LEAN CONSTRUCTION: FROM THEORY TO PRACTICE

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ABSTRACT

The application of Lean Construction principles and techniques implies the adoption of a new organization design that can make Project Management systems feasible in the construction sector. The flexibility achieved by Production Management systems with the adoption of this model should come together with new applications that monitor the operating performance of each Project being executed. They go from execution deadlines and production costs to compliance levels related to quality standards and job safety specific to each particular Project. This paper discusses the results obtained by the practical application of Lean Construction to ventures located in several Brazilian cities, with a total accumulated built-up area of more than 250,000 square meters. We emphasize the example of building an upscale, 18-floor residential building in São Paulo with four flats per floor and a built-up area of 14,230 square meters. The Project employed specific control techniques that sought to consolidate a management vision focused on the systematic reduction of activities that did not add value to the end product.

KEY WORDS

Lean Construction, Project Management, Production Management, Cost Performance.

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INTRODUCTION

After World War II Japan adopted the Toyota Production System (TPS). The system was based on a scenario of fluctuating demand that required swift assembly line alterations due to the large number of different parts to be produced. The model developed by Ohno (1988) was infinitely superior to Ford's mass production system because it provided for the batch production of small quantities of parts. It required smaller physical areas, fewer resources and a smaller inventory of raw material and work in process.

Ohno's original ideas were based on the adoption of production strategies identified according to the demand of the downstream production chain, part of a production planning that ensured that the planned pace was maintained throughout the production process. In other words: the idea was to achieve a continuous production flow by adopting monitoring measures for each process phase, aiming to reduce inventories. If we add this rationale to an attempt to reduce the waste associated to activities that add no Value to the final product we obtain a systematic and consistent model – the model that gave Toyota high performance levels.

In Construction the application of the lean production model stems from a discussion of Koskela's work (1992), which emphasized the importance of the production process flow, as well as aspects related to converting inputs into finished products as an important element to the creation of Value over the life of the project. Production should be seen as a flow that generates Value through conversion processes, characterized by Cost, Time Frame and the degree of Added Value. (Melles 1994) In this context, considering the high uncertainty typical of the Construction sector, it was essential to adopt management attitudes able to make the operating environment stable, reducing production process variability and significantly increasing the reliability of the Production Planning phases, including the jobsite's internal logistics.

Howell and Ballard's studies (1994) about the "Last Planner" technique showed that the use of formal and flexible Production Planning procedures is the first step to keep the production environment stable. It emphasizes in this case the use of the Daily Production Plans, Constraint Analyses, Lookahead, and the Percentage of Planned and Concluded items – PPC as tools for immediate implementation on any jobsite.

The practical results of the original technique, expressed by the rise of PPC levels to close to 100%, translate a heightened confidence in short-term planning processes. They can usually be felt after two or three months application and encourage the commitment of the production team (engineers, foremen and sub-contracted parties) who obtain simple and efficient tools with which to perform their respective activities.

A well-executed Project mirrors its Production Planning precisely. And good Production Planning comprises planning elements that can effectively be executed. Personally, we would like to add a third aspect: being flexible and able to readapt your Production Plan taking into account eventual deviations observed during the daily sequence of jobsite operations is just as important as planning a Project.

Here, the basic idea is the fact that flexibility is a key issue to keep project under control, facing every change during daily production processes. It's obvious that the Project needs a baseline defined by its Master Schedule, but it's very difficult to keep it consistent during the production cycles, due to the uncertainty characteristic of each construction stage.

A PPC close to 100% does not guarantee that the Project is being executed in compliance with the foreseen conclusion date, cost and quality.

It is fairly common to see Projects with a high PPC that end up moving away from their foremost targets because there is no information able to monitor precisely how far the Project is from its initial objectives during every control period. Thus the production teams are unable to change and adapt their activity plans and recover their grip on the situation originally planned.

This scenario reinforces the need for new tools to measure the weekly actual deviation from the original plans, which needs to be analyzed in the same approach used by PPC.

