Manufacturing Performance Improvement through Integrated Six Sigma: An Aircraft Industry Case Application

Sri Indrawati, Agil Firmansyah, and Sunaryo

Abstract— In Aircraft industry, product quality is a key factor for manufacturing performance. However, there are some problems faced in the standard specifications fulfillment of aircraft components that being produced. Under that conditions, this research is done to minimize and eliminate failures that occur in the manufacturing process of aircraft components. The method used in this study is integrated six sigma and failure mode and effect analysis. Six sigma approached is used to reduce the variation in the product. While the failure mode and effect analysis document is designed to identify potential failure modes of the parts manufacturing process. The research shows that the quality of performance is in the level of 4.3 sigma. The most dominant type of defect is the fault dimension (43.02 %), the error of making a hole (26.58 %) and cracked part (15.09 %). While the priority is to repair an old machine with RPN value of 200, the process of hand forming with RPN value of 192, uneven press tool with RPN value of 144, untidy warehouse with RPN value of 120 and unsharpened drill with RPN value of 105. So, that corrective actions recommendation are regular engine maintenance, arranging work stations according 5S, re - sharpening blades and more stringent inspection in process sheet.

Keywords— manufacturing performance improvement, six sigma, FMEA

I. INTRODUCTION

DUE to Increased globalization and competitive pressures, product quality is a key factor in manufacturing performance. The quality of a product is defined as the degree products ability to satisfy the customer needs (fitness for use). Therefore, companies must be able to know what are the factors that can affect the quality of a product that being produced in order to facilitate the company to improve the quality and reduce the level of product defect.

Six sigma method has been broadly accepted by the manufacturing industries in some areas to improve its product quality performance. The function of this method are analyzing manufacturing process and reduce product defects [1]. The method can be integrated with failure mode and effect analysis (FMEA) methods to provide a comprehensive analysis of potential failure modes in a system that is further classified in accordance with seriously or the possibility of influence. Thus the company can analyze the factors causing failures so it will reduce the level of product defect.

Many Researchers has studied and documented their analysis on six sigma application. Implementation of six sigma and kaizen is successfully support the product quality improvement efforts by evaluating the root cause of failures and provide an alternative manufacturing process improvement [2]. Six Sigma has also been applied to monitor employee time and activity operators in marine containers industry [3]. That research conclude that a serious action in order to improve the performance of operators and improve the administration of marine containers are needed.

Six sigma explicitly links the tactical activities with the strategic ones in engineering education institution case [4]. In that study, it is concluded that a key element in improving the quality of teaching and learning in an educational institution are the presence of mind awareness in the management of the institution as well as a strong commitment by each student. The recommendations of six sigma methods to reduce product defects also categorized as a strategic decision are making a new standard operational procedure, resetting every product order delivery and improve communication with the customer [5]. Manufacturing performance measurement can also being done through the six sigma method [6]. This research is conducted in a cigarette company with a sigma value results to the data attribute = 4.69. This indicates that the performance of the company is at the industry average in America.

There are some others tool that being used to implement six sigma in a manufacturing industry. Based on the research, efforts that being made to improve the quality of cables are failures data collection, data analysis using failure mode and effect analysis, and determine the cause and take corrective action to reduce the level of failures [7]. The conclusion of this study is to make flow charts which set out the lead time around four hours and also the use of one-piece flow to eliminate unexpected delays in the manufacturing process.

PT D is an aircraft manufacturing industry. PT D has core competencies in the design, development, and manufacture aircraft for commercial and military interests. On the production line, PT D has produced more than 300 units of aircraft and helicopters, defense systems, aircraft components and other aircraft services. PT D has already implemented several standard specifications for the quality of the aircraft parts and components that being produced. However, there are 2,32% defective products from the manufacturing process. It

Sri Indrawati is with the Industrial Engineering Department, Faculty of Industrial Technology, Universitas Islam Indonesia (corresponding author's e-mail: sriindrawati@uii.ac.id).

Agil Firmansyah is with the Industrial Engineering Department, Faculty of Industrial Technology, Universitas Islam Indonesia.

