An Empirical Study of the Machine Assembly Efficiency Improvement Based on Lean Six Sigma Technique

Chien-Chih Wang [1] , Chun-Ting Liu [2]

[1]Department of Industrial Engineering and Management, Ming Chi University of Technology, Taiwan
[2] China Metal Products Col., Ltd, Taiwan

***Abstract* –Effectively controlling inventory is one of the key factors for small and medium-sized enterprises to make profit. Most small and medium-sized enterprises solve their problems through experience or trial and error, but they are often unable to achieve the desired enterprise performance under limited time and cost. The real case adopted herein covers a manufacturer of optical lens equipment, and the bottleneck is the shortened period of delivery caused by refunded, reduced, and delayed orders due to changes in the market. Under the framework of Lean Six Sigma, this study identified the key factors affecting working hours and product cycle and then formulates strategies to import the actual process. The results show that the inventory turnover rate increases from 20.8% to 41.6%, deriving a financial effect worth of NT$15.57 million. For the practical verification of the case company, Lean Six Sigma really does improve the assembly process efficiency, achieving a result beyond the expected target. With this successful case, this study can be a reference for other firms.**

***Keywords* –Lens Assembly Machine, Lean Production, DMAIC, Inventory Carry Rate.**

1. Introduction

Under the trend of the information revolution and high-speed changes in industry, the industrial cycle period is getting shorter, with many products disappearing from the market shortly after they come into the market. In the operating model of an enterprise, process efficiency and meeting the requirements of client customization are the key factors to make profit. If inventory turnover and production line are inflexible, then this leads to capital being idle, thus affecting the competitiveness of the company. This is especially true for the small and medium-sized enterprises, which can only carry out improvements and update their production process under a limited environment due to resource constraints and a shortage of talent. In face of the short life cycle of globally competitive products, small quantity but greater in variety, as well as fast delivery, a systematic procedure and a successful reference case are needed to overcome bottlenecks in practice. Under the structure of Lean Six Sigma, this study adopts an optical lens manufacturer as an example to develop a model that can efficiently improve the turnover speed of the working flow and reduce the overall working hours.

Lean Production originates from the Toyota Production System in Japan in the 1960s and 1970s. Womack et al. (1990) were the first to completely demonstrate Lean Production in the book entitled "The Machine That Changed the World" [1]. Through the model of looking for value, knowing the value stream, moving the operation, and carrying out the production according to customer requirements and continuous improvement, the production system and efficiency of inventory management are strengthened, while wastes in manpower, equipment, space, etc. are eliminated to increase the work value. The system's goal is to reduce cost, lead time, and inventory to respond to the needs of customers more elastically and acutely. Six Sigma is the quality management method developed by Motorola in 1980, which is a kind of improved activity of total quality management (TQM). It uses a variety of statistical tools for continuous improvement of the efficiency (do things in the correct way) and performance (do the right things) of organizations to meet the demand of the customers.

DOI: 10.18421/TEM82-21
https://dx.doi.org/10.18421/TEM82-21

Corresponding author: Chien-Chih Wang,
Department of Industrial Engineering and Management, Ming Chi University of Technology, Taiwan
Email: *ieccwang@mail.mcut.edu.tw*

Received: 04 April 2019.
Accepted: 08 May 2019.
Published: 27 May 2019.

Lean Six Sigma (LSS) integrates the management structure of Lean Production and Six Sigma to use a lean management method for solving the problem of time or inventory as they relate to quality so as to achieve the goals of a smooth process and the elimination of stagnation and sluggish inventory [2],[3],[4]. It focuses on good quality and breakthroughs in speed and efficiency. Six Sigma targets on how to make the production and the enterprise processes become more efficient [5]. LSS looks at the quality and speed of the process. When Six Sigma is unable to significantly improve the process speed, then LSS can be adopted to reach the goal. On the whole, LSS can improve customer satisfaction, reduce costs, improve quality, accelerate the process speed, and improve capital investment so as to maximize shareholder value [6].

The case company is a Taiwan manufacturer of high precision automation equipment. Its main products are automation equipment and high optical lens assembly equipment, equipment used for the LED process, process equipment used for customers' special professions, etc. (Figure 1.).

Fig. 1 The production equipment of co-operative manufacturer.