LEAN CONSTRUCTION IN PRACTICE

In the last six years we applied the model proposed by Lean Construction to more than 20 Brazilian construction companies, always bearing in mind Womack's basic Lean Thinking principles (1996). We sought to define our activities according to the following principles:

Production Planning and Control

- All Production Planning must be based on keeping the pace of the work instead of seeking productivity peaks that improve the performance of a given activity but do not always ensure the best combination for the Project as a whole.
- The Line of Balance (LOB) technique should be used to optimize the study of the pace of the services to be executed. This technique provides for the immediate identification of production bottlenecks and eventual buffer insertion points. The aim is to offset the differences in pace for the Work Packages identified for the Project. The ideal situation occurs when all Work Packages have the same pace, eliminating inventory that does not really add Value to the end product.
- A Process Design should be devised for every Work Package planned in the LOB. This Process Design will determine the scope of the work to be executed, the daily sequence of partial targets, the size of the production team, the material, equipment and tools required and the moment when they should be available at the service fronts; the expected quality and operating performance standards and, lastly, the attention that must be given to job safety for the production teams defined. Thus the solutions adopted can be studied and discussed from the standpoint of the executive process in a single document, as well as the respective logistics related to the raw material, labor, equipment and tools required for the execution of the services within the specified time-frame. The preparation of this document should involve the engineer in charge, the foreman and all sub-contracted parties involved in the scope of each Work Package.
- Based on the LOB and the Process Design developed it is possible to use a new performance indicator for the Project, represented by the forecast of a Conclusion Date calculated every week. Thus a Project with a high PPC whose conclusion dates are under control is probably in compliance with the expected result for the final execution date, and there isn't much uncertainty

in the Project's daily operations. This approach gives the production teams more time to adapt to the next services to be executed and permits the adoption of more advanced strategies for future negotiations with material and service suppliers, as well as the study of new technical solutions. It is the key to applying Pulled Production to Construction and enhances cost and quality performance.

- Weekly control of the work should follow the Last Planner technique. The constraint analysis involved in the mid-term plans must be very detailed, and will allow the early anticipation of eventual barriers to the Project's natural pace. There are usually two different types of constraints, depending on the time when the Work Package is analyzed:
  - ♦ Type 1: Purchase and Contracting Constraints
  Marked by aspects linked to product and/or service, design, technical specs, the purchase and/or contracting of raw material, labor, equipment, tools and service specs. These issues are generally analyzed before the beginning of the Work Packages in point.
  - ♦ Type 2: Allocation and Availability Constraints
  Marked by no longer depending on purchasing or contracting but on optimizing internal jobsite logistics with the aim of ensuring that each planned cycle can effectively be executed. They should occur after the start of the respective services, and the constraints linked to material, equipment, tools and especially labor – an important source of redundancy and waste on Brazilian jobsites – have been analyzed.

- A weekly analysis of the PPC leads results in identifying the reasons for the disruption of the pace observed in the work and, consequently, contributes to systematic learning on the jobsite, generating a mindset effectively geared to improving Competitiveness in Construction companies.

- The Project must reassess its strategies every week, after analyzing the projected conclusion date and the stability of the production processes, expressed by the global PPC and by the PCC of each sub-contracted party. If necessary the production logic of the downstream services should be changed. This can occur in three different ways:
  - ♦ by inserting or removing resources from the Work Packages;
  - ♦ by modifying the relations of precedence among the services to make the superimposition of activities feasible and reduce the global execution time;
  - ♦ by reorganizing the different Work Package activities with the aim of making fewer simultaneous production cycles feasible. This significantly simplifies internal jobsite logistics, reducing the size of the work teams and showing the actual demand on raw material, labor, equipment and tools.

- We can state, based on our experience on Brazilian jobsites, that the third form of interference in the pace of the work is the least obvious one. It is also the one that most tends to present optimized results for the Project due, above all, to the following facts:

