LEAN PRODUCTION IN THE PRECAST CONCRETE COMPONENTS' INDUSTRY

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ABSTRACT

This article is a case study applying Lean Thinking and Lean Production principles in a factory that produces prefabricated reinforced concrete components. The objective is to reduce waste production and increase productivity. Nine factories were analyzed, of which one was chosen for developing an implementation model. A number of changes were proposed based on Lean concepts and the study of several similar factories to improve productivity. A Black Belt Team was created to improve the execution and continuance of the lean concepts. Value Stream Mapping was also used as an aid in the identification of existing waste and improvement opportunities, to which various Lean tools were applied in order to solve the identified problems.

The main conclusions of this study are that it is possible to achieve a significant improvement in the production system of prefabricated reinforced concrete components using Lean philosophy. Improvements in the reduction of lead-time, reduction of waste and increase in productivity are achieved with simple and low cost techniques.

KEY WORDS

Lean Production, Value Stream Mapping, Black Belt Team, Implementation Model, Prefabrication

INTRODUCTION

Conventional construction with on site solutions have been criticized for a long time, with their low productivity, poor safety records and large waste production (Chen et al. 2010, Albarran 2008). Prefabrication can offer significant advantages, such as reducing overall costs, reduction in construction time, improved quality, enhanced safety on site and reduction of waste production. The advantages depend on standardization and good organization of work.

Lean Production was born just after World War II, with the development of Toyota's automotive production by Taiichi Ohno. The essence was to no longer focus on individual parts of production but to analyse the production line as a whole. This was to ensure flow throughout the process and eliminate waste, with the ability to deliver variety of consumer products.

The term Lean was proposed by James P. Womack's research team and described in the book "The Machine That Changed The World" (Womack et al., 1990). Lean is a dynamic way of thinking; its goals are to produce more using less.

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This article sets out to study the benefits of Lean principles and tools in the precast concrete industry. For this purpose, 9 factories that agreed to participate in this study were analysed and a set of production processes identified that could be improved through the implementation of Lean solutions. One case study was then selected among the factories analysed. Its current state was analysed changes were proposed, their impact accessed and the gains quantified. The Lean solutions were chosen based on their potential to increase efficiency, eliminate waste, increase flow and reduce lead-time. The work was developed at a precast reinforced concrete components factory of a Portuguese company. The scope of this work is to study and verify the status of a "Non Lean" production and apply Lean principles and tools, this provides useful evidence to demonstrate and support the benefits of Lean.

LITERATURE REVIEW

According to Warnecke and Hüser (1995), Lean management is an intellectual approach consisting of a set of measures and methods, which have the potential to bring about a lean and therefore more competitive state in a company. A Lean organization means Lean principles are used in all its actions. The basic idea is to do all activities as lean as possible (Kosonen and Buhanist, 1995).

The concept of eliminating waste is an important aspect to Lean Production. Ohno (1988) stated that waste is any activity that does not add value to the product, establishing seven main waste factors calling them "Muda": overproduction, transportation, inventory, motion, defects, over-processing and waiting

LEAN TOOLS AND MYTHOLOGIES

Value Stream Mapping (VSM): This is a commonly used tool in Lean applications. VSM is a paper and pen tool where a map of the complete process is drawn out with a set of standardized icons, introduced by Rother and Shook (1998). With a map of the complete process, it is easier to analyze and identify any weaknesses or waste sources. Once these are identified, changes are proposed and implemented and the new process is evaluated.

Black Belt Team (BBT): One of the main problems to the application of Lean concepts is the lack of time (Melton, 2005). For an effective Lean implementation, teams should be formed to coordinate the transition and keep continuous improvement. This team is the BBT, and its functions are to have a deep understanding of Lean concepts, analyze and understand the process, and find improvement opportunities, providing the changes and verifying that they are implemented correctly.

