The Application of Six Sigma Approach in Construction: A Case Study for Improving Precast Production Management

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ABSTRACT: Six Sigma has been developed in the 1980s at Motorola; this approach is now extensively applied in the manufacturing and other industries for improving productivity and profitability. In Taiwan, after 921 earthquake in 1999 and huge floods in 2009, the construction industry have realized that the importance of construction quality and harmony with the environment. The Six Sigma takes attention to the quality that customers concerned and also contribute to achieving efficiency and reduce costs. By the way, the thinking of Six Sigma approach should also be applied in the construction industry. Therefore, this paper will take the Six Sigma approach into the practice of precast construction management.

KEYWORDS: Six Sigma, Lean Principle, Precast Concrete Construction

1. INTRODUCTION

Quality, duration, and cost are often treated as the basic indicators to evaluate the performance of a specific construction project. Generally, cost is the most important consideration for both the owners and construction contractors, In particular, when the rush of construction or cost overruns, quality control might easily be ignored or missed. However, after the huge natural disasters suffered and the development of construction technologies and management tools, modern construction enterprises start to pursue higher service level, such as continuously shortening the duration, improving the quality, and creating more values for customers.

Six Sigma has been developed in the 1980s at Motorola; this approach is now generally used in the field of manufacturing and other industry. Six Sigma is based on the critical quality that customers concerned, that can help enterprises to pursue high level quality, promote efficiency and reduce costs. Hence the advantages of the Six Sigma should also be taken for construction management. Therefore, a better understanding of this improvement approach would have significant profit for establishing better management model of the construction industry.

1.1 Objectives

This paper will take the Six Sigma approach into the practice of precast construction management. First, the precast construction quality characteristics concerned by customers would be investigated; then take the precast building components to the application of Six Sigma's approach for manufacturing and construction process improvement, and verify the method applicability in the construction project. Finally provide recommendations for continuously improving quality and competitiveness to construction enterprises. Therefore, this study would take the precast production process as an example; aims at the improvement of productivity. Provide the systematic improvement of the precast components production through Six Sigma. And reviewed relative issues of the precast concrete production management with DMAIC sequence which being the standard methodology of Six Sigma.

2. LITERATURE REVIEW

Six Sigma developed by Motorola in the 1980s, which is a quality management approach, solved problems with processes and scientific methods. In the 1990s, Allied Signal and General Electric have successfully implemented and achieved breakthrough growth of business, makes Six Sigma approach as the leadership methodology in the field of quality management.

There are some different meanings of Six Sigma defined by various authors:

- Harry and Schroeder (2000), defined Six Sigma as a disciplined method of using extremely rigorous data gathering and statistical analysis to point sources of defects and ways to eliminate them.
- .Pande et al. (2000), considered Six Sigma as a comprehensive and flexible system for achieving, sustaining, and maximizing business success. It is driven by a close understanding of customer needs, disciplined use of facts, data, and statistical analysis, and diligent attention to managing, improving, and reinventing business processes; a way of measuring processes, a goal of near perfection represented by 3.4 defects per million opportunities; and more accurately.
- Snee (2000), stated that Six Sigma is a strategic method that works against all processes, products, and industries
- Pande and Holpp (2002), defined Six Sigma as a statistical measure of the performance of a process or a product; A goal that reaches near perfection for performance improvement; and a system of management to achieve lasting business leadership and world-class performance.

3. METHODOLOGY

3.1 DMAIC

The standard Six Sigma methodology consists of five phases: Define, Measure, Analyze, Improve and Control (DMAIC). It sequences the steps that are essential to achieving results, and briefs as follow:

(1) Define: this phase is to define the requirements of customers, the scope of processes to be investigated. Project targets then set based on the customer's requirements.

(2) Measure: identify the key metrics, possible factors that affect the key metrics, the data collection plan, and execute the plan of data collection. And also preliminarily analyze the causes that result of variation.