Its industry has the characteristics of short delivery time, high cost, and short cycle, because enterprises update, increase, or replace their production equipment in order to meet the demand for order production under the conditions of a peak season and recovery in the electronics industry, as well as an increase in intended consumption. However, the conditions of refunded, reduced, or delayed orders are easily caused by changes in the market and imitation by competitors. Therefore, efficiently shortening delivery time is a significant topic for equipment manufacturers. Based on the decision of the case company, this study helped reduce the original working time of 132hrs by 5% to 126hrs and used the mechanical and electronic simultaneous operation model to reduce the cycle from the original 33 days or above to 12 days as the goal.

Aiming at the bottleneck problem of the case company in the production process, this study adopts DMAIC steps of LSS to solve the problem and achieve the improvement goal. In the arrangement of the following contents, this study first states the adopted LSS, then uses the case company to illustrate the method, analyzes the procedure, and finally puts forward the conclusion and suggestions in the result.

2. Methodology

2.1 The Case Problem

Poor equipment assembly efficiency in recent years has meant the case company has been unable to meet customer demand, and so its order receiving rate has been declining, causing a gradual fall in the company's profitability. There are three main problems after diagnosis: the procurement process, schedule management, and working hour management.

For the firm's procurement, the current process sets four months as the delivery time after the business receives an order. The research unit then completes and confirms the design of the equipment drawings and specifications based on the customer's needs, with the time set at 0.5~1.5 months. For production, procurements are made according to the specifications, with a time of 0.5~1 month to purchase long-term materials and 2 months to purchase short-term delivery materials. Equipment assembly is carried out one month before the delivery, and the goods are shipped after product testing. The current bottleneck is that the components are needed in advance after considering the site productivity, thus resulting in an increase in inventory and cash flow.

2.2 Lean Six Sigma Implementation

This study adopts Lean Production and the Six Sigma DMAIC technique to improve the company's assembly machine. The five aspects of Lean Production, including Specify the Value, Identify the Value Stream, Flow, Pull, and Perfection, are integrated into the DMAIC structure, confirming the appreciated value from the Define Phase, searching the factors that affect the value process in the Measure Phase, knowing the impact magnitude in the Analyze Phase, and executing the improvement method in the Improve Phase. For example, this study imports Lean Production Pull and modular operation and adopts statistical validation for result verification, finally concluding the operation and converging the variation in the Control Phase so as to pursue perfection. Through this integration, LSS can be smoothly imported in the current practical work, making it certain that errors will not be made once again so as to achieve the benefit of Lean and Value.

In terms of the derived problems of the case company, this study puts forth the procedures of LSS as follows.

1. The requirements of the customers and the bosses, as well as the company's standards are put forward in the Define Phase, whereby the factors of multiple relevant problems are defined in the overall process, and SIPOC and Cause-and-Effect (C&E) matrix methods are adopted to highlight problems and to decide upon the controllable factors.
2. The related overall operation data are collected in the Measure Phase, the value stream drawing is then used to datamize the highlighted problems, and the wasted or convertible benefits are finally changed to a countable amount.
3. Some significant factors that can affect the turnover cycle and the working hours are analyzed in the Analysis Phase.
4. The concept of Lean Production is used to activate the schedule operation in view of the key points needed for improving in the Improve Phase, thus refining the change in the control cycle and making it changed into a countable amount.
5. SOP and related regulatory approaches are established to improve the overall operation in the Control Phase.

The following is the statement based on the practical operation mode of DMAIC [7].

- Define Phase

First of all, the workstations that may have abnormalities in the process as well as the reasons are sorted in the Define Phase with the respective use of SIPOC and the Cause-and-Effect matrix. SIPOC extends Input-Process-Output to Supply and Customer. The main purpose is to find any abnormal process with customer demand as the core. Figure 2. is a case SIPOC, whose process mainly has six phases, and the customer demand is to receive delivery on time.

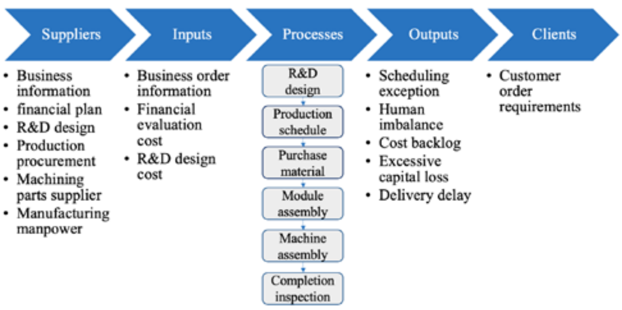

Figure 2. The SIPOC diagram

Table 1. lists the sorting relationship between a customer's expectation and the process station with the Cause-and-Effect matrix. The customers' main expectations are large fund flow, long production cycle, high idled inventory, and low utilization of productivity, whose weights are respectively 7, 9, 5, and 5. Table 1. shows that the schedule of the production schedule station is not accurate and the time used for the assembly of modules is too long, which are targets that need improvement.

