LEAN SIX SIGMA FRAMEWORK TO IMPROVE THE ASSEMBLY PROCESS AT A PRINTER MANUFACTURING COMPANY

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Article History: Received 12 September 2022; Revised 24 March 2023; Accepted 15 April 2023

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ABSTRACT: The printer manufacturing company under study was looking for ways to continuously improve the manufacturing process transparency, compliance and control to manage process variations and waste elimination. This study aims to apply Six Sigma framework to aid in the defect reduction at a printer manufacturing company specifically the molding process. The systematic Six Sigma Define, Measure, Improve, Analyse, and Control (DMAIC) framework was used as a powerful diagnostic tool that has been proven to improve processes by reducing or eliminating the process variations. The technique used together with the Lean Kaizen tool has enabled the possibility of identifying the defect waste occurrences prior to focusing on the root cause of the problems and eliminating them. Five proposals for improvements were identified and a control plan was devised for the management to carry out in order to achieve a more robust and leaner manufacturing. As a result, a 25% reduction in defect rates were observed with the mold process now able to meet the customer specification with process C_p value increased from 0.59 to 1.15. Thus, the designed Lean Six Sigma framework is proven to be successfully applied in the assembly line of the printer manufacturing company.

KEYWORDS: *Six Sigma, DMAIC, Process Improvement, Lean Manufacturing*

1.0 INTRODUCTION

Manufacturing companies nowadays experience intensive competition in the market, complex customer demand and high expectations from the stakeholders. These factors have forced the manufacturing companies to constantly improve their quality and strategic competitive advantage. Thus, manufacturing industry has to maintain their service quality or product quality to survive in the fierce competition and able to delight their customers. Therefore, process improvement is an ongoing practice such that if successful implemented, the results can be measured in improving products quality, customer loyalty, customer satisfaction, increasing productivity of firm and employee skill development [1].

Lean Manufacturing is the industrial management paradigm to achieve increased productivity, high profitability and flexible production capability [2]. The main purpose of Lean Manufacturing is elimination of work losses, especially any activity in the process that consume resources but does not create any values. To complement the Lean principle, Six Sigma is another influential process improvement methodology in manufacturing. Six Sigma has been well recognized as a powerful business strategy and an imperative for achieving and sustaining excellence in operational and service industries [3]. Albliwi et al. [4] emphasized that operational excellence through continuous process improvements is the aim of Six Sigma methodology and has been successfully implemented worldwide for over 30 years. This systematic methodology has proven to produce significant improvements to many large and small organizations [5].

The printer manufacturing company under study was looking for ways to improve the manufacturing process transparency, compliance and control to manage process variations so that the wastes can be eliminated. Further, this company wanted to increase their current production rate without increasing the existing resources. In addition, the company also was looking for a proper approach to tackle the top 10 defects they were constantly encountering; part broken, short shot, shape NG, crack, flash, broken, gate protrude, no through hole, abnormal shape and gate flash. Therefore, the aim of the study is set to investigate the problem using systematic Six Sigma Define-Measure-Analyze-Improve-Control (DMAIC) methodology together with the Lean tools and techniques in order to propose a solution to improve the mold process variation.

Swarnakar and Vinodh [6] stated that there is a need to augment the Six Sigma DMAIC to enhance its effectiveness. The framework should be flexible and practical for the industry practitioners to choose the best tools to be implemented. Throughout the years, researchers have continuously improved the use of LSS framework in various manufacturing and services. Many instances can be drawn from the International Journal of Lean Six Sigma, an established Q1 journal publisher on the use of LSS enhanced frameworks in various manufacturing. For instance, Demirtas et al. [7] in a surgical mask production, Rebull et al. [8] in the food can manufacturing and Ren et al. [9] in a resin manufacturing company. Further literature reviews showed limited studies on the LSS approach being used in the printer equipment manufacturing. Two studies were found related to the LSS framework but both were only on the printing process and not on the printer equipment manufacturing. The first study was from Roth and Franchetti [10] where the LSS framework was used at the Northwest, Ohio's printing process with a fixed cycle time. Another study was from Jie et al. [11] which showed a contribution to research knowledge through a structured implementation of LSS framework in the Small and Medium Enterprises printing company. Therefore, this paper provides another opportunity for a practical LSS framework applicable to be used in a new manufacturing setting; the printer equipment manufacturing. Specifically, the aim of the study is to continuously improvise or to Lean Kaizen the LSS framework on a defect reduction project at the printing manufacturing's mold process.