(3) Analyze: Analyze the data collected and the process to determine the root causes of the problem that need to be improved.

(4) Improve: verify the relationship of key root causes that affected the variation of the key metrics. Then, aim the key factors and develop solutions to improve the process or production tools. Plot them on a small scale to determine if they positively improve the process performance, Successful improvement methods are then implemented on a wider scale. Results of process changes are quantified.

(5) Control: develop and implement a control plan to ensure that performance improvement remains at the desired level. The process have to be monitored to prevent abnormal changes occurred. (Pande et al. 2000; Ecke 2001).

3.2 Lean Principle

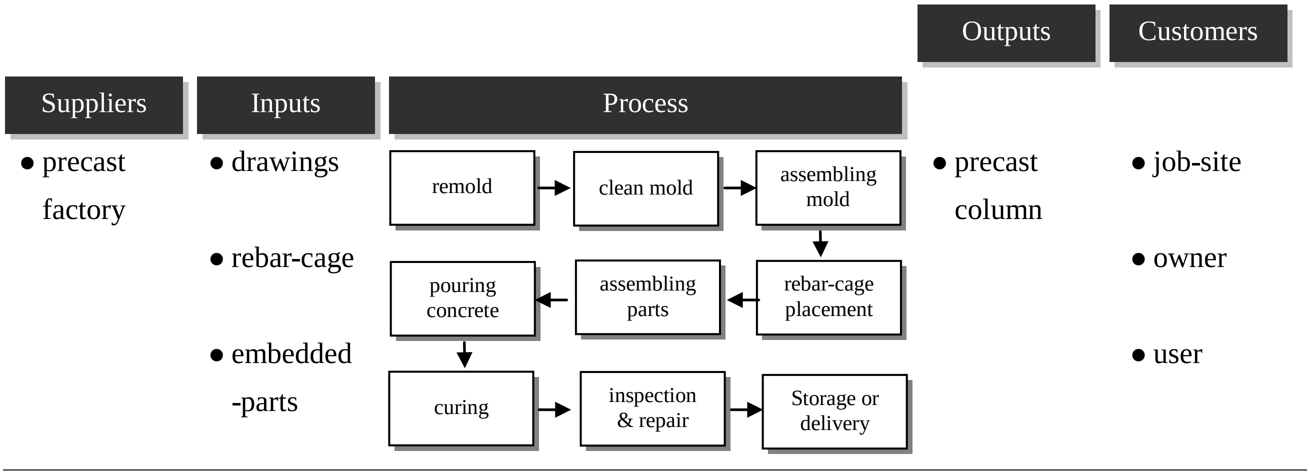

Figure 4.1 SIPOC Process Diagram

Womack and Jones (1996) present value specification, value stream (waste elimination), flow, pull, and continuous pursuit of perfection as the lean principles. Ballard and Howell (1998) indicated the goals of lean thinking redefine performance against three dimensions of perfection: (1) a uniquely custom product, (2) delivered instantly, with (3) nothing in stores. This is an ideal that maximizes value and minimizes waste. Toyota Co., have developed the lean production as the Toyota Production System (TPS), which is a combination of methods with consistent goals—cost reduction, quality assurance, respect for humanity, and ensure sustainable growth. Among the methods of TPS, just-in-time (JIT) is a famous way to eliminate process waste, based on the concept that inventories are not valuable and should be viewed as waste, and all materials or resources should be achieved only when required.

4. CASE STUDY

The goal of the Six Sigma project is to improve the manufacturing process of precast column components and achieving savings. The scope is shown in Figure 4.1, including the mold assembly, the reinforcement cage and embedded assembly, concrete pouring and curing to the finished product activities, but not includes the banding of the reinforcement cage and storage of finished products, the above process operated by specific manufacturing crews.