- It provides real opportunities to reduce the global execution time, because:
    - to keep the designed Work Packages in a standard pace, you need to reorganize the production strategy, grouping minor tasks in the same production cycle. As a consequence, the global execution time is reduced simply by the fact that you have less production cycles to perform until the end of the project;
    - it reduces the opportunity for any interruption of the normal work pace due to internal logistic problems;
- It provides real opportunities to reduce production costs, because:
    - fewer simultaneous Work Packages make it easier to estimate the size of the production support teams, now allocated directly to the foreman instead of only working with specific tasks. This approach drastically reduces the number of non-specialized workers at the jobsite which, in turn, as well as reducing the direct cost of operations also reduces any waste linked to Non-Added Value, typical of redundancy when this type of labor is used.
    - fewer simultaneous Work Packages and smaller production teams allow the execution of a bigger number of simultaneous services within a single cycle, especially those that do not add Value to the end product but that cannot be eliminated from the original Work Packages;
    - fewer simultaneous Work Packages drastically reduces the cost of the internal logistics dedicated to production support;
    - fewer simultaneous Work Packages reduces the cost of supervision and quality control by engineers and foremen because fewer service fronts must be contracted at the same time;
    - the cost related to safety requirements in the working environment also drops, because few service fronts are active simultaneously and the active ones have smaller work teams;
    - the cost associated to services, demand for material and labor drop, especially because the jobsite's data gathering tools become simpler and less vulnerable to mistakes, as we will see later.

CONSTRUTORA HERNANDEZ AND THE GERONA BUILDING – A PRACTICAL CASE OF LEAN CONSTRUCTION

Construtora Hernandez is a 37-year-old family-owned company with main office in Tatuapé, in the city of São Paulo, Brazil; dedicated mainly to the construction of residential buildings. Up to the year 2000 Construtora Hernandez had a built-up area of approximately 210.000 square meters, comprising approximately 1350 middle and high-class apartments.

The company’s market activity is defined by property acquisition, development and the construction of high-rise buildings. It has its own funding system, which makes its operations feasible. Construtora Hernandez uses its own labor or subcontracts from parties who have worked with the company for some time.

At the start of 1998 Construtora Hernandez began the construction of the Gerona Building, a high-rise, high-class, 18-storey residential building with four flats per floor and a total built-up area of 14.230 square meters. When the Lean Construction production management model was deployed approximately 40% of the concrete structure had been executed and bricklaying was about to begin.

PHASE 1: STABILIZATION OF THE OPERATING ENVIRONMENT

Initially our major concern was to stabilize the production environment, defining production cycles for concrete structure and masonry tasks, compatible with the Project's strategic targets. The reduction of the variability of these tasks was achieved using the Last Planner technique and the unconditional support of the company's directors and production teams, including the foreman and the main subcontracted parties.

Although during the first weeks there was a high PPC (it rose from 50% to approximately 82% in six weeks) it was necessary to develop tools to support strategies aimed at:

- Estimating the conclusion date of the Project and other extremely important milestones, like the start of the work on the facade of the building and the delivery schedule for the lifts. The idea was to control the progress of the work, ensuring that each control period (a week, in this particular case) didn't lose sight of its original target;
- Optimizing the size and allocation of the production teams with the aim of reducing the number of men/hours required to execute the tasks.

For this end we devised an Excel spreadsheet using LOB concepts that made it very easy to run simulations of the plans for each Work Package, allowing the pace of activities to be adapted downstream of the production process.

The spreadsheet was also meant to ensure the allocation of work teams for every production cycle and identify idleness or redundancy in the men/hours allocated. This led to two management positions:

- The use of surplus men/hours for unscheduled activities, increasing the speed of construction;
- The systematic reduction of the size of the team.

The direct consequence of the use of this tool by the engineer in charge and by the foreman was to reduce the estimated time until the conclusion of the Project by two months (the initial forecast was 24 months) and the size of the team by 30%. In Brazil this signifies an 11% reduction of the total Project cost, as due to the production technology used by Construtora Hernandez, the labor force employed in a vertical building historically represents approximately 40% of the total cost.

From that point on there began a weekly control of the conclusion date. We also measured the interval between the conclusion date foreseen by Engineering every week and the conclusion date the customer expected, aiming to keep the values of this interval close to those defined by Construtora Hernandez at the beginning of construction. (Goldratt 1997)

This result was attained four months after the start of construction and gave the program great credibility. A new phase in the development of production management support tools for the Project began, optimizing the time to prepare and discuss Daily Production Plans and especially the Lookahead and Constraint Analysis.

There was a weekly two-hour meeting with the engineer in charge, the foreman, the main sub-contracted parties for the period and Construtora Hernandez planning engineer, responsible for supporting the company's Lean Construction program and divulging the knowledge acquired to other ventures in progress.