Inaccuracy of the production management schedule will cause idle production and delayed delivery time, thus leading to increased difficulty for the leveling of site operation. A long assembly time causes delays in production and delivery and increases personnel cost. Therefore, the efficiency of the production management schedule must be improved, and the assembly time must be reduced.

Table 1. The C&E matrix results

Processes	Impact on improvement goals (boss requirements)	Large capital flow	Long production cycle	Inventory idle high	Low capacity utilization	Total
		7	9	5	5	
Production schedule	Production schedule is not accurate	9	9	7	7	214
Module assembly	Module assembly time is too long	5	9	7	7	186
R&D design	Research and development BOM is not complete	3	5	9	7	146
Machine assembly	The assembly time of the whole machine is too long	3	7	3	7	134
Purchase purchase	Delay in purchasing materials	3	3	7	7	118
Module assembly	The site supervisor is unable to grasp the progress	1	7	3	5	110
Production schedule	Not considering online work time	5	1	5	1	74
Production schedule	No live billboard	5	3	1	1	72
Machine assembly	The factory environment is too small	3	3	1	3	68
Completion inspection	Insufficient test laser equipment	3	3	1	1	58

- Measure Phase

The value stream drawing is used in the Measure Phase to analyze the operation process, to find the steps with non-value added, and to put forward the goal for expected improvement. Figure 3. shows the value stream drawing of the current assembly process, and it is found from the results that the average waiting times of 1.09hrs, 1.126hrs, and 1.17hrs are produced respectively between the machine arranging/XY line rail screw assembly station, the tie line station of disk fixation, and the fixation station of mesa module and the HEAD set station.

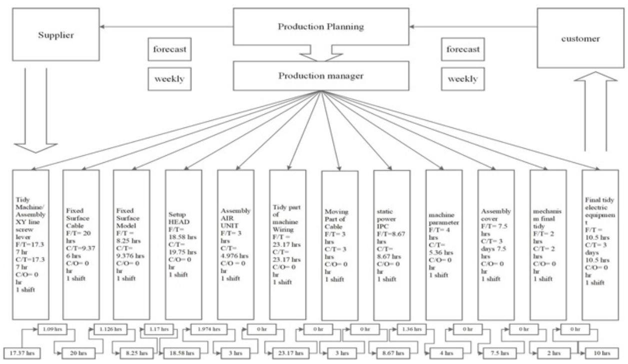

Figure 3. The value stream mapping of operation process

The main reason is due to waiting for the complete appliance exchange of mechanical and electrical machines and waiting for the company's preparation. In addition, on average the whole machine module has a delay of 1.974hrs and 1.36hrs produced respectively between the HEAD set station and AIR UNIT assembly station, as well as between the static IPC station and the setting station for the parameters of the whole machine. Eliminating the wasted waiting time mentioned above is the goal of LSS.

- Analyze Phase

This study conducts a statistical analysis on the current conditions in terms of the bottleneck found in the value stream drawing in the Analysis Phase. The status of the actual process is then deduced on the confidence interval through the use of the historical data.

In terms of the working time of the whole machine, the 95% confidence interval shows 131.616 and 133.753hrs, which are 6.6hrs longer on average compared with the 126hrs of standard working time. In terms of the working time of the XY line rail screw assembly station, the 95% confidence interval shows 15.277 and 15.928hrs, which are 1.77hrs shorter on average compared with the 17.37hrs of standard working time. In terms of disk fixed tie line working time, the 95% confidence interval shows 23.40 and 23.75hrs, which are 3.57hrs longer on average compared with the 20hrs of standard working time. In terms of the fixed working time of the working platform module, the 95% confidence interval shows 9.08 and 9.71hrs, which are 1.14hrs longer on average compared with the 8.25hrs of standard working time. In terms of the working time of the HEAD set station, the 95% confidence interval shows 22.01 and 22.99hrs, which are 3.92hrs longer on average compared with the 18.58hrs of standard working time. In terms of the working time of the static IPC station, the 95% confidence interval shows 8.42 and 9.05hrs, which are 0.07hrs longer on average compared with the 8.67hrs of standard working time.