4.1 Voice of Customers

For external customers, after the precast products

Table 4.1 Voice of Customers

Internal Voice of Customers		Exterior Voice of Customers	
Corporate Goals & Objectives	1. manufacturing cost must be under budget 2. Enhancing quality	Voice of Market	1. Efficient producing and delivery on time
Voice of Process	1. unskilled workers, slow motion 2. lack of worker resources 3. limited resources and conflicts of route in precast factory	Customers	1. lower price 2. high production quality 3. short duration for production 4. customers prefer alternatives with lower cost
Voice of Employee	1. lack of engineers for management 2. insufficient areas for production	Competitors	1. with better production equipments and space

3. irregular attendance of out-sourcers	2. price competition

delivered to the job-site, these components will be installed by construction workers, hence the workers primarily concerned about the workability and correctness of the precast products, the purpose is to reduce the repairing job or waiting in the job-site, and keep the operation of construction smoothly. Therefore, the critical quality is the precision of the size, embedded parts and decorative material (such as granite, tile, etc.). The owners might concern about the economy and aesthetics of a construction, such as lower price and better looks. If precast method cannot correspond to these requirements, the owners may choose other construction methods.

In terms of internal customers, factory manufacturers would like to catch more resources of raw materials and tools to execute the production process smoothly. However, the limited resources like lifting cranes and concrete batching equipment are restricted. Then, a precast production manager shall always optimize use of resources for the sharing of all projects. The instructions detailed in Table 4.1.

4.2 Affected Factors of Productivity

In Taiwan, most precast building components such as columns, beams, walls are customized design, for specific properties of each project, so the size, weight, or even appearance are varied. And the scale and quantity are also different, resulting in the change of factory output. Therefore the yield level and resource requisition of each production projects may affect productivity. The affected factors of productivity are analyzed by the cause-and-effect diagram shown in Figure 4.2.

(1) Personnel: The common production mistakes occurred often due to the manufacturing engineers are not familiar with the control points,

