

# Lean Construction: From Theory to Implementation

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**Abstract:** This article compares the techniques developed for lean construction with those developed for lean manufacturing. Lean manufacturing and lean construction techniques share many common elements despite the obvious differences in their assembly environments and processes. Manufacturing plants and construction sites are different in many ways that might explain why lean production theories and practices do not fully fit the construction industry. Though many lean construction tools and elements are still in an embryonic state, lean construction techniques are gaining popularity because they can affect the bottom line of projects. Additionally, this paper presents a study of 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. The assessment tool evaluates six lean construction elements: last planner, increased visualization, huddle meetings, first-run studies, five S’s, and fail safe for quality. This paper provides a simple and comprehensive approach that is transferable to any construction project.

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## Introduction

Construction and manufacturing differ significantly in the physical features of the end product. In manufacturing, finished goods generally can be moved as a whole to retailers or end customers. Construction, on the other hand, deals with larger units that cannot be transported. Additionally, the construction industry has three other features that distinguish it from manufacturing: On-site production, one-of-a-kind projects, and complexity (i.e., temporary multi-organization and regulatory intervention) (Koskela 2002).

**On-site production:** Construction is site-position manufacturing, as opposed to fixed-position manufacturing, which applies to ship and airplane manufacturing and in which the product can be moved after assembly (Schemenner 1993). In construction, installation and erection are the activities that most increase the value of the product. The contractor must ensure that all components

assembled on site meet high-quality standards that are greatly influenced by specific site conditions.

**One-of-a-kind production:** Normally manufacturing takes advantage of specialized equipment to make standardized units, allowing only a limited level of customization by retailers. In construction, customers play a key role throughout the project cycle. Under guidance from the designer, customers define their product explicitly through the bid package or contract. The owner or the owner’s representative can modify the requirements and details of the contract by addenda (before bids are opened) or change orders (once the bid is closed).

**Complexity:** In manufacturing, many components from different subassemblies can be easily managed because suppliers are selected early in the design phase. Specialized facilities with suitable technology and layout ensure the reliable flow of the product. With repetition, this supply network eventually becomes manageable and optimized. In contrast, in construction, the completion of activities is highly interrelated and complicated. Construction projects are characteristically complex, unique, dynamic systems that must rely on an initial design that involves a number of subassemblies with variable specifications (Bertelsen 2003). Being an on-site production, the installation of those subassemblies is constrained by the interacting and overlapping activities of different contractors, making it more difficult to meet a fixed schedule.

The combined effect of on-site, one-of-a-kind, and complex production is uncertainty. The manufacturing process makes it possible to reduce uncertainty by increasing control over the process itself. A steady state is desirable in order to increase efficiency through repetition. In construction projects, significant uncertainty exists throughout the project. Weather conditions, soil conditions, owner changes, and the interaction between multiple operations can produce unique circumstances, which could be as critical as the planned activities and have a significant impact on project cost.

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## The Manufacturing Process versus the Construction Process

In the long term, both construction and manufacturing strive to add value to their products via high returns on investment; however, each employs different means to achieve this objective. In manufacturing, the lifecycle of a product on the market is long enough to develop related research and training capabilities. In construction, a product's lifecycle is the relatively short project duration, and thus it is more difficult to justify research and training. According to Banik (1999), this lack of investment is damaging to the construction industry's capacity for innovation in process and technology and threatens its competitiveness in local and global markets. Further, decision making in manufacturing planning is concerned with capacity optimization to combat the trade-off between future growth and machine depreciation. Equipment in construction is commonly seen as a resource that can be purchased or rented/leased for the project based on the appropriate time-value analysis. Contractors seek to minimize ownership and operation costs while ensuring equipment availability.

The extent of operations in manufacturing is well defined from the beginning. The components to be produced or purchased will change only if there is a drastic change in costs. In construction, the supply chain is more flexible. Subcontractors or the main contractor can perform operations based on the resources and costs of each specific project. Similarly, the workforce in manufacturing generally enjoys more stable wage policies and higher employment security. Positions are well defined and people gain ample experience in performing specific tasks. In the construction industry, wages vary depending on skill, experience, and employers. Job security is low, and workers perform a range of tasks throughout the development of a project. The manufacturing industry has shown how experience and specialized skills are valuable, highly regarded, and well compensated.

