IMPLEMENTING LEAN SIX SIGMA: A CASE STUDY IN CONCRETE PANEL PRODUCTION

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ABSTRACT

Lean Six Sigma method is recognized widely and has been implemented predominately in manufacturing rather than in the construction industry. To illustrate the point, this paper draws attention to the adoption of Lean Six Sigma in the construction industry with a case study. The combination of Lean tools and Six Sigma methodology is used on projects to improve the process by eliminating the variations and creating workflow in a process. Despite its relatively new introduction to the construction industry, it has been popularized by several organizations and adopted as the primary improvement process.

The hypothesis of this experimental study was that the Six Sigma technique can be applied to the construction-based production system along with lean construction techniques. To test the hypothesis, we applied Lean Six Sigma methods on concrete-panel production system in a multi-housing complex project. The paper shows how the production rate of concrete panel was improved and stabilized along with the use of Lean Six Sigma tools. Also the case study uses the variation of panel production as a critical total quality (CTQ) to measure the performance indicator of Six Sigma system.

KEY WORDS

Lean Six Sigma, Case Study, Critical Total Quality (CTQ)

INTRODUCTION

Many construction projects suffer delays from variability stemming from single or multiple causes. An associated principle with waste removal is variability reduction (Bertselen and Koskela 2002). In the construction industry, sources of variability include late delivery of material and equipment, design errors, change orders, equipment breakdowns, tool malfunctions, improper crew utilization, labor strikes, environmental effects, poorly designed production system, accidents, and physical demands of work (Abdelhamid and Everett 2002).

Koskela (1992) pointed out that architects, engineers, and construction practitioners have for the longest time focused on conversion activities and

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overlooked issues of flow. Therefore, it is important to create flow by eliminating waste. Flow is important because work or materials that do not flow sit idle in inventory, tying up money as well as space (Tommelein and Weissenberger 1999). On the other hand, Six Sigma is a statistical-based project-driven approach to improve the organization's products and production system to achieve near perfection or 'closest to zero-defect' product by focusing on defect rates; in other words, eliminating variations in a process. The combination of Lean tools and Six Sigma methodology is used on projects to improve the process by eliminating the variations and creating workflow in a process.

The objective of this research paper is to investigate how Lean and Six Sigma methodologies are implemented together on construction projects through a case study and to measure the process capability index (Cp) to measure the performance of Six Sigma efforts. We claim that Lean Six Sigma can be used in construction. The paper tries to support the claim with a case study where Lean and Six Sigma are used concurrently.

LITERATURE REVIEW

SIX SIGMA

In 1985, Bill Smith of Motorola developed and implemented an approach to achieve near-perfection in product manufacturing called Six Sigma (Breyfogle, Cupello and Meadows 2001). The focus on defect rates and the explicit recognition of the correlation among the number of product defect, high operating costs, and the level of customer satisfaction makes Six Sigma unique amongst other process improvement initiatives (Abdelhamid 2003). In the context of the Six Sigma approach, 'sigma' has been used as a metric that reflects the ability of a company to manufacture a product or provide a service within prescribed specification limits (or within zero defects) (Abdelhamid 2003).

There are two methodologies used to achieve Six Sigma goals; Define, Measure, Analyze, Improve and Control (DMAIC) and Define for Six Sigma (DFFS), the latter is not part of this paper; therefore, it is not discussed here.

DMAIC, a five phase closed-loop problem solving pattern that eliminates unproductive steps, and applies technology for continuous improvement. DMAIC is generally used on business process that fails to meet customer requirements.

- **D**efining and understanding the critical requirements, key factors and expectations of the customer which affects the process output.
- **M**easuring the process and relevant data to the process primary through Six Sigma metrics.
- **A**nalyzing the causes of defects and sources of variation using statistical quality control tools.
- **I**mproving the process by deriving in the analysis phase the most critical source of variation.
- **C**ontrolling and monitoring the process variations using a statistical process strategy to sustain the gains and improvements.