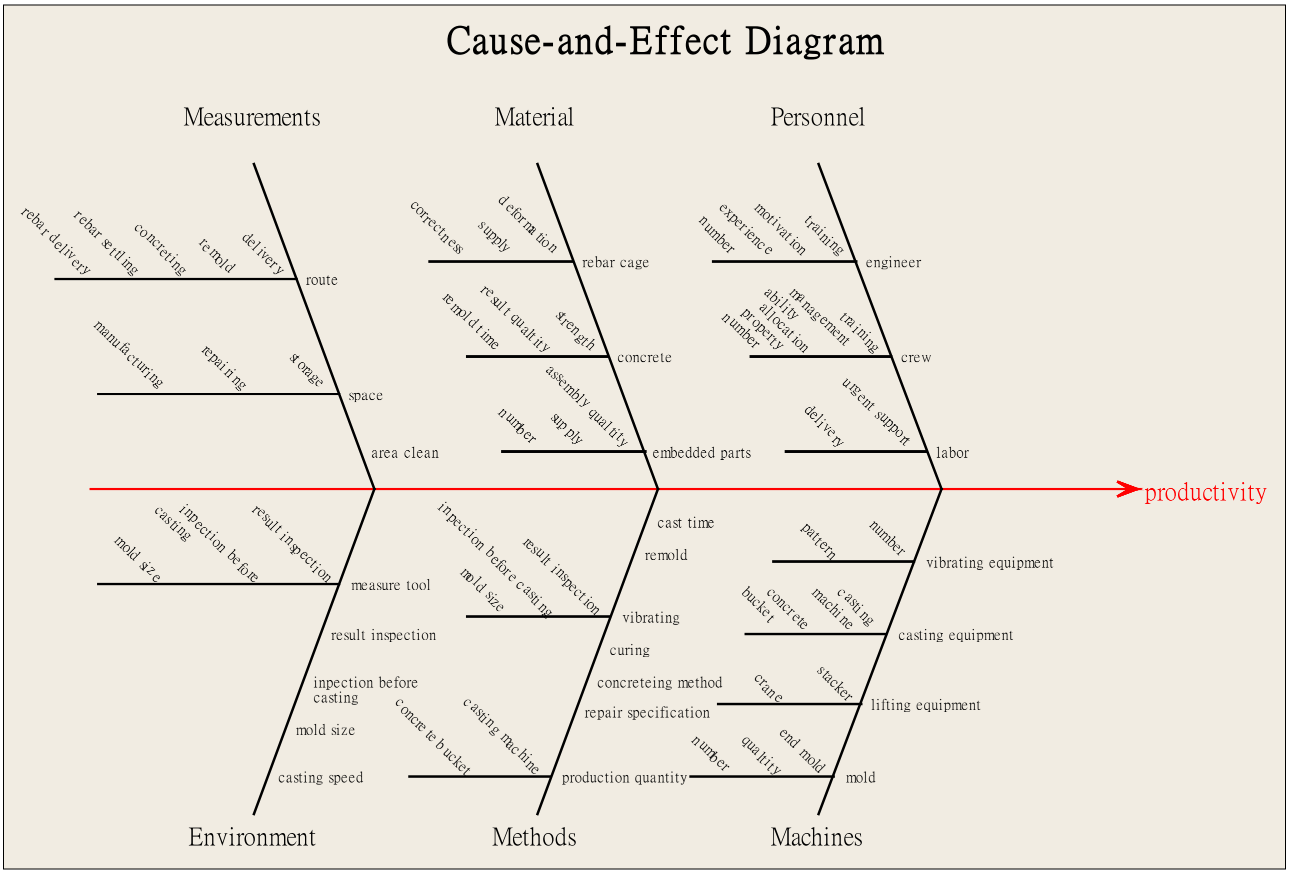

Figure 4.2 Cause-and- Effect Diagram of affecting productivity

especially the new staffs. While the cost of a single product is quite high, the production processes need to be strictly managed to avoid loss. In addition, since the throughput changed with variation of the orders of factory, the labors for manufacturing were often obtained by outsourcing. Unstable labor resources and varied ability of crews might also affect the quality control.

(2) Machines: the volume of a precast component is rather large, the corresponding weight is around 10 ~ 15ton, varied with the size and design; so the lifting and shipping of production must depend on the crane equipment and trail device. Regarding to the molds for manufacturing components, the assembly, demolition and flatness of surface may affect the production efficiency and quality, but costs of mold still have to take into consideration.

(3) Material: the constituent materials of the precast components are as follows

- Raw materials: concrete, reinforcement steel or section steel.
- Embedded parts: hanging fasteners, anchor bolts, connected, switch boxes, and etc.

It is sometimes seen that work was suspended due to shortage of materials.

(4) Methods: the production process can be separated as 5 steps; respective sequences are mold preparation, pouring concrete, surface finishing, component repairing and removing to the trailer. The time of mold preparation take highest proportion of the production time, known by actual observation, so the time of mold preparation is too much should be given priority to improve.

(5) Environment: in the precast factory, there are several activities with different purposed as described above execute at the same time, hence conflict of moving lines or waiting often occurred. In addition, due to the production space is limited, if the preceding process failed to complete, then the waiting of rear process result.