Cellular Manufacturing: Is a model for workplace design. It is based on the principles of Group Technology, which seeks to take advantage of similarity between parts. Cellular Manufacturing consists in bringing equipment and work areas together joined by their similarities, in order to maintain a steady product flow throughout the process (Abdullah, 2003)

5S Methodology: The 5S's are of Japanese origin and are distributed in five actions aimed at organization and standardization of work. The 5S's of this methodology are:

- ***Seiri* (Sorting):** Go through all tools and materials, keeping only essential items and eliminating all others throughout the work area.
- ***Seiton* (Stabilize):** All items should have a specific place for them, clearly labeled and marked. Items must also be arranged in such a way that it promotes efficient workflow, being accessible at all times.
- ***Seiso* (Systematic Cleaning):** Maintaining cleanliness should be part of the daily job. Keeping the workplace tidy and organized makes it easier to know what goes where and ensures better workflow.
- ***Seiketsu* (Standardizing):** The work practices should be consistent and standardized, following the previous rules established.
- ***Shitsuke* (Sustaining):** Once the previous rules have been established, they become the new way to operate. The focus now is to maintain these new rules and continuously seek improvement, repeating the steps all over again.

Just-In-Time (JIT): This is a production method based on "Pull", where each step demands from its previous step. This is in opposition to "Push" production, where each step pushes its finished product on to the next step. JIT strives to deliver the right product at the right time in the right quantity. It is used by high-tech manufacturing to minimize inventory and stock (Chan, 2001).

Kanban: This is a subsystem of JIT, which is a cue card that controls production flow. The Kanban controls the time and amount required for delivery (Junior and Filho, 2010). It is often used for ordering raw materials with a cue card that signals the need to place the order. This signaling system can be varied, such as; empty boxes, light signal or a marked item.

First In – First Out: Used in chain production the first item to go into a process should be the first one to leave. All processes must be scheduled and processed by order of flow entry.

RESEARCH METHOD

This article spans a theoretical analysis of the Lean philosophy to a practical application. It was therefore necessary to perform an extensive study on the subject, in order to obtain a good theoretical framework. At the same time it was necessary to search for companies in the precast reinforced concrete industry that would authorize the study of their production facilities and allow for a practical application of changes according to Lean Production. A total of 9 factories where achieved that allowed to study their production, as long as their identity was kept confidential. Those factories set a sample for identifying a number of production processes that could be improved through Lean principles and tools, as well as to assess the generalization of these solutions to the Industry. One of the factories was then selected as a case study for the implementation of the selected Lean solutions and an in-depth analysis of their benefits. This selection was based on the combination of three criteria: the possibility to implement the highest number of selected solutions and the willingness of its management to implement those solutions.

The evaluation of the current state of operation was developed through numerous visits to the factories, with desk research and many interviews.

Factory Visits: In order to achieve a good analysis of the production process, it is necessary to experience the situation firsthand. One must go see for oneself to thoroughly understand the situation.

Interviews: The aim of the interviews is to collect data from the stakeholders' view on the production process. This is one of the most important sources of understanding the activities in the production. These interviews follow a standard protocol with two main parts:

- Identification: Collection of information concerning the respondent, such as name, age, occupation, training and years of experience.
- Main Section: Sequence of questions to evaluate and characterize the present state of production and check on how Lean the manufacturing process is. This part follows the criteria stipulated by Womack (2008) for a Lean process, where every process must be: Valuable, Capable, Available, Adequate and Flexible.

A total of 57 internal stakeholders were interviewed, namely 4 Board members, 7 Factory Directors, 3 Staff from the Technical Department, 4 Staff from Health and Safety Management and 39 Workers involved in Production.

The interviews conducted with the workers included a set of questions to evaluate their job satisfaction. A *Likert* scale was used, as follows:1 – Unsatisfied, 2 – Moderately Unsatisfied, 3 – Satisfied, 4 – Very Satisfied and 5 – Totally Satisfied

The level of job satisfaction at the case study factory was calculated based on the average of the responses deemed valid. These interviews were carried out before and after the implementation of the selected changes, and the results compared.

Desk Research: To complete the research on the factories a desk research was conducted. Most of the information collected was taken from the following documents: plants of the factories, company and factory flow chart, raw materials sheet, production equipment specifications, health and safety plan, balance sheet, workers detail information and performance records.

Value Stream Mapping: VSM was used in the case study factory, to assist in the identification of possible improvement areas. A future state VSM was then drawn, based on the Lean solutions selected. A Black Belt Team was created to help in change decisions and to monitor these changes. The improvements were quantified and evaluated, as well as the limitations and conditions for a successful implementation. This was carried out in two stages: first, each single change carried out and analysed individually, then they were implemented simultaneously and studied as a whole.