It can be known from the analysis above that the 95% confidence intervals of the whole machine working time, the working time of the XY line rail screw assembly station, the working time of the disk fixed tie line, and the working time of the HEAD set station do not meet the standard working time. Thus, these are the significant factors that need improvement.

- Improve Phase

In terms of the significant factors found in the Analyze Phase, countermeasures are now put forward. A statistical test is carried out for improved results in order to present proof of concrete improvement. The statistical analysis method adopted is the Two-sample t test.

As the case company involves to project and polytrope assembly process, it is suitable for JIT mode assembly, like an auto assembly line. After confirmation of the order and at the same time of the main structure operation, it is required that the assembly of each module line should begin. they should be added in the body assembly one by one at the time of the integral assembly of the back-end production line.

Changes occur respectively to the order/order dispatching mode as well as production at the XY line rail screw assemble station, disk fixation tie line station, and mesa module fixation station. It is found from the result that the average working times of the XY line rail screw assemble station before and after its improvement are respectively 15.6hrs and 11.15hrs, with a p-value=0.000 after the statistical test. The average working times of the disk fixation tie line station before and after the improvement are respectively 9.4hrs and 6.8hrs, with a p-value=0.000 after the statistical test.

The improvement of the HEAD set station is for removing materials that do not belong to the module process and transferring them to the modules for the correct operation so as to reduce the waiting time for finding the materials, and then the research department is required to amend the BOM table to match the operation. This method can achieve the follow-up operation modularization and standardization. It is found from the result that the average working times before and after the improvement of the HEAD set station are respectively 22.50hrs and 21.578hrs, with a p-value=0.000 after the statistical test.

After the analysis of the overall improvement results, it is found that the average working times before and after the improvement of the whole machine are respectively 132.68hrs and 110.741hrs, with a p-value=0.000 after the statistical test. This result is better than the set target of 126hrs.

- Control Phase

The Control Phase mainly evaluates whether the improved strategy can truly make a profit. Figure 4. presents the comparative results before and after the improvement of the 20 process steps. The average working time changes from 34.495hrs before the improvement to 15.250hrs after the improvement (p-value<0.0001).

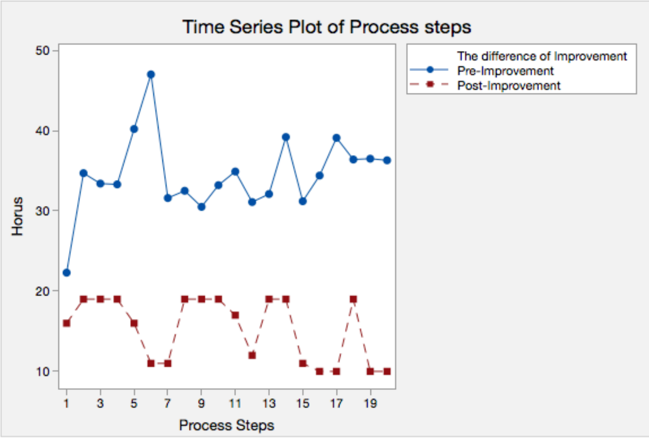

Figure 4. The comparative results before and after the improvement of the process

The following projects must be controlled in order to make the improved effect be carried out in practical production: the formulation of the site SOP and the execution of the performance evaluation. This part will be stated in the next section.

1. Third-party payment is the primary means of cash flow, and it will conform to community e-commerce as in the case of Facebook PAY.
2. In logistics, community e-commerce is more stable than other forms of e-commerce because of the community. High purchase rates and human communication make the logistics more flexible.
3. The main differences are preorders, shipping problems, and the mechanism of delayed shipping.

3. Case Study analysis and discussion

The case company is a leading manufacturer of sealing machines for optical lens in Taiwan. The problems faced in the process are the bottlenecks of most small and medium-sized enterprises. To look at the problem of assembly efficiency, this research team spent 3 months importing LSS to achieve the expected effect at the case company. In addition, the effects produced in the process were imported in the company and discussed with management to finish the following specific items.