2.0 LEAN SIX SIGMA FRAMEWORK

Six Sigma approach is a customer-oriented performance management technique to continuously minimizes defects and variations. Since the mid-1980s, implementations of the Six Sigma methods have helped many companies to retain their competitive advantage [12]. Six Sigma was pioneered by Motorola and has been widely adopted by a range of global, larger-scale corporations. Six Sigma's literatures and practical application primarily illustrate the fact that multinational companies are more likely to accept Six Sigma due to the proven concept that helps the company be more sustainable [13]. Not only unique to manufacturing, Six Sigma approach is also flexible to be applied in the services industry. For instance, Six Sigma was used to reduce the cycle time of a pantry workstation in a United Arab Emirates (UAE) hotel sector resulting in a profit of more than USD50,000 per annum [14].

Defect is described as something other than customer specifications [15]. Antony and Banuelas [16] indicated that throughout the business environment, Six Sigma is described as the business method used to increase the productivity of the company, boost the quality and efficiency of all activities to satisfy or surpass the needs and demands of the customer. Specifically, pervasive deployment of Six Sigma applications is possible since companies can express the benefits in financial returns by relating the improvement done with cost savings [17].

An integral part of Six Sigma framework is the DMAIC which is referred to five interconnected stages that effectively help manufacturing companies to solve problems and improve process quality. DMAIC framework uses several tools of Six Sigma such as the Pareto chart, process mapping, and regression analysis [18]. On the other hands, Mandahawi et al. [19] reported that DMAIC model is a systematic quality management inspired by Deming's Plan-Do-Check-Act (PDCA) Cycle. Smętkowska and Mrugalska [20] and Uluskan [21] detailed the DMAIC phases as:

i. Define (D); define problems, set goals, helps to identify project focus
ii. Measure (M); gather data, apply tools such as Pareto, Cause and Effect Diagram
iii. Analyse (A); Determine root cause, perform risk analysis
iv. Improve (I); Use of experimentation, statistics, lean techniques to explore and implement possible solutions
v. Control (C); Maintain and continuously improve the solutions

Johnson and Swisher [22] deduced that among the key factors for successful implementation of Six Sigma programs include continuous and clear management commitment, setting clear goals, choosing the right project leaders, choosing a strategically relevant projects and providing continuous training to encourage the cultural change. Evidently, Six Sigma is synonymous with improving the process efficiency, effectiveness and quality of product and services [23].

Globalisation has required inventive manufacturing and continuous improvement so as to remain competitive. Lean Six Sigma has become a leading business improvement methodology which is a combination of two quality improvement initiatives of Lean and Six Sigma. It has been successfully implemented in a wide range of manufacturing industries. Zhang et al. [24] stated that Lean and Six Sigma have different focuses and different viewpoint so combining them together can enhance business performance to the extent not achievable through the implementation of either one alone. In other sayings, the implementation of Lean Six Sigma methodology is integral of Lean and Six Sigma as a means of compensating for the limitation in each method resulting in significant impact on business performance [25]. These authors claimed that the manufacturing system implementing Lean Six Sigma will be more effective in the operational and finance performance compared to the manufacturing system that used either Lean or Six Sigma concept only. Similarly, Lean Six Sigma is also defined as a quality improvement method used to improve business profitability and the effectiveness and efficiency in the operation in order to meet customers' needs [26]. Abu Bakar et al. [27] concurred that Lean Six Sigma is more efficient that separate implementation of Lean or Six Sigma in waste reduction. Lean Kaizen is a method of continuously enhancing the conventional manner of doing work [28]. Thus, by continuously looking for ways to improve and adopt the Six Sigma DMAIC approach in various manufacturing industries will provide practitioners with a proven tool to apply in their workplace.