CHANGE PROPOSALS

Based on the observation and analysis of the production processes in the 9 factories that built the research sample, a set of common problems were identified and Lean solutions selected for their mitigation or elimination. These problems occurred in 5 specific areas: steel inventory, aggregates' inventory, molding process, vibration process, stocks of finished products and work area. They will now be portrayed, the respective change proposals and their limitations described and discussed.

Steel Inventory Management: Excess raw material requires large storage areas. This excess inventory, along with its poor management, overuses financial resources and does not favor product flow. In this case it also undermines product quality because the stock is not well organized. When a new order of steel is delivered it is unloaded onto the previous stock of steel, trapping the older steel. This means that the workers then use the new steel, leading to the oxidation of the older steel, thus affecting the quality of the final product.

For this situation the level of inventory will be reduced and, for better inventory management, Just-In-Time will be used along with *Kanban,* to signal the need to place a new order of steel. Each kind of steel will be given two basket systems, where the steel is consumed from one basket until it is empty. When this happens the steel is taken from the other basket and signals the need to place an order of steel. After placing an order, the steel takes between three to five working days to be delivered. Thus, each of the baskets is designed to store enough steel to keep production running for five days.

Steel Inventory Location: Unnecessary moving and transportation are a big waste in production. This increases lead-time, consumes manpower and increases damage and safety risks. The steel inventory is located far and in a perpendicular way from the next stage in the process. This makes it necessary to use a vehicle for the transportation of the steel and includes labor consumption.

Following Cellular Manufacturing and 5S methodology, the steel inventory is aligned and moved close to the next stage in the process, promoting product flow.

Aggregates Inventory Location: The transportation of the aggregates from their inventory to the concrete mixer is a waste of time and energy. The aggregates are pushed into a recipient that dosages it into a bucket, which then elevates it into the mixer. Production layout should not only be analyzed horizontally but also vertically. Focusing on "Sorting" from the 5S methodology, the aggregates inventory should be located at a higher point than the mixer. This way the filter basket can drain the aggregates directly into the concrete mixer.

Molding: All equipment, tools and processes should be adequate. These should also work at a similar pace, in order to create product flow. The molds used presently are fixed and may only be used once each day. This system strangles production and limits the number of components produced daily to the number of existing molds. Also, because the molds are fixed, another problem arises, which is the transportation of the steel frame and the concrete. The transportation of the concrete requires a vehicle and consumes labor.

For this problem the molding equipment will be changed for a molding system that can almost instantly de-mold the component onto a platform. This means that only one mold is necessary and may be placed directly below the mixer, eliminating the need to transport the concrete to the various molds. This also allows reducing used space because the platforms may be stored neatly and staked occupying less space.

Vibration: Once the concrete is placed in the mold it has to be vibrated to fill all corners and areas of the mold with concrete, thus eliminating all the air pockets. This process adds a great amount of time to the manufacturing process, also damaging the molds on a long term basis. This also produces a high level of noise, affecting particularly the workers in this step. An easy way of eliminating this problem is to use additives in the concrete that render vibration unnecessary.

Stock: In the factory there is an excess stock of products. This occupies a great amount of the factory area. Based on “Pull” production, which seeks to produce after order, the stock of products will be reduced. This will reduce the space necessary and will increase product flow.

Work Area: Over-processing, waiting and unnecessary movement, be it of work, material, tools or products, contribute to an increase in lead time and production costs. The work area is usually unorganized and overloaded with tools and materials. The workers spend too much time looking for tools and materials to perform their tasks. In the work area there should only be the tools, materials and workers needed for the job. In addition, these tools and materials should be stored in strategic locations so they are easily accessible at all times.

To solve this issue all workers will receive a brief training on Lean concepts, focusing on 5S methodology and Cellular Manufacturing. This way they may organize their work areas and promote a good working environment.

RESULTS AND DISCUSSION

The changes proposed needed to be followed closely and were analyzed in two ways. First the changes were evaluated independently, revealing their results without being influenced by the others. Next, all changes were be taken into consideration and analyzed as a whole, and the final conclusions were reached.