Deming and many others defined two kinds of variation: common cause and special cause variation. In Figure 1, Xn represents the inputs to the process and Y is the output. Due to variations in the inputs (common or special causes), the resulting Y will also be variable (Abdelhamid 2003). Six Sigma is a data-driven problem solving approach, where process inputs (Xn) are identified and optimized to impact the output (Y). The fundamental equation that drives Six Sigma is:

$$\mathbf{Y = f(x)}$$

Y: output (things important to business)

f: Function (how to treat and manage interrelationships)

X: Variables that must be controlled to consistently predict Y

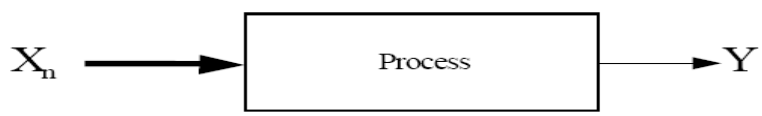

Figure 1: Typical single-stage manufacturing/service process (Abdelhamid 2003)

In 2002, Bechtel Corporation, one of the largest engineering and construction companies in the world, reported savings of $200 million with an investment of $30 million in its Six Sigma program to identify and prevent rework and defects in everything from design to construction (Kwak et al. 2004).

Further examples of Six Sigma implementation in engineering are applied on a national telecommunication project to help optimize the management of cost and schedule, and on a chemical project to streamline the process of neutralizing chemical agents (Moreton 2003).

THE SYNERGY OF LEAN SIX SIGMA

Hahn et al. (1999) addressed the issue that Six Sigma has escaped canonical in both the academic and the practitioner literature. This is primarily caused by lack of an abstraction of the underlying theory of Six Sigma approach.

It is believed that Six Sigma does not directly address process speed and so the lack of improvement in lead time, and only modest improvement in Work in Process (WIP) and finished goods inventory turns are achieved (George 2002).

But Lean methods aren't the answers either. Many of the firms that have shown little on the improvement in inventory turns have in fact attempted to apply Lean methods.

Furthermore George (2002) describes the Lean Six Sigma methodology as follows:

"Lean Six Sigma is a methodology that maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed and invested capital".

George (2002) also concluded that rapid improvement in an organization requires both; Lean and Six Sigma. How do Lean and Six Sigma complement each other? The answer is that Lean cannot bring a process under statistical control, and Six Sigma alone cannot dramatically improve process speed or reduce invested capital.

This research paper concentrates on the DMAIC Six Sigma methodology proposed in Six Sigma literature and the Lean principles proposed in Lean literature.

CRITICAL TOTAL QUALITY (CTQ) AS SIX SIGMA PERFORMANCE INDICATOR

Critical total quality (CTQ) is one of process performance indicator used in previous Six Sigma projects (Han et al 2008). In implementing Six Sigma principle, CTQ is a main indicator in the phases of DMAIC (Han et al 2008). In this paper the reliability of panel production rate of each day was a main CTQ, because the process in study depends mainly on the production rate.

The study adopts the process capability index (Cp) to measure the performance of Six Sigma efforts on the reliability of panel production rate. Cp can be calculated using the following equation (Montgomery 2004):

$$\text{Cp (process capability index)} = (\text{USL} - \text{LSL}) / (6 \times \text{STDEV}) \quad (1)$$

If only USL and LSL given

Where USL = upper specification given; LSL = lower specification given; STDEV = standard deviation of the data.

Process capability indices are constructed to express more desirable capability with increasingly higher values. Even though Cp value recommended for new process is 1.5 (Montgomery 2004), recommended level for construction process was not fully discussed in the industry. Previous Six Sigma application to construction processes showed that the value of Cp was less than 1.0 (Han et al 2008).

A CASE STUDY

Due to the lack of available information and many organizations' reluctance to disclose Lean Six Sigma Process Improvement Project (PIP) case study, we were able to study only one case study. The case study is presented in this paper to investigate the Lean Six Sigma methodology and the implementation in the construction industry. A brief description of this case study project is given to provide the context. A description of the analysis and key findings from this case study is also explained.