3.0 RESULTS AND DISCUSSION

The proposed Lean Six Sigma DMAIC framework for the printer manufacturing integrates tools namely, project charter, process flow chart, pareto chart, cause and effect diagram, failure mode and effect analysis (FMEA), why-why analysis and control chart. These tools were used throughout this study in the effort to achieve zero error performance and a leaner manufacturing.

3.1 Define

A project charter was formed which consisted of the project champion, project manager, coordinator, mentor, researcher, project title, problem description, objectives, project scope, tools and technique used in project. Next, the product information was gathered where a total number of thirteen mold products were identified being produced at the plastic injection molding department. Each of the mold products was identified using a part number. Different products were produced by different molding machines. There were five units of high precision servo electric molding machines which included two units of 550 tons and three units of 450 tons.

Six-months data related to the occurrence number of defects at the mold process were collected and tabulated as shown in Figure 1. Among the thirteen mold products, part number of A7U43400 contributed to the most defect followed by part number of A0XV3740 and part number A2XN3433. The project team decided to focus on the defects of the A7U43400 mold product.

3.2 Measure

Antony et al. [29] explained that the measure phase engages more on the data collection and making extensive analysis, numerical and statistical studies. The defect data for the A7U43400 mold product during the six-months period were investigated and collected. According to the data analysis, the types of defect were divided into ten categories; flash, gate flash, no through hole, shape NG, abnormal shape, short shot, broken, gate protrude, part broken and crack. Figure 2 shows the Pareto chart plotted to visualize the biggest contributor to the defect problem; the mold flash (73%) followed by the gate flash (8%). Therefore, decision was made to focus on these two problems. A mold flash in a plastic product is defined as a projection of undesired material beyond the desired injected features while a gate flash is referred to a particular location called gate and flash occurring at that point. A gate on molding products is defined as a point of the opening in a mold through which the molten plastic is injected into the product and the boundary between the part and the scrap.

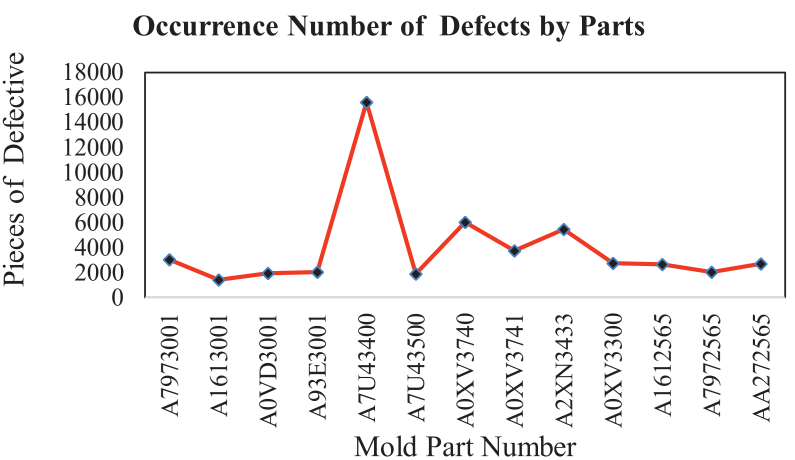


Figure 1: Mold Product Defect Trend

3.3 Analyze

The analyze phase began with the statistical analysis of the highest occurrence defects which were the mold flash and gate flash. This phase of DMAIC statistically reviews the significant contributors to the defects to help identify the root cause for the product defects. The analyze phase utilized the cause-and-effect diagram and ranking table to spot the sources of mold flash and gate flash defects in the molding process.