INDEPENDENT ANALYSIS

Steel Inventory Management: The changes in this sector reveal a reduction of the necessary area by 42%, the area occupied is now 340m^2 comparing to the initial 586m^2. This is due to the fact that the inventory levels were reduced and that the steel is now organized and limited within the basket. Another benefit lies in the capital invested in inventory, which was reduced by 50%. Regarding quality, the problem of steel oxidation is completely eliminated, since the oxidized steel went from representing 29% to 0% of the steels inventory. The improvement in quality results from the steel being separated in two basket systems. This way the new order of steel is never unloaded on top of existing steel. A precaution that must be taken into consideration is the fact that the steel should never be in direct contact with the ground. It should always be placed on top of wooden pallets. This precaution was already taken into consideration in the factory prior to this work.

Steel Inventory Location: The relocation of the steel inventory eliminates the need to transport the steel with the use of a vehicle and reduces the time in the preparation of the steel by 38 seconds from its original time of 4 minutes and 33 seconds, representing a reduction of 14%. There is a substantial increase in product flow with the elimination of the unnecessary transportation of the steel. This change not only promotes an increase in work safety, but also reduces production costs. Without the need of a vehicle for the task, factory insurance becomes cheaper, fuel consumption goes down, and vehicle maintenance or even purchase is eliminated. Regarding the area occupied for this purpose, it was hoped to achieve its reduction. This did not happen, since the trucks that deliver the steel still need the space to maneuver around.

Aggregates Inventory Location: This proposed change could not be tested because the factory director did not accept it. The justification was that it would take a large investment in new equipment and the implementation would compromise production far beyond the benefits that this change would bring.

Molding: With the change in equipment and layout of the molding process, production rose from 55 to 76 components produced per day, representing a 38% increase. The benefits do not arise solely in this field, the area required was reduced by $230m^2$ from $720m^2$, giving a 32% reduction in the occupied area. Also the transportation of the concrete was eliminated, no longer needing a vehicle for this task and the respective waste in manpower. This new system uses only one mold for the entire production, where the components are de-molded onto a platform. This is very beneficial, since the cost of molds is very high, comparing to the platforms, which are small, light and easy to maneuver. However, a problem arises with this new process, regarding the First In - First Out principles. As the platforms are stacked after de-molding ,the first one to enter the next step in production is the last to leave. Also this system has limitations on the kind of product that can be produced. According to the equipment manufacturer, its use is not advisable for items with lengths over 11m. This is due to the vertical settlement being too great after de-molding, as well as the longitudinal deformations that arise from product manipulation while the concrete is still fresh.

There is also another limitation regarding the cross section of the components produced. They must have a cross section that allows to proceed with instant de-molding without it losing its original shape. Some examples are shown in Figure 1 below:

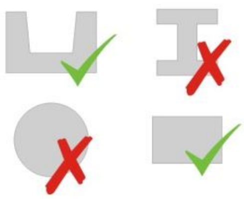

Figure 1: Cross section comparison

Vibration: The introduction of an additive in the concrete eliminates the vibration process, reducing the number of workers by one in a team of 4 while simultaneously increasing production by 3 components per day. Also this increases product flow and contributes to the prolonging of the molds life span. But the cost of this additive must be taken into consideration. Although this may seem to increase cost, in reality it is more beneficial, since the additives cost represents only 45% of the cost of one worker. There is also the benefit of not having to invest in the vibration equipment and the frequent maintenance or purchase of new molds caused by the damage from the vibration process. This also reduces energy consumption and eliminates the high level of noise produced by the vibration of the molds. However, this additive may only be used for the fixed molds. This additive may not be used simultaneously with the new molding equipment, since it makes the concrete too fluid for the instant de-molding process.

Stock: The reduction of stock was not implemented. The company did not allow it, stating that orders are not constant, varying with the season. Also when these orders are placed they are of great quantities, therefore forcing the need for a large stock to balance the difference in orders. Supporting this idea, Dawood and Marasini (2002) state that seasonality is inevitable for the precast concrete industry, obliging the creation of a stock able to address this imbalance.

Work Area: With a clean and organized work area followed by 5S principles and Cellular Manufacturing, work efficiency was increased and required work space was reduced. For this section, three different areas were studied with efficiency percentages relating to the number of units produced daily. The results are as followed:

- Preparation of Steel: Efficiency Increase 8%; Space Reduction 17%.
- Steel Frame Production: Efficiency Increase 11%; Space Reduction 8%.
- Molding: Efficiency Increase 2%; Space Reduction 0%.

In the overall production, efficiency suffered an increase of only 2%, since this value is limited by the lowest of the three. This is due to the molding process which is extremely limited by the transportation of the concrete from the mixer to the molds. It consumes a fair amount of time and requires lots of space between the molds so the vehicle may pass to unload the concrete into the molds.