Quality in manufacturing is related more closely to process control than to product conformance. Common tasks are defect prevention, monitoring, and intervention. Rework is generally avoided, and in some cases, parts are discarded rather than reprocessed. In contrast, quality in construction primarily related to product conformance (Arditi and Gunaydin 1997). Specifications and drawings determine quality standards, and quality assurance is the joint effort of the construction company and the owner to meet safety requirements, environmental considerations, and conformance with applicable regulations. Rework is a common practice because only one final product will be delivered.

Supply in manufacturing is an order-driven activity that is synchronized through material handling systems. The operations sequence in manufacturing is determined during the product design phase, and changes are limited by the determined layout. Supply in construction is schedule driven because the process span is longer and the sequence of tasks can be modified, if required, by unforeseen exceptions. The construction supply chain is main contractor-client based (Matthews et al. 2000). Subcontracting can account for most of the value of the project, and because project activities are totally interrelated, the relationship between subcontractors and the general contractor demands much cooperation and transparency.

## The Lean Enterprise Philosophy

Japanese manufacturing techniques have been benchmarked by Western manufacturers for more than three decades (Druker 1971;

Schonberger 1982). After the study conducted by the International Motor Vehicle Program (IMPV), the Japanese techniques were seen as part of a new production system, known as lean production (Krafick 1988; Bartezzaghi 1999). The scope of the techniques was not limited to manufacturing. In fact, Bowen and Youngdahl (1998) present cases of process-based services that apply lean production practices.

Having the characteristics of both "production" and "service" systems, the construction industry has also taken some steps toward applying the lean production concept (Howell 1999). However, lean construction, presents challenges because it involves project-based production. The lean enterprise concept (Murman et al. 2002) comprises a variety of production systems that share certain principles, including waste minimization, responsiveness to change, just-in-time, effective relationships within the value stream, continuous improvement, and quality from the beginning.

Lean construction has sought a new foundation for project management (Koskela 2002): the International Group for Lean Construction (IGLC). The IGLC has led research on the application of lean techniques in the construction industry and 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 sociotechnological construct (Niepce and Molleman 1998), in which the combination of human and technical elements ensures higher performance outcomes (Moore 2002). In practice, however, it is important to determine the set of tools that can be applied to achieve higher performance outcomes for construction projects.

## Techniques in Lean Manufacturing

Lean manufacturing combines the capabilities of the workforce with organizational techniques to achieve high outcomes with few resources (Katayama 1996). Lean principles determine the goals of lean manufacturing. Womack and Jones (1996) present value specification, value stream (waste elimination), flow, pull, and continuous pursuit of perfection as the lean principles. The lean organization defines the activities on which the system focuses; Womack et al. (1990) refer to design, supply, and manufacturing as the core activities of the lean organization. Japanese manufacturers, especially Toyota Co., have developed the techniques that support the principles of lean production. Monden (1983) and Ohno (1988) introduced the Toyota Production System (TPS) as a combination of methods with consistent goals—cost reduction, quality assurance, and respect for humanity—to ensure sustainable growth. Monden identified four main elements of the TPS: just-in-time (JIT), automation, workforce flexibility, and creative thinking.

Just-in-time is based on the concept that inventories are not valuable and should be regarded as waste; accordingly, units should be available only when required. Three methods are associated with just-in-time: First, the *kanban* (Japanese for "card" or "sign") system is used to minimize inventories according to backward requests that flow through cards, baskets, or digital signals (Chaoiya et al. 2000). Second, production leveling ensures that fluctuation in demand can be met by the right sequence of products in minimum batches (Miltenburg 2002). Third, decreasing the number of setup activities reduces the number of activities

performed during downtime so that changeovers do not interfere with minimum batches. Planned critical activities supported by single-minute exchange devices (SMED) should reduce the effect of alternating different products.

Autonomation is the prevention of defects, an alternative to traditional quality control. Autonomation is supported first by a functional management system, which promotes quality and cost management companywide (Ho and Fung 1994). Quality is translated into all the activities of the organization: design, supply, and production. A second method, autonomous control, prevents the flow of defective parts through the process. Visual inspection (*Poka-yoke*) devices support this level of control, differing from traditional autonomation that does not allow direct intervention in the process (Shingo 1985).