The results were highly positive and the production teams adopted the model proposed. It made short-term strategies flexible and precise without losing sight of the conclusion of each phase of the work.

PHASE 2: DEVELOPMENT OF PRODUCTION PLANNING TOOLS AND TECHNIQUES – ASSEMBLY AND SUPERIMPOSITION OF PRODUCTION CYCLES

The company observed, however, that the natural pace of each of the Work Packages planned was uneven. This led to idleness and redundancy in the production processes. The company decided to adopt a new Production Planning technique consisting basically of identifying and assembling all the sets of Work Packages with cycles smaller than the natural Project cycle that could be executed simultaneously by the same work team. The approach was expected to reduce the construction period and direct production costs.
Below follows a practical example that perfectly illustrates this strategy:

- The idea is to plan the construction of a vertical building, at present with reinforced concrete structure and masonry brickwork tasks in progress. We know that during the production phase the activities in progress and their respective production teams are as follows:

A. Reinforced Concrete Structure	one floor every 7 days	12 carpenters
B. Floor Finish	one floor every 3 days	2 masons/2 assistants
C. Preparation for Masonry	one floor every 4 days	2 masons/1 assistant
D. Masonry	one floor every 7 days	4 masons/4 assistants

In the above example it is very clear that the cycle of Work Packages B and C was systematically interrupted because the prior services only delivered a new floor every seven days. The strategy employed here was to assemble Work Packages B and C with the following result:

- All Work Packages being executed within 7 days in a perfect pace for all production teams;
- Reduction of the conclusion date of the work by four days;
- Reduction of the production teams, as follows:
  - ♦ Initial situation: 4 masons plus 3 assistants
  - ♦ Closing situation: 2 masons plus 2 assistants

The gain obtained using this approach in all Project production processes had other benefits, such as:

- The systematic reduction of costs linked to the support teams for production and internal logistics – with fewer simultaneous Work Packages in progress there is less need for labor and equipment to support the planned pace of production;

- More ease in controlling the end result of the finished work, concentrating a bigger number of simultaneous activities in a single site;
- Cost reduction with sanitary and safety procedures on the jobsite.

The Gerona building began with 43 planned Work Packages for the Project as a whole. We ended with 29 Work Packages, assembled using the above-mentioned technique or techniques of superimposition of independent tasks.

PHASE 3: CURRENT SITUATION AND SUBSEQUENT TARGETS

The results attained have surpassed the company directors' expectations. Now they intend to adopt the same rationale for production phases without repetitive work cycles like foundations and underground work and roofing, witch represents a significant part of the time and total production cost.

The company's Procurement sector adapted very well to the pulled production strategy, significantly reducing the inventory of material at the jobsite. In addition, the certainty that the production cycles will be met makes it possible to contract a global amount of material from suppliers, with better end prices and the freedom to schedule partial delivery according to the expected progress of the work.

The company's Design and Technical Specs sector held meetings with its designers to develop production-driven designs, reducing the time it takes for the production teams to understand the plans and reducing eventual mistakes and rework during construction. The company's engineering team worked with the Project designers, adding lean production concepts learned on jobsites to new Projects.

After the conclusion of the Gerona building – within the foreseen time frame and with the expected cost reduction – the company adopted the same strategy for other ventures, attaining important results like the reduction of more 20% (in addition to the initial 30%) in direct labor costs.

CONCLUSIONS

The deployment of production managed models based on lean production principles and techniques are feasible and can be applied to any type of Construction venture, regardless of the execution technology employed.

It must be clear that this philosophy intends to optimize the production management process, above all. That does not mean that it will ignore technological developments underlying the improvement of the actual process.

Our personal experience has shown that we can attain an average reduction of the expected construction time between 20% and 30% of the initial estimate, and a reduction of the production cost between 5% and 12% of the total amount in totally different Projects, like the construction of McDonald's stores or churches (a 40% reduction of the foreseen global construction time, using the same production team), the execution of horizontal residential condos (a 20% reduction of the production time), commercial and buildings and shopping malls.

We are certain that the impact of Lean Construction in Brazil is feasible because of the recognition of the importance of Planning and Design functions by the companies in the sector. This has consolidated new types of sustained competitiveness in environments marked by uncertainty and risk.

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