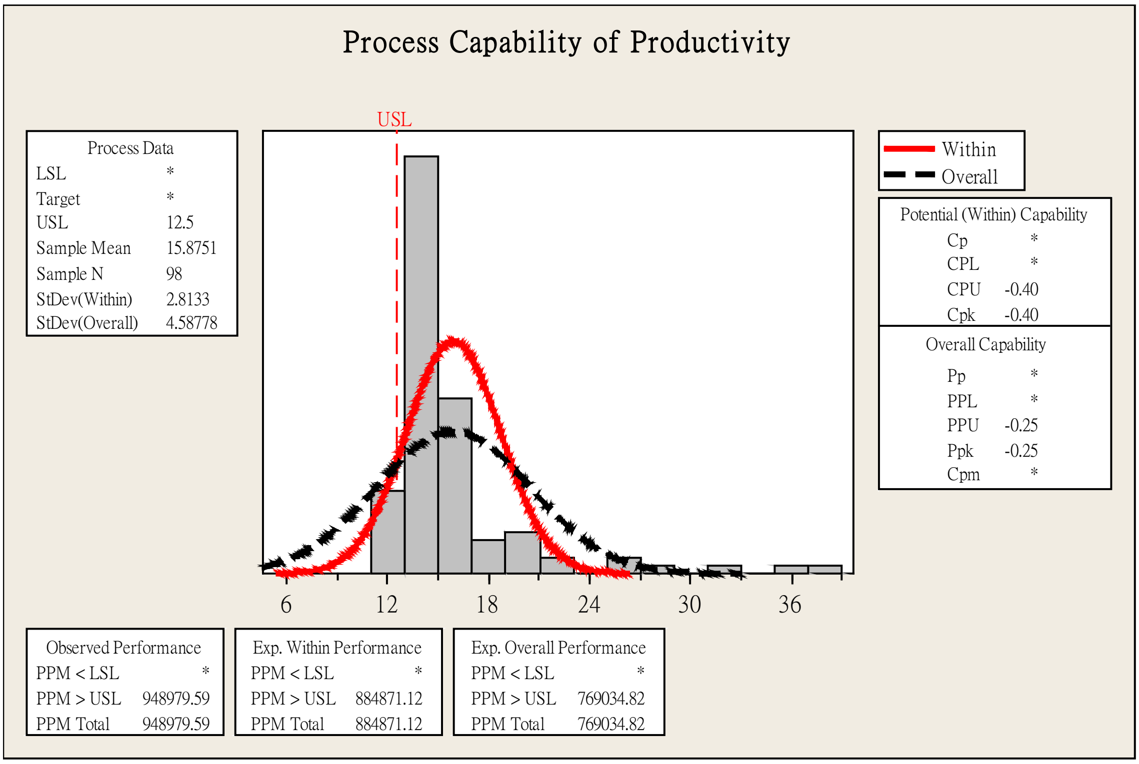

Figure 4.3 Process Capability of Column before improvement

4.3 Data Collection

The average productivity was 15.87 hr/pc sampling of the present records, as shown in Figure 4.3, this amount corresponded to the baseline productivity generalized by precast plant with long-term experience. The executives instructed to 12.5hr/pc as the goals of this six-sigma project.

Based on previous analysis, in order to find out the factors that caused the variation of productivity, the sampling plan to be implemented is as follows:

(1) Key indicators: manufacturing productivity of precast column component (hr/pc)

(2) Possible factors: which likely impact the productivity deducted previously. In this study, 10 variables selected will be collected for analysis.

(3) Sampling frequency: a day of each sampling, collecting time is about one month.

4.4 Quantitative Analysis

Collected by the measure phase of the possible factors and manufacturing productivity, applying significant test analysis and achieve the results as shown in Table 4.2.

The analysis got the affected factors, which are the production quantities, assembly hours, pouring hours; max need number of concrete for production line and period of start to pour concrete and other factors have a significant difference.

(1) Daily throughput: the production quantity of column have a significant effect for the productivity, Figure 4.4 displayed that the more quantities produced the better performance of productivity; this event stated that when the production line reaches full production, the processes and resources will be adjusted and optimized, so the relative waste can be eliminated.