Maintaining a flexible workforce allows a company to match its labor requirements with the fluctuating level of demand for its product. Two methods support flexible labor: multifunctional layout design and standard operations. With a flexible machine arrangement (Yang and Peters 1998), it is possible to rotate positions in the production line and adjust the size of the crew to the pace required. Only with well-defined operations can the crew attend multiple machines reliably. Machine operation should also be planned through preventive maintenance activities.

All of these techniques rely on workforce capabilities that have been overlooked by Western manufacturers. First, creative thinking offers continuous improvement through feedback and supports the continual improvement of a production line's daily tasks. Second, problem-solving skills prevent defects from recurring. Third, teamwork empowers workers with control over the operation and allows for task rotation. The human component, made up of these three capabilities makes lean manufacturing a dynamic system that always seeks to achieve higher performance. To ensure a balance between value addition and employee satisfaction, Toyota is now working with TVAL (Toyota Verification of Assembly Line), i.e., an ergonomic assessment of the workload of each position (Fujimoto 2000).

## Moving from Lean Manufacturing to Lean Construction

Ballard (2000a) divides the Lean Project Delivery System into four interconnected phases: project definition, lean design, lean supply, and lean assembly. His study focuses on lean assembly, the phase beginning with the first delivery of resources to the site and ending with project turnover. Lean assembly is particularly important to general contractors (GC), who develop the human and technical structure for this activity.

By definition, techniques follow a heuristic approach; practices are designed and tested through trial and error until they can be implemented at 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. Following is a discussion of the transfer of lean manufacturing techniques to construction:

### Flow Variability

In lean manufacturing, production leveling addresses the impact of flow variability (*Heijunka*). Production leveling controls, the impact of fluctuating demand levels controlled by optimizing the sequence of products with minimum batch sizes. When batches

are reduced, demand fluctuations can be managed by making small adjustments to the production volume and the resources allocated. Techniques associated with production leveling are product sequence scheduling, flexible standard operations, multifunctional layout design, and total preventive maintenance.

Flow variability greatly influences lean construction practices because the late completion of one trade can affect the overall completion time of a project. "Last planner" is a technique that supports the realization of plans in a timely manner (Ballard 2000b). Last planners are the people accountable for the completion of individual assignments at the operational level. The last-planner 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, a "look-ahead" schedule provides the activities to be completed during the coming weeks and the backlog of ready work. Each planner prepares weekly work plans to control the workflow. If assignments are not completed on time, planners must determine the root cause of the variance and develop an action plan to prevent future recurrences of the problem.

### Process Variability

Autonomation (*Jikoda*) is the notion that immediate action should be taken to prevent defects at the source so that they do not flow through the process. In lean manufacturing, visual inspection allows workers the autonomy to control their own machines so that when they identify defective parts, they can stop the process to 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 a job site to ensure first-time quality compliance on all assignments (Milberg and Tommelein 2003).

### Transparency

In lean manufacturing, any resource that does not contribute to better performance is regarded as waste that should be eliminated from the system. The five S's can be used to identify housekeeping in plants. They are sort (*Seiri*), straighten (*seition*), standardize (*sieso*), shine (*seiketsu*), and sustain (*shisuke*). In construction, the five S's allow for a transparent job site, at which materials flow efficiently between warehouses and specific jobs in the field (Dos Santos et al. 1998). Since construction has mobile workstations, increased visualization can help identify the work flow and create awareness of action plans on a job site (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 via problem solving and creative thinking. However, in lean manufacturing, quality circles provide an opportunity for workers to actively participate in process improvement. These teams meet periodically to propose ideas for the most visible 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.

Based on a set of targets, workers give their input on their progress during daily huddle meetings to develop and improve assignments (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). Operations are examined in detail, bringing ideas and suggestions to explore alternative ways of doing the work. The PDCA (plan, do, check, and act) cycle is used to develop the first-run study. First, one “plans” a work process to study, analyzes the process steps, and brainstorms how to eliminate unneeded steps. To “do,” one tests new ideas on the first run. To “check,” what actually happens is described and measured. To “act,” the team is to reconvene, and teammates communicate the improved method as the standard to meet. To ensure continuous improvement, the team’s capabilities must be best used to develop both individual and joint contributions (West 1998).