- Formulation of the site SOP

This study defines the new standard working hour and matches the classification of materials in the process. Taking the HEAD assembly as an example, this study writes the four procedures onto a billboard to clearly state the order of assembly and the details that need attention. Reducing mistakes can reduce errors, which can also increase the profit of the whole assembly, thus helping to gradually establish the SOP of each module and making them coherent. After the formulation of the SOP, new standard working hours can be defined.

- Execution of performance evaluation

This study classifies the case participants into project and standard types for a comparison competition. In addition, a performance audit mechanism is put forward to give practical encouragement to colleagues, such as promotion, salary and bonus, etc. Under performance competition with each other, the employees can begin to form the spontaneous use of LSS to achieve the goal of continuous improvement.

It is found in the process of Lean Six Sigma that LSS can break through the abnormal thinking that the change in working hour in the site manufacturing operation is production efficiency, which is previously assumed by the manager. After evaluation of the finished projects, the research achievements can reduce the production cycle from the original 132hrs to 111hrs. As the decreased production working time improves the efficient working hour rate from 50% (132hrs/(33day×8hrs)) to 86% (111hrs/(16 day×8 hrs)), the inventory turnover rate changes from the original 20.8% (per quarter) to 41.6% (per quarter).

The calculation of the inventory turnover rate before the improvement is (Cost of machine NT$718,551× (Turnover time 32 days/32 days))×(99 sets/4 quarters))/((inventory at the beginning of period NT$80,000,000 + inventory at the end of period NT$91,000,000)/2) = 20.8%. The calculation of the inventory turnover rate after the improvement is (Cost of machine NT$718,551×(Turnover time 32 days/15 days)×(99 sets/4 quarters))/((inventory at the beginning of period NT$80,000,000 + inventory at the end of period NT$91,000,000)/2) = 41.6%. The improvement of the inventory turnover rate has positive benefits: the acceleration of capital turnover and a better capital utilization rate. The improvement results above can annually create NT$15.57 million in financial benefits as estimated by the financial department.

4. Conclusion

The main contribution of this study is using LSS to successfully improve the efficiency of a case firm's equipment assembly, which has significant benefits from the practical results. The company focuses on improving site manufacturing personnel before importing the materials, and it is found after their importing that the actual problems lie in waiting for the materials during the process and the waiting of the personnel caused by production schedule problems. After finishing the improvement project, the study also notes significant improvement in production working hours and the inventory turnover rate. In addition, the company will use the capability learned in this process to improve other projects. The achievements have thus greatly promoted the competitiveness and the operations of the company. They also indirectly prove that the stop-gap measures used in the past cannot take most of the impact factors into account and cannot help the firm to honestly face problems and solve them, and so they may be effective in the short term and not really solve the problems in the long term.

Quality, cost, delivery period, and service are problems frequently faced by small and medium-sized enterprises. Under limited manpower and resources, people typically use experience and trial-and-error methods to solve manufacturing problems, and hence systematic and effective methods are needed to help them better solve such problems. Most successful cases of LSS in the past were usually limited to large enterprises, with few successful cases existing for small and medium-sized enterprises. This study successfully imports LSS to a small and medium-sized enterprise and shares the achievements of the case study, which can be of reference for other manufacturers in the future.

References

[1]. Womack, J. P., Jones, D. T., & Roos, D. (1990). The machine that changed the world, Rawson Associates. *New York*, *323*.

[2]. Baker, B. (2017). Innovating Lean Six Sigma: A Strategic Guide to Deploying the World's Most Effective Business Improvement Process. *Quality Progress*, *50*(2), 60.

[3]. Pepper, M. P., & Spedding, T. A. (2010). The evolution of lean Six Sigma. *International Journal of Quality & Reliability Management*, *27*(2), 138-155.

[4]. Krafcik, J. F. (1988). Triumph of the lean production system. *MIT Sloan Management Review*, *30*(1), 41.

[5]. Pyzdek, T., & Keller, P. A. (2014). The six sigma handbook (Vol. 4). New York, NY: McGraw-Hill Education.

[6]. Arnheiter, E. D., & Maleyeff, J. (2005). The integration of lean management and Six Sigma. *The TQM magazine*, *17*(1), 5-18.

[7]. Ansar, A. R., Shaju, S. U. C., Sarkar, S. K., Hashem, M. Z., Hasan, S. K., & Islam, U. (2018). Application of Six Sigma using Define Measure Analyze Improve Control (DMAIC) methodology in Garment Sector. *Independent Journal of Management & Production*, *9*(3), 810-826.