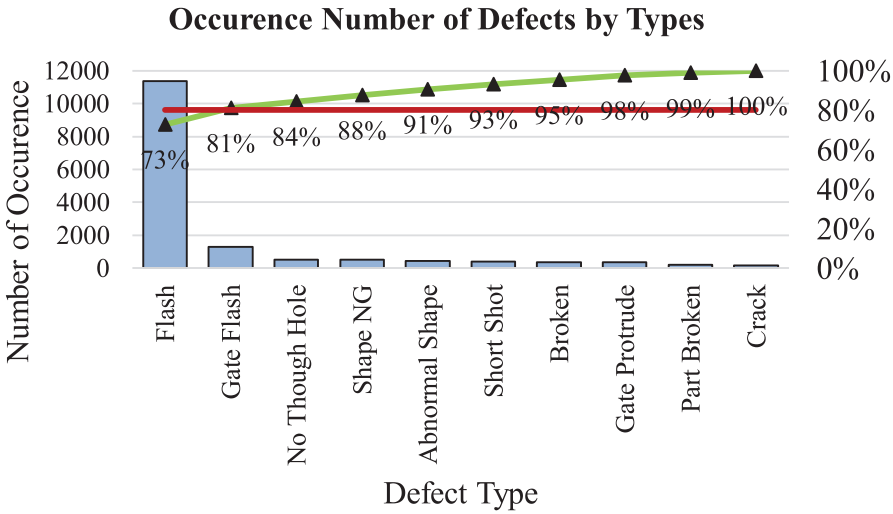


Figure 2: Pareto Chart of Number of Occurrence by Defect Type

The cause-and-effect diagram, also known as the fishbone diagram due to the shape was developed based on the project team members brainstorming session to generate as many sources of possible causes to the mold flash and gate flash problem. Based on the fishbone diagram developed in Figure 3, there were four main factors contributing to the mold flash and gate flash defects; man, machine, method and material. For the man factor, there were four issues that caused these defects; (i) the low frequency of maintenance of the machine, (ii) the carelessness of operators to insert part, (iii) the wrong sealing of the mold surface and, (iv) the improper alignment of the mold.

For the method factor, the process parameter was identified as the main issue. The use of an unsuitable process parameter caused the mold flash and gate flash defects. In order to produce a high-quality product, an optimized process parameter should be studied and implemented.

Furthermore, there were six possible causes contributed as the machine factor consisting of the depth of the venting system being too deep and the presence of gap between the mold cavity causing functionality issue with the molding machine where the injected material flowed through the unwanted sections of the mold cavity. This could possible lead to mold flash and gate flash defects where the material leaking out of the hot runner slide and the nozzle cracks in the mold cavity damaged the molded parts.

For the material factor, there were many types of materials used in the molding production; Polystyrene (PS), Acrylonitrile-Butadiene-Styrene (ABS), Polycarbonate (PC) and glass fibre. The use of these different materials may also be the possible factor contributing to mold flash and gate flash defects. The team suspected that the material with a high fibre content could affect the viscosity of the molten material. Therefore, the material temperature plays an important role in ensuring the material's viscosity of material is at an appropriate flow rate.