## Case Study

The main objective of the case study is to implement and assess the values of different lean construction techniques for a general contractor in Ohio. The GC pursues human and technical learning through the implementation of lean construction. The GC management agreed to implement and test six lean construction techniques: last planner, increased visualization, first-run studies, huddle meetings, the five S’s, and fail-safe for quality. A research team monitored the implementation of these techniques in a parking-garage project during a 6-month period. Based on the results and the feedback provided by all participants, an overall assessment was prepared and improvement suggestions for future implementations were proposed.

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

## Findings of the Case Study

### Last Planner

#### Reverse Phase Scheduling

All subcontractors were encouraged to chart their schedule on a wall display using Post-it notes. Subcontractors could see how their planned schedules affected the completion time of a particular phase of the project. Within a few weeks, planners started to rely on reverse phase scheduling to estimate activity durations instead of going back to the original master schedule.

#### 6-Week Look-Ahead

The project manager was not familiar with the look-ahead schedule, so the research team prepared the first look-ahead schedules. Once the project manager realized that the look-ahead schedule could provide an updated picture of the project assignments to be

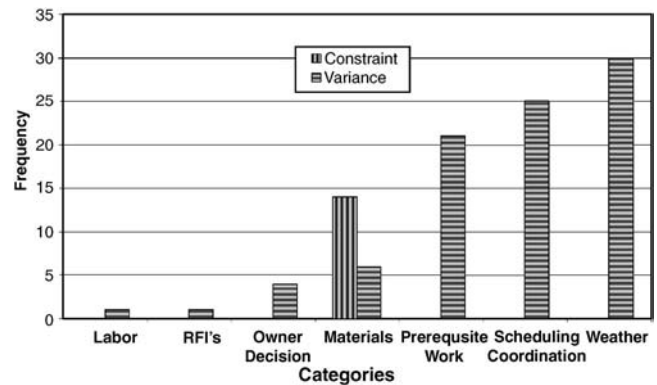


Fig. 1. Constraints and variances by category

completed, he started to prepare it regularly. The project manager focused the constraint analysis on material issues. A more inquisitive look at potential constraints would have anticipated some variances during the execution, as shown in Fig. 1.

### 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 to deal with delays.

### Percentage Plan Completed Charts

The research team prepared percentage plan completed (PPC) charts at two levels: project and subcontractor. Subcontractors were concerned about their weekly PPC value, so they tried to improve the quality of their own assignments. During the study, the project staff prepared the PPC charts and posted them in the site 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 of how to maintain safety practices on a job site. At the end of the presentation, a commitment pledge 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 job site.

#### Project Milestones

The project personnel were not regularly informed of completion dates at the beginning of the 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 felt more involved in the execution of the project.

**Table 1.** Lean Implementation Tool

Scope	Technique	Requirements	Criteria/change	
Flow variability	Last planner	Reverse phase	Pull approach	↑
		Scheduling	Quality	↑
		Six-week look-ahead	Knowledge	↑
		Weekly work plan	Communication	↑
		Reasons for variance	Relation with other tools	↑
Process variability	Fail safe for quality	PPC Charts		↑
		Check for quality	Actions on the job site	↑
		Check for safety	Team effort	↑
			Knowledge	↑
			Communication	↑
Transparency	Five S's	Sort	Action on the job site	↑
		Straighten	Team effort	↑
		Standardize	Knowledge	↑
		Shine	Communication	↑
		Sustain	Relation with other tools	↑
	Increased visualization	Commitment charts	Visualization	↑
		Safety signs	Team effort	
		Mobile signs	Knowledge	↑
		Project milestones	Communication	↑
		PPC charts	Relation with other tools	↑
Continuous improvement	Huddle meetings	All foreman meeting	Time spent	↓
		Start of the day meeting	Review work to be done	↓
			Issues covered	↑
			Communication	↑
			Relation with other tools	↑
	First-run studies	Plan	Actions on the job site	↑
		Do	Team effort	↑
		Check	Knowledge	↑
		Act	Communication	↑
			Relation with other tools	↑

### **Huddle Meetings**

#### **All-Foreman Meetings**

An informal meeting of all project foremen was replaced with the weekly work plan meeting, which focused on the completion of assignments during the following week. The discussions during the meetings addressed overlapping activities and identified potential problems on the job site. Actions agreed to at the meetings were recorded in minutes and were reviewed the following week.