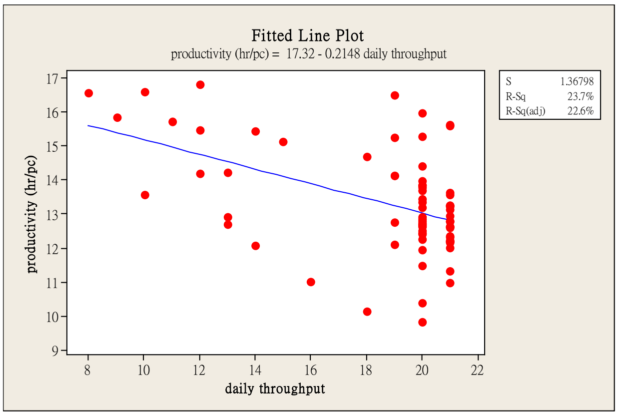

Fig. 4.4 Regression Analysis: productivity vs. DT

TABLE 4.2 Significant analysis results of possible factors

Variable	Code	T-Test	ANOVA	Regression	Summary
1	WD		P=0.736		No significant difference
2	DT			P=0.000; R2=23.7%	significant difference
3	CON		P=0.03		No significant difference
4	RH			P=0.919; R2=0.0%	No significant difference
5	MAH			P=0.001; R2= 12.4%	significant difference
6	CPH			P=0.001; R2=31.7%	significant difference
7	SMN			P=0.336; R2= 0%	No significant difference
8	PA	P=0.056			Slightly different
9	ADO			P=0.017; R2= 19.9%	significant difference
10	PSC	P=0.002			significant difference

Note: WD=weekday; DT=daily throughput; CON=number of crane operator; RPH= repair hours;

MAH=mold assembly hours; CPH=concrete pouring hours; SMN= number of shaped mold; ADO= amount of demand concrete order; PSC=period of start to pour concrete

(2) The amount of demand concrete order: in the production cycle of precast column, the pouring concrete time is about 23% of the total production time. The delay of production line occurred obviously when the number of production lines need to pouring at the same time, due to concrete batching plant with limited capacity, as shown in Figure 4.5.

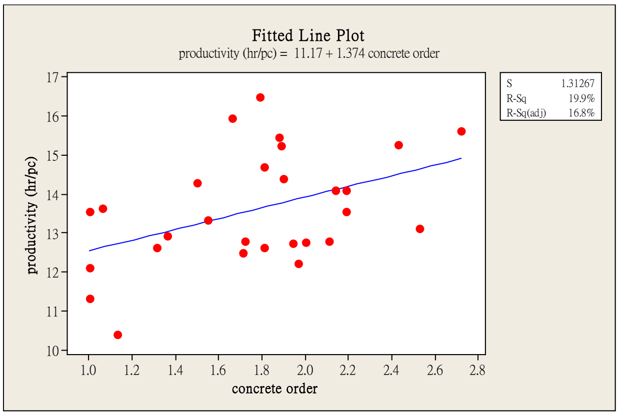

Fig. 4.5 Regression Analysis: productivity vs. MNC

(3) Period of pouring: in order to verify the affection of pouring period, distinguish the pouring period as section of morning and afternoon, as shown in Figure 4.6, the average and variation of productivity of afternoon section is higher than productivity of morning section. This also displays that the characteristic of the precast factory, that is, most production lines carry out the preparatory work in the morning and pouring concrete in the afternoon. Thus, the demand should be decentralized to avoid creating a conflict and waiting.

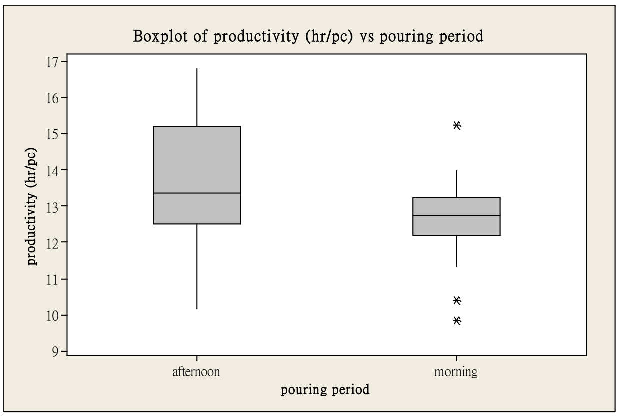

Fig. 4.6 Boxplot of productivity vs. PSC

4.5 Improvement

Through the investigation of the above phases, the key factors of productivity have been identified as the number of worker, the amount of concrete order, and the workability of cast mold. Then the improvement solutions will be piloted in the practical production and validate the effects during the phase of improve.