Sunaryo is with the Industrial Engineering Department, Faculty of Industrial Technology, Universitas Islam Indonesia.

means that PT D can't fulfilled the standard of defective product rate around 1,1 % that already being determined.

Based on that condition, a research to minimize and eliminate failures that occur on the part of EC - MK2 production aircraft is needed. The method used in this study is the method of six sigma and FMEA. Six sigma approach is used to reduce the variation in the product. While the FMEA document is designed to identify potential failure modes on the part of EC - MK2 helicopter production before it happens, considering the risks associated with the failure mode, identify and implement corrective actions to address the most important issues.

II. Basic Theory

A. Six Sigma

In six sigma approach there is a methodology DMAIC (define, measure, analysis, improve, and control). DMAIC is a process that is carried out continuously toward the target for six sigma and systematically conducted based on science and facts. There are five steps implementing six sigma quality improvement, namely [8] :

A.1. Define

Define is the determination of the six sigma quality improvement activities target [9]. Operationally, the objectives can be a decrease product defects level and operational costs as well as increased production quality and productivity. This step also defined an action plan that should be taken to perform each step.

A.2. Measure

Measure is a step where a mapping process, systems evaluation and assess the baseline performance of the company's capabilities. There are three main points in this step, namely:

a. *Establish the critical to quality*

   In determining the critical to quality , every aspect and operational processes that affect the customer 's perception of quality value should be considered. Companies must take measurements of some factors that relevant to customer satisfaction and the company's business strategy. There are two variables that being used in this step, namely: defect per million opportunities (DPMO) and Sigma Level. DPMO is a performance measure of a process which is calculated by the following formula [10]:

$$DPMO = \frac{1.000.000 x number\ of\ defect}{number\ of\ units x number\ of\ opportunities\ per\ unit} \quad (1)$$

   After knowing the value of DPMO then it can be converted in the form of sigma.

b. *Develop a data collection plan*

   Basically, quality characteristics data can be collected at three levels, namely: at the level of process, output and outcome.

c. *Performance measurement baseline*

   Before the six sigma project starts, the company must determine the current level of performance (baseline performance). Once this is achieved then the improvement can be measured along the implementation of the six sigma project. Baseline performance in six sigma can be determined by using DPMO and sigma level.

A.3. Analysis

The manufacturing industry must find and understand why defective products may occur in this step. So the company must do several things: determine the stability and process capability, set performance targets of critical to quality, identified sources and root causes of quality issues.

A.4. Improve

An action plan to improve the quality of six sigma is determined [11]. The team must know the quality improvement targets to be achieved, why a plan of action that must be done, who is responsible for the action plan and how to implement the action plan.

A.5. Control

The quality improvement results are documented and disseminated. The best practices are then used as a standard operational procedures and the leader responsibilities of six sigma team is being transferred to the owner or person in charge of the process.

B. Failure Mode and Effect Analysis (FMEA)

FMEA is a methodology that reveals the mechanism of action of potential sources and causes of defects that will occur related to its occurrence, the defect seriousness, the defect impact and the ability of defect detection [12]. FMEA will help in analyzing potential failure modes in a system that is further classified in accordance with seriousness level or the possible influence of a system failure. The general approach in performing FMEA, namely [13]:

a. Identify difference in failure modes
b. Determine the cause of failure
c. Determine the effect of failure
d. Identify how to detect failures
e. Determine how serious the ultimate effect of the failure mode (severity) and convert the level into a rank as shown in Table I.

TABLE I
SEVERITY CRITERIA

Severity of Effect	Rank
Minor effect	1
Low effect	2-3
Moderate effect	4-6
High effect	7-8
Very high effect	9-10

f. Determine the frequency of occurrence probability of failure and convert the level into a rank as shown in Table II.

TABLE II
OCCURRENCE CRITERIA

Probability of Failure	Rank
Remote (failure is unlikely)	1
Low (relatively few failure)	2-3
Moderate (occasional failure)	4-6
High (repetitive failure)	7-8
Very high (failure is almost inevitable)	9-10

g. Determine the probability of failure can be detected (detection) and convert the level into a rank as shown in Table 3.