CASE BACKGROUND

The owner company is developing the Phase II of the Jubail Industrial City in Saudi Arabia. Part of the Jubail Phase II development is to provide 405 villas for the community. Due to the speed and efficiency in production and installation, it was decided to construct the villas using precast wall and floor panels.

Figure 2: Erection of Villas

However, one year after issuance of Notice to Proceed (NTP) to the contractor, the contractor was 25% behind the schedule. In order to avoid the high risk of additional delays and shortage of housing, a Lean Six Sigma study was undertaken by Bechtel's Six Sigma Black Belt team. The aim of the study was to understand and solve the problem by achieving following goals; 1) Improve productivity of fabricating and delivering pre-cast insulated panels to construction site, 2) Establish causes for delay, address inefficiencies at the pre-cast plant & propose remedial measures, 3) Operate at takt time interval, and 4) Achieve all critical milestones per contract terms and conditions

Figure 3: Pre-cast Plant

FINDINGS: LEAN SIX SIGMA PROCESS

A Lean Six Sigma study starts with a problem statement followed by defining the primary metric, which aids to focus on the problem area and measures the output or resulting Y. The primary metric for this case study was the 'Number of Exterior Insulated Panels Delivered to Construction Site per Day'. The current state baseline production rate was 18 panels/day, and in order to recover the schedule, 75 panels/day was targeted.

To illustrate common cause and special cause variation in a typical Six Sigma process, the critical X's which are the input to the process are represented in Figure 4. Figure 4 clearly indicates how Lean tools were integrated with Six Sigma methodology by identifying the critical X's in this process. The Value Stream Mapping (VSM) is the first step to determine the potential X's. It shall be noted that the output or resulting Y may also be variable, due to variations in the inputs. In this case, the prime Y is the daily production rate of the pre-cast panels.

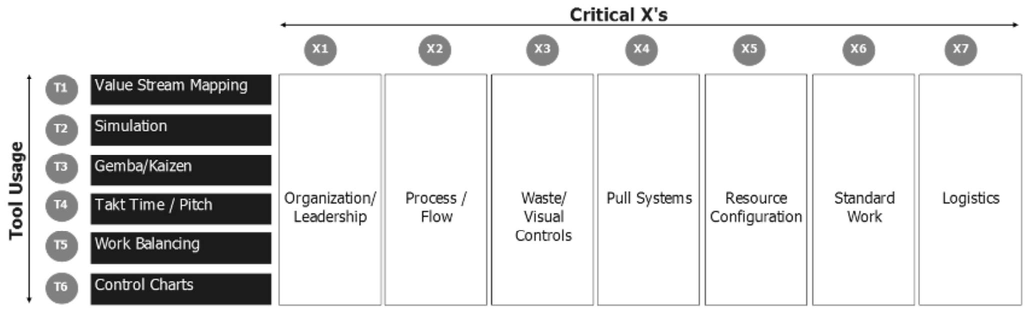

Figure 4: Lean Implementation Matrix

Following are examples of actions taken care of for some Critical X to improve the productivity (All actions for each critical X are not shown here for the reason of space allowed):

X1: Improve Leadership / Supervision

- Deploy dedicated plant manager;
- Appoint general superintendent
- Appoint four foreman, each dedicated to 6 production
- Hire full time Project Quality Engineer

X2: Optimize process flow by increasing Resource Utilization

- Dedicate two (2) Gantry Cranes for production area
- Add one (1) concrete bucket to allow simultaneous work on multiple tables
- Start use of Ready-mix Trucks for grey concrete delivery
- Add night shift to recover schedule

X3: Eliminate Waste through improved Inventory Management

- Reconfigure stockyard for better access and control
- Reduce Inventory Level to maximum of 250
- Use Visual Controls to display product status (red-curing day 1, yellow curing day 2, green ready for blasting)
- Status inventory and develop Electronic Inventory Logs to track storage and deliveries

X6: Document Standard Work & Improve Logistics

- Prepare a list of standard activities with clear roles, responsibilities and accountabilities

- Measure cycle times and reduce lead time by eliminating waste
- Streamline deliveries by loading trucks with panels for one lot only

By identifying the problems on the VSM (Figure 5), and tackling over the critical X's, the production rate of 75 panels/day was achieved (Figure 6).