(1) The control of worker number: the worker number for each process should be well allocated by using the motion study for crew plan. Confirm the grouping of each process crews, then the process can be performed effectively and reduce the variation of working hours.

(2) The order control of supplying concrete: too much and suddenly inserted orders are the reason that cause the variation of pouring hours, the improvement may be taken by coordinating and dispersing the time section of pouring for each lines.

(3) Workability of cast mold: since the poor cast mold will cause the variation of the repair hours, the improvement could be taken by modifying the design of mold and application of gasket materials to avoid leakage from molds.

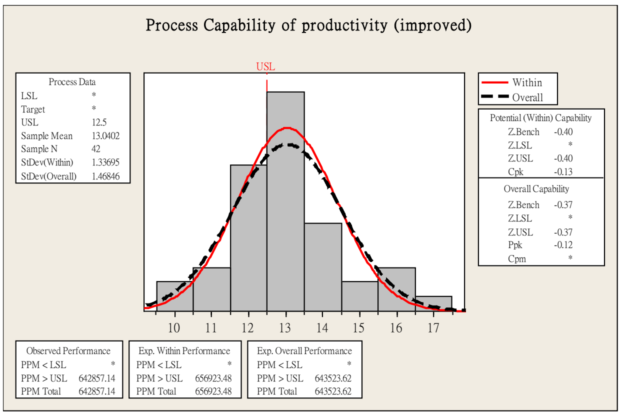

Fig. 4.7 Improved Process Capability

TABLE 4.3 Lean Production of Precast Production

Waste pattern	Description	Improvement Action
Redo	● mold unsuitable clean of mold causing surface defects	● establishing working specifications and training for operators
	● insufficient vibration will cause excessive air bubbles and cellular, resulting in working hours of repair	● training for concrete work
	● pouring elevation or poor surface quality will lead to uneven surface, affecting the appearance and increase the repair action	● training for surface finish work
	● the junction of the side mold and bottom mold not close will result in the mortar leakage around the junction, that would affect the appearance quality and increase the repair job	● find out the cause of reason, and improve the mold design
Process	● unnecessary repair job	● define the standard of the customers' needs to minimize unnecessary repair job
Transportation	● shipped immediately after production is completed, otherwise it will cause the finished product must be temporary stored	1. scheduling production based on shipping schedule 2. stored in the plant to reduce extra transportation
Action	● some workers are slow motioned or not familiar, resulting in delay of work time	● the implementation of the standard action training
	● workers are not in accordance with the specification, resulting in extra actions	● the implementation of the standard action training
	● poor moving routes or unwell material stock area will cause waiting	analysis and coordination of the moving routes in order to reduce conflict
Waiting	● concrete supply less will lead to all production area waiting	● coordinate the demand time of projects and principle of supply
	● mold preparation takes much time resulting in subsequent jobs wait	● Applying motion analysis studies to reduce unnecessary action

Lean manufacturing could be applied as well in order to eliminate the waste in the process, as shown in Table 4.3.

After the improving phase, the manufacturing productivity collected currently has been improved form 15.87hr/pc to 13.04hr/pc, and the standard deviation improved from 4.588 to 1.468, as shown in Figure 4.7, the improvement case have contributed to save more than 2.5 million NTD in one year for this factory. It validates that the Six Sigma approach does contribute to the improvement of production efficiency and reduce variation of capability, with significant effectiveness.

5. CONCLUSION

In this study, by using the standard sequence of the Six Sigma approach to review and improve the productivity, the efficiency and profit of precast column production have been enhanced, and reached the goal of the improvement. It validated that Six Sigma approach can be effectively applied in the management of precast production.

This approach is also applied for other processes and quality improvement in the case factory; these Six Sigma projects have also achieved impressive savings. Hence the Six Sigma approach may also provide the construction industry for pursuit of high level quality and competitiveness.

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