TABLE III
DETECTION CRITERIA

Detection	Rank
Very high	1-2
High	3-4
Moderate	5-6
Low	7-8
Very low	9
Absolute certainty of non detection	10

h. Criticality analysis of failure modes with RPN (Risk Priority Number) that can be calculated using formula (2). High value of the RPN will help give consideration to corrective action on any mode of failure [14, 15].

$$RPN = Severity\ xOccurencexDetection\ rating \quad (2)$$

III. CONCEPTUAL FRAMEWORK

Object of this study is manufacturing process of part EC MK-2 helicopter. The first stage that being done is make an observations and collect global of non conforming data containing defective products at a certain period. The data is then processed using some tools of six sigma such as operation process chart diagrams, pareto diagrams, control charts, DPMO, sigma level and fishbone diagram. Then a depth analysis is done using FMEA method. the final stage is to provide recommendations for improvement that are used to control the further manufacturing process.

IV. RESULT AND DISCUSSION

A. Define Phase

In PT D has some quality standard specifications for each aircraft components that being produced . However, the established standard specifications of aircraft components are still not being fulfilled by the manufacturing process. One of the crucial helicopters part is EC MK - II, where the standard part rejection rate is set in 1,1 %. But the real manufacturing process rejection rate reaches 2,32 %. In order to reduce the defect rate of the product, there should be an improvement program.

B. Measure Phase

a. Determining Critical To Quality (CTQ)

There are nine critical to quality (CTQ) existing defects in the manufacture of helicopters parts EC - MK - II, namely: wrong dimension, failure in hole process, cracked part, scratch /tool mark, non- conforming parts for next process, layer defect, did not match with part process sheet, wrong and wrong application of chemical addition.

b. Baseline measurement of work

In the performance measurement baseline measurement, DPMO is used to determine the level of sigma. The result shows that the DPMO average around 2579, 93 with the 4.3 sigma level. That sigma level is quite good, but still far from the target that should be achieved in 6 sigma level.

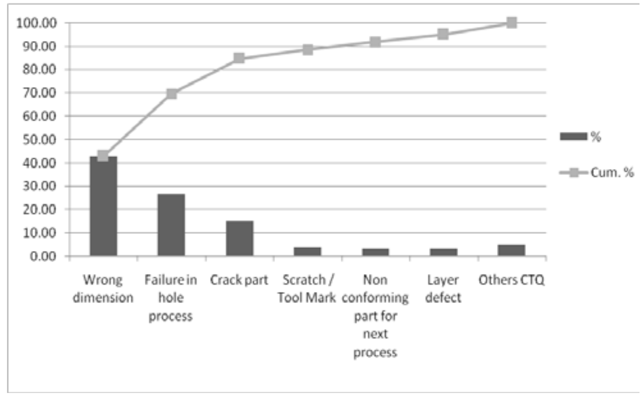

Fig.1 Pareto Diagram Of Critical To Quality

c. Knowing the sequence of potential CTQ

The most dominant type of defects that occur in the amount of 80 % are dimension error, the error of making holes, and cracked part as shown in Figure 1.

C. Analysis Phase

After knowing the dominant defect type, then the causes of defect are being analyzed using fishbone diagrams. The result are:

a. Method

- Process sheet error made part does not fit with expected.
- The error of numerical control (NC) programming process sheet so that the location of the hole is not as expected.
- The raw material that previously stored in the cold storage is not subsequently being processed and in the stretching process also occurs over pulling frequently part that caused the cracked part.

b. Material

- Some raw materials are not being inspected well so it causes a difficulty in cutting process.
- The raw material has a higher thickness and hardness levels than other so it is difficult to be processed.
- The raw materials is thicker than the other so it is quite difficult to be proceed. In the manufacturing process, a scratch raw materials frequently presence and lead to a cracked part.

c. Man

- A poor trained operators who work primarily in the hand forming station make the risk of dimensional error is high.
- Operator error in drilling process, the position does not correspond to those in the process sheet. The holes are too big can also cause parts not installed properly.
- Less precision of work in raw materials press station and entering the program