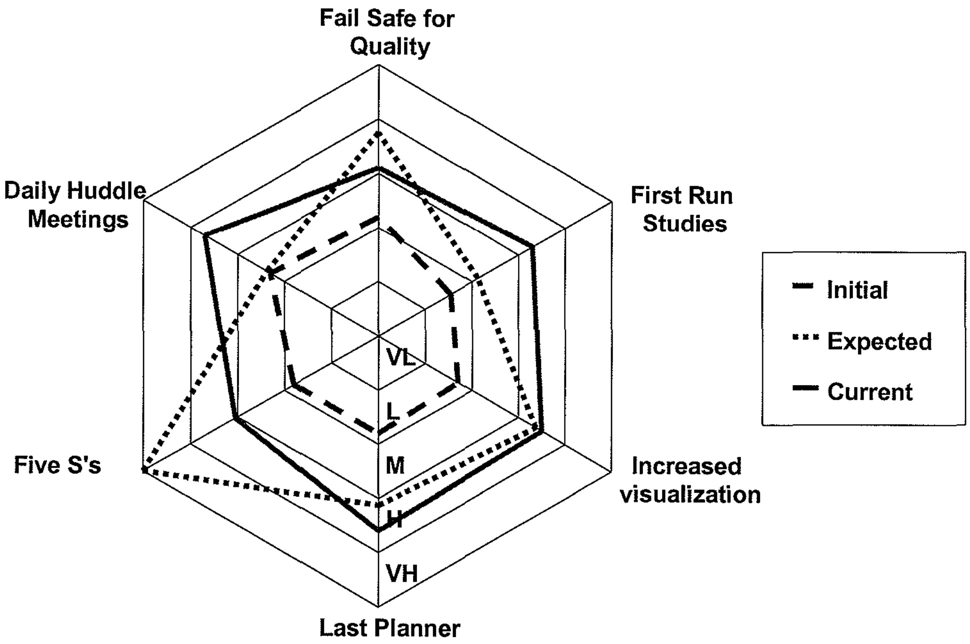

Figure 3: Lean Assessment Tool

The lean construction assessment shows an improvement at the end of the study in most of the lean elements. Last Planner is ready to be implemented in future projects with more emphasis on variance analysis. Increased Visualization is ready to be implemented focusing not only in safety but also in quality and housekeeping. Daily Huddle Meetings are ready to be implemented with some modifications: reduced frequency of meetings (two or three times a week) and smaller groups (less than ten people). The First Run Studies needs some modifications before future implementations. The project manager has to lead the process, setting activities to be documented and reviewing them on a monthly basis. The Five S's require a different approach: an awareness program and some disciplinary actions. Fail-Safe for Quality needs to use some indicators such as Quality-at-the Source (Massoresky et. al., 2002) and Percentage of Safe Work (Saurin et. al., 2002) that quantify the performance of subcontractors and crews. The GC also realizes that it needs to combine training and additional support for the project's team to expect further benefits from the implementation of the proposed techniques.

CONCLUSION

The benefits of the implementation were tangible: the project was under budget, three weeks ahead of schedule, and subcontractors were more satisfied with the relationship between them and the GC. The average PPC value was 76%, twenty points above the initial performance. No major injuries occurred during the project and the incident rate was below similar projects in the company. Most the planners associate the performance of the project with the implementation of the techniques and they would like to continue with most of the practices. In particular, they enjoyed the learning process involved in the new approach of lean construction.

The proposed tool could be used as a self-assessment instrument for tracking the non-financial improvements in any project. The set of techniques included could be modified or extended to fit the interests of a particular company. The tool should be led by the Project Manager with the support of the staff members, who are the champions of different techniques. The company is now extending the implementation of some of these tools to other projects and is considering the proposed assessment tool as part of an ERP implementation.

Further research is required to validate this approach. A cross-sectional study should demonstrate the association between higher level of leanness and better performance outcomes. A longitudinal study should show the long-term effects of intangible benefits such as know-how and personnel growth on business performance.

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