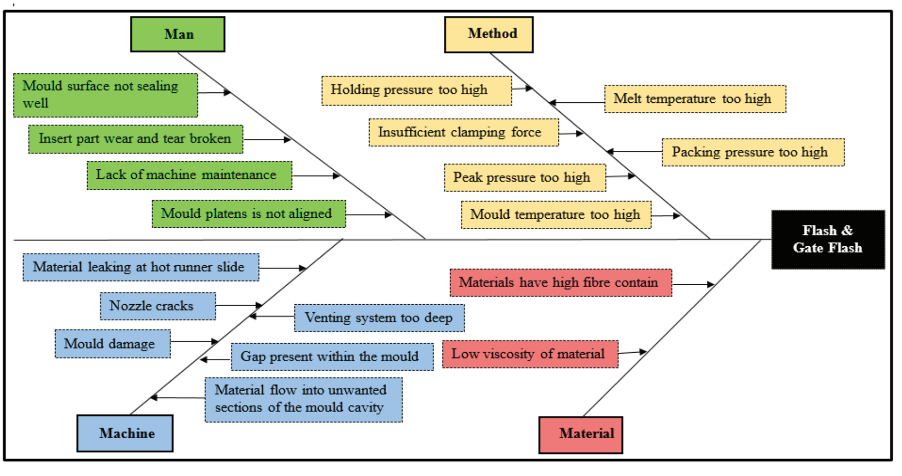


Figure 3: Cause-Effect-Diagram for Mold Flash and Gate Flash Defect

Once the cause-effect-diagram was confirmed, the project team consisted of the design engineers, quality engineers and the manufacturing personnel proceeded to rank the problems using the Failure-Mode-Effect-Analysis (FMEA) as shown in Table 1 specifically focusing on the severity, occurrence and detection criteria. Severity ranking refers to the rate of critical potential sources of mold flash and gate flash problems. The occurrence is defined as the rate of the likelihood that the sources of the problems will occur, while the rate of detection indicates the likelihood that the problem will be detected before it progresses to the next stage. The risk priority number (RPN) is the value resulting from the multiplication of the severity, occurrences and detection that is the risk assessment measure that has enabled the team to identify the critical failure mode associated with mold flash and gate flash problems.

The higher the RPN of the failure mode, the more urgent the issue needs to be resolved. The results in Table 1 showed that the top five RPN values belonged to the failure modes of 'material leaking at hot runner slide', 'peak pressure too high', 'mold temperature too high', 'mold damage' and 'gap present within the mold' with the value of 196, 192, 189, 147 and 144 respectively.

Table 1: Failure-Mode-Effect-Analysis of Mold Flash and Gate Flash Problem

No.	Causes	Ranking			RPN
		Severity	Occurrence	Detection	
1	Material leaking at hot runner slide	7	4	7	196
2	Peak pressure too high	4	6	8	192
3	Mold temperature too high	3	7	9	189
4	Mold damage	7	7	3	147
5	Gap present within the mold	6	6	4	144

3.4 Improve

This stage focused on determining a solution for the mold flash and gate flash problem. Firstly, a why-why analysis was developed to identify the countermeasures of the problem, followed by developing an improvement plan.

The why-why analysis is a very well-known tool to identify the sources of problem, also known as the five whys method. It is a simple but powerful tool to use that can help eliminate the problem of mold flash and gate flash frequently occurring with the mold product. By repeatedly asking the question "Why", the layers of symptoms can be peeled away leading to the root cause of the problem. A discussion between project team was carried out in order to gather the 'why-why' information related to the mold flash and gate flash problem.

The top five causes from the FMEA were analysed using the why-why analysis. The solution for the root cause of 'peak pressure too high' was identified as changing the core and cavity block size. This resulted in avoiding the larger block size from being undercut. While, increasing the cooling channel acted as the countermeasure for the cause of 'mold temperature too high'. The countermeasure for the root cause of 'material leaking at hot runner slide' was identified as to increase the number of hot runner gate and redesign its shape. Furthermore, for 'mold damage', the team proposed a solution to change the mold machine lifter design. The idea to redesign the mold base size was also suggested to solve the cause of 'gap present within the mold'.

3.5 Control

In the control phase, the aim is to reduce the quality defects and monitor the improvement plans in the molding process. Accordingly, process capability chart is used periodically to ensure the product meets the customer requirement at the desired specification. The process capability examines whether or not the process output is capable of meeting the specification while, Xbar-R chart examine whether or not the output of process is in the state of statistical control. 20 samples were plotted using Xbar-R Chart to monitor the before improvement made to the mold process and the respective 25 samples were taken after the improvements were implemented.