Looking upon the steel frame production, the increase in efficiency is due to the development of a new working bench, which was built and designed with the help of the Black Belt Team, following 5S principles. This increases standardization, increasing production speed. For the preparation of steel the simple fact of eliminating all unnecessary materials and tools, cleaning and organizing the work area, increased job efficiency.

The workers influenced by these changes were again interviewed briefly to analyze their job satisfaction. Out of the 57 interviews, only 18 were used to calculate the level of job satisfaction.

The results on job satisfaction before the changes came to an average of 2.8. After the changes it came to 3.4. This means that job satisfaction, on average, went from “Satisfied” (tending towards “Moderately Satisfied”) to “Satisfied” (but on the verge of “Very Satisfied”).

These changes lead to an increase in efficiency, reduction of occupied space and increase in the workers job satisfaction. The satisfaction and productivity are affected by a number of variables, but they are related. High satisfaction of the workers leads to higher productivity, and higher productivity leads to greater satisfaction (Shikdar and Das, 2003).

OVERALL ANALYSIS

Once these changes were individually analyzed, they were studied as a whole. In this step the changes taken into consideration were: steel inventory management, steel inventory location, molding and work area.

The changes in the Aggregates Inventory Location and Stock were not tested due to lack of authorization. Regarding the changes in the vibration, because it is incompatible with the equipment changes, it was not implemented in the overall analysis.

In this analysis some of the values did not change from the results obtained in the individual analyzes, such as the areas occupied, equipment reduction and capital invested in inventory. However, production did increase by 58%, comparing to the original value. This means production has gone from an initial 55 to 87 components produced daily. According to the information provided by the Board of the company, this increase in production represents an increase in profit of 155.358,72 € a year for the first 5 years, since the equipment was purchased with a loan. Once the credit is paid off, the annual profit increases by 410.55,68 €, assuming that there is no market inflation.

The same 18 workers were again briefly interviewed to obtain results regarding job satisfaction. This came to an average of 4.1 taking job satisfaction to an average of "Very Satisfied". Although these results may be a reflection of the novelty in the changes done around the production line, it was astonishing to notice the enthusiasm that these changes have made among the workers and stakeholders of this process. But this high level of satisfaction may not be totally beneficial. One of the Lean principles is continuous improvement and if the workers are very satisfied with the present state of production, an interest in pursuing improvement may not arise.

Although independently all changes proved to be slightly beneficial in various ways, when all aspects are taken into consideration production efficiency increases dramatically.

CONCLUSIONS

The objectives outlined in this work were successful at both development and achievement level. The intense study of the Lean concepts resulted in a good knowledge of its principles and features. The initial analysis of the sample set of factories allowed to draw an overall picture of production process in the precast reinforced concrete components' industry and to determine a series of changes based on Lean principles. The case study selected for in-depth analysis and implementation allowed the assessment and quantification of the benefits obtained.

For a successful application of Lean concepts, the creation of a Black Belt Team, consisting of various stakeholders in the production and the use of Value Stream Mapping are very important. These proved to be extremely important tools in the application of lean concepts. But these are not the solution to the problems. They highlight the problems in the process and help improve and monitor the changes performed. The key to successful results lies on the knowledge of Lean concepts and the industry to which it is being applied.

The main tools used to solve the issues in production were Just-In-Time, Kanban, 5S and Cellular Manufacturing.

Just-In-Time and Kanban resulted in a reduction of required space and capital invested in inventory. Also they contributed with an increase in product quality, eliminating oxidation of the steel.

5S and Cellular Manufacturing proved to be great tools for this industry. They successfully reduced lead time in production, product flow was increased and health and safety risk levels were improved. Also the necessary equipment was reduced and productivity increased.

The results obtained in this work confirm previous studies on the benefits that Lean concepts may have, by increasing productivity using less resources. The results achieved were: reduction in occupation area of the steel inventory by 42%., financial investment in steel inventory was reduced by 50%, oxidized steel was eliminated increasing product quality, increase in product flow, reduction in production costs, increase in job satisfaction from 2.9 to 4.1 in a scale from 1 to 5, health and safety risk improvement and increase in available factory space.

These improvements in the precast production also directly benefit construction projects by reducing expenses and increasing delivery.

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