#### **Start-of-the-Day Meetings**

Project personnel met at the beginning of each workday for 5 to 10 minutes to review the work to be done that day. Scheduling, safety, and housekeeping were the most common issues to arise during these meetings. Based on job surveys, at least 67% of the workers found value in the meetings. More than 42% of the workers provided some feedback during the meetings. Most of them stated that they are more likely to talk directly to their foremen during that time of the day.

#### **First-Run Studies (Plan, Do, Check, Act)**

##### **Plan**

Two assignments were selected with input from the foreman, superintendent, and project manager: installing bumper walls and

construction joints. Bumper wall installation was chosen because it is a high-cost activity, and construction joint installation was selected because of its high variability.

##### **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 instead of 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 as to what could 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

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
						<b>Average Score</b>	<b>4.2</b>
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 constraint 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
						<b>Average Score</b>	<b>7.2</b>

Fig. 2. Lean assessment format

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

Next, materials were piled in a regular pattern and tools were placed in gangboxes. Each subcontractor took responsibility for specific work areas on the job site.

#### Standardize

The next level included the preparation of a material layout design. The layout contained key information of each work activity on the job site. 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 job site. Workers were encouraged to clean workplaces once an 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 project personnel did not view housekeeping as a continuous effort. They had 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 appeared. A new vibration method for shear walls was suggested and implemented by the superintendent of the project.

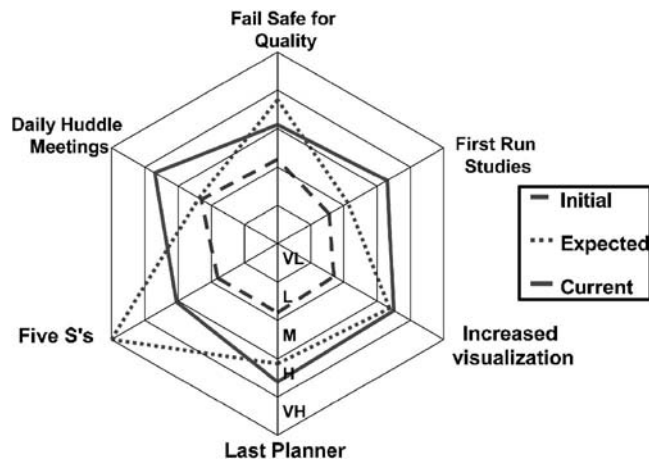


Fig. 3. Lean assessment tool: spider-web diagram

### Check for Safety

Safety was tracked with safety action plans, i.e., lists 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 evaluate the implementation of each technique. Similar assessment tools have been developed in lean manufacturing (Soriano-Meier and Forrester 2002; Sánchez and Pérez 2001). 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 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.

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 Fig. 2.

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. Fig. 3 shows a summary of the scores for each tool on what the authors called a spiderweb diagram. The purpose of the diagram is to provide management with a simplified way to assess the progress of implementation.

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 on safety but also on 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 (fewer than ten people). The first-run studies need 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 requires the use of 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 realized the need to combine training and additional support for the project's team to expect more benefits from the implementation of the lean construction techniques.

### Conclusion

The benefits of the implementation were tangible: the project was under budget and three weeks ahead of schedule, and subcontractors were more satisfied with their relationships with the GC. The average PPC value was 76%, 20 points above the initial performance. No major injuries occurred during the project, and the incident rate was below that for similar projects in the same company. Most of the planners associated the performance of the project with the implementation of the lean construction techniques, and they would like to continue with most of the tools. In particular, they enjoyed the learning process involved in the new approach of lean construction.

The presented assessment tool could be used as a self-assessment instrument for tracking 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 the implementation.

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

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