Figure 4 shows the Xbar-R chart consisting of the mean sample graph and sample range graph. Based on these graphs, the centre limit indicates the average of all 45 subgroup averages. Furthermore, the upper control limit, UCL represents the 3-Sigma above the centre line while the lower control limit, LCL represents the 3-Sigma below the centre line. The mean sample graph before improvements were made shows that there are six out-of-control points represented by the six red points. The same is true of the sample range graph, with two samples out of control. The sample mean graph indicates that the current state of A7U43400 production line is out of control, while the sample range graph providing the second evidence. However, the Xbar-R Chart is showing the success of the improvement plans with sample 21 onwards starting to be within the process control which results in an improvement of 25% in the defect rates being observed.

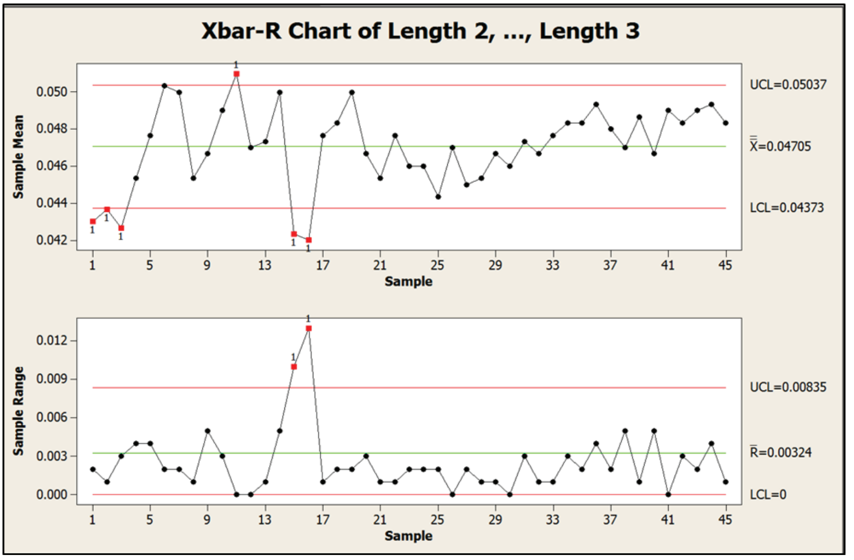
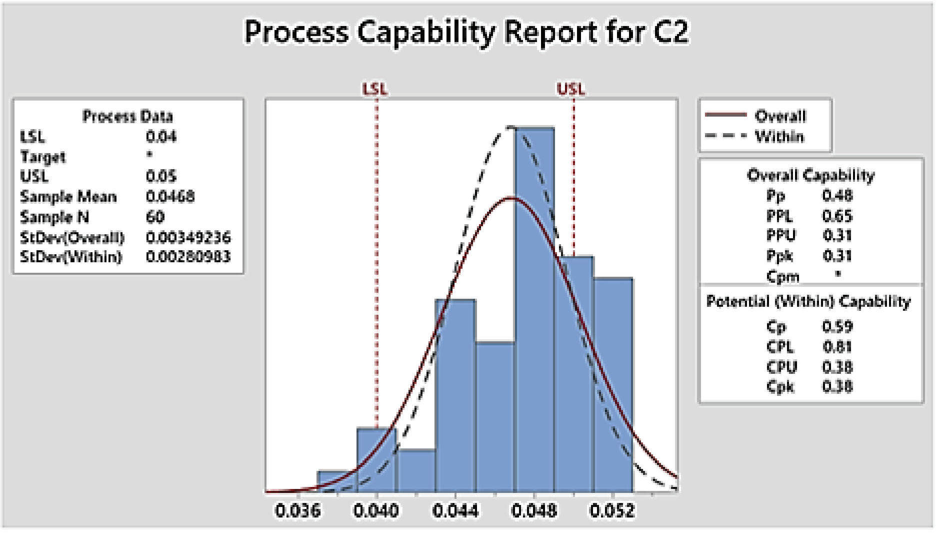
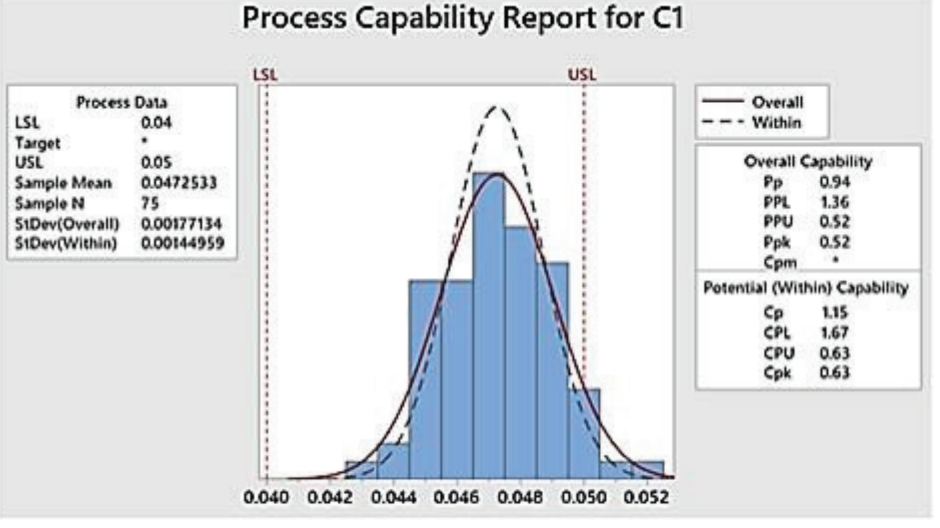