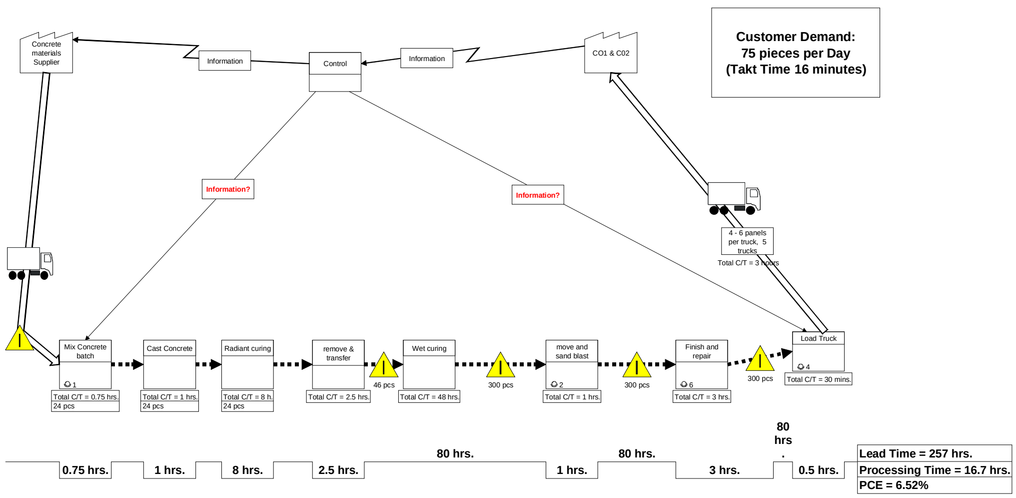

Figure 5: Value Stream Map

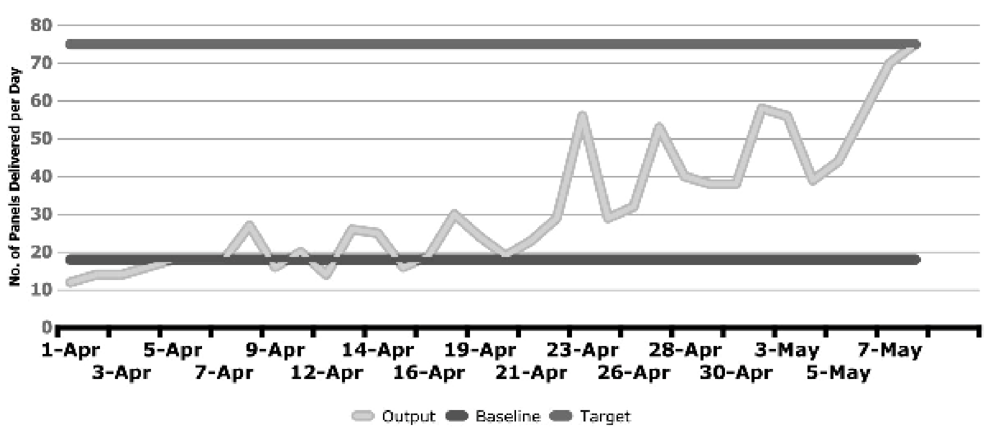

Figure 6: Performance Improvement

Furthermore, Figure 6 shows the statistical control chart which is used to isolate common from special cause variation. The chart in Figure 6 shows hypothetical dimension figures, which is in this case the 'No. of Panels Delivered per day', for the product of Y plotted against time for month of July. The Upper and Lower Control Limits (UCL and LCL) shown are a function of the process mean, process range, and the standard deviation of the measured data (Montgomery 2001; Abdelhamid 2003; Breyfogle 2003).

The chart clearly indicates that the process is under statistical control. In Six Sigma, a process is considered under statistical control if all the data points fall within the LCL and UCL. The Cp (process capability index) is calculated using the equation (1) as follows:

Cp (process capability index) = (USL – LSL) / (6 x STDEV)

$$= (143.2-42.3) / (6 \times 18.76) = 0.90 \qquad (2)$$

The value of Cp is 0.9, which is less than 1.5,, a recommended level for a new production in manufacturing-based environment. However, the value seems acceptable taking into account the differences of production context in the industry.

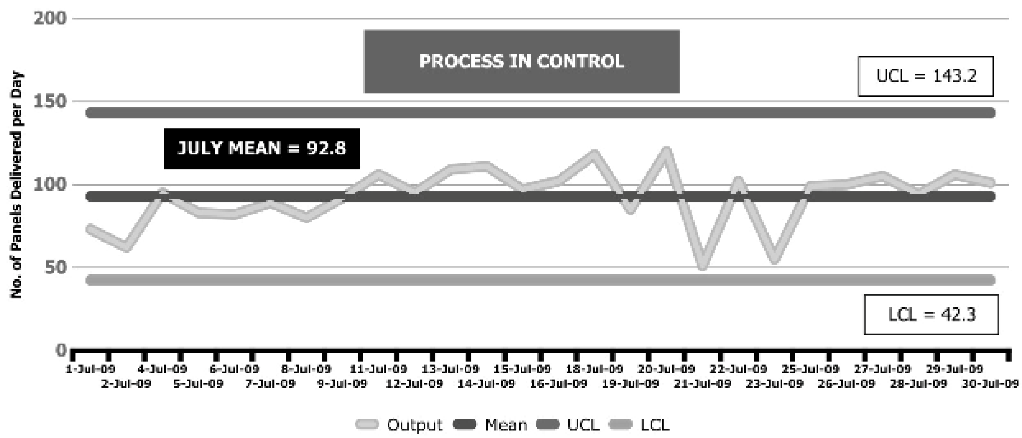

Figure 6: Sustained Performance – Control Chart

DISCUSSION

Observation on the case studies has revealed that Lean tools were used to identify and to improve some critical X's in a process. In some cases one of the critical X may be related to technical problems (such malfunction of crane or concrete pump, etc.), which then neither Lean nor Six Sigma would apply to solve and improve the critical X. However, it would be fair to say, that Lean is best to use to address production (or physics) problems (Ballard 2000) where flow in the process is not optimal, whereas Six Sigma is to identify the defects.

It has been seen that adoption of Six Sigma production tools to improve the organization's products and production system were not sufficient, as it fails to achieve a reliable workflow.

The above case study makes use of both Lean and Six Sigma tools together to solve construction problems. It is considered neither of the methods in isolation would have been fully successful. However, the combination has a multiplier effect of the ability to reach a successful outcome. Large organizations are more willing to adopt the Lean Six Sigma methodology to improve and solve business problems on daily activities.

CONCLUSIONS

This research paper explores the use of combined Lean and Six Sigma in the construction industry. This research has included a review of literature, interview and case studies of Lean and Six Sigma in the construction industry. Some of the conclusions drawn from the literature review and case studies, and can be summarized as follows;

(1) Both Six Sigma and Lean are strong production management tools and the combination complements each other. Lean in principle eliminates anything that doesn't add value to the customer and achieves reliable workflow. On the other hand Six Sigma aims to control and reduce the variations by understanding the root cause. As discussed in this paper, as well as in Abdelhamid (2003), the combination of both tools can lead to a very useful methodology to improve any process.

(2) The complexity of the construction project has its own unique and uncertain environments, which made the use of Lean Six Sigma methodology somehow different from the other industries, especially manufacturing. However, as seen on the case study, major Lean Six Sigma tools have been successfully applied to improve the process.

(3) The methodology of Lean Six sigma was effective in reducing variability of daily panel production rate. However, taking into account inherited uncertainty in construction processes, the value of Cp can be applied flexibly to construction processes.

Construction companies already adopting Six Sigma may recognize that Six Sigma by its own is not sufficient to tackle problems, as it lacks to achieve a reliable workflow. Lean Six Sigma promotes continuous improvement of processes by both analyzing root cause of variation and eliminating waste. Therefore, and in order to be competitive and innovative, construction companies need to apply both tools to tackle their business problems.

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