Figure 4: Xbar-R Chart for the A7U43400 process

Furthermore, Capability Ratio (C_p) and Process Capability Index (C_{pk}) are usually used to measure the process capability [30]. The value of C_p and C_{pk} greater than 1.0 means that the process is able to meet the expected requirement. The C_p shows how the process fits to the specification limit while C_{pk} shows how the process spreads to the specification limit. Figure 5 shows the process capability charts for the before and after mold process improvement. In Figure 5(a), value of C_p is 0.59 which is less than 1 and in Figure 5(b), the improved mold process shows the value of C_p of 1.15 which is more than 1 which means the process is successfully controlled. The value of C_{pk} although is still less than 1 shows an improvement from 0.38 to 0.64.



(a)



(b)

Figure 5: Process Capability Charts for the A7U43400 part;(a) before improvement, (b) after improvement

4.0 CONCLUSION

The Lean Six Sigma DMAIC approach was successfully used in this study to address the major defects of the printer manufacturer, specifically at the mold process. From the six-months data gathered, part number of A7U43400 was identified as the major defective product out of thirteen parts, and upon further investigation using the Pareto analysis, the mold flash and gate flash were identified to be the top 80% contributor of the problem. The Cause-and-Effect diagram and FMEA analysis were conducted to further analyse the possible contributors of the problem. Further, a why-why analysis was constructed to define the potential root cause and the countermeasures for these issues. To control the process variations, a process capability chart and Xbar-R Chart was plotted and monitored. An improvement of the c_p and c_{pk} values were observed indicating the success of the implementation strategy. Through this Lean Kaizen activities, the defect rates were observed to reduce by 25%. Thus, the proposed LSS DMAIC framework has proven to be effective to be used for quality improvement projects for the printer manufacturing. Thus, regardless of the size of the organisation, this framework can be extrapolated to similar business operations that exhibit comparable production failure, waste rate, and equipment stoppage symptoms.

ACKNOWLEDGMENTS

The authors would like to thank the printer manufacturing company for providing the facility and data for this study and the Universiti Teknikal Malaysia Melaka for the support to ensure the success of this study.

AUTHOR CONTRIBUTIONS

Individual contributions of authors:

R. Abdullah	Conceptualization, Methodology, Writing Original Draft Preparation, Reviewing and Editing
H.K. Lee	Data Curation, Writing Original Draft Preparation
A.H. Abdul Rasib	Reviewing and Editing
H.O. Mansoor	Reviewing and Editing

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission and declare no conflict of interest on the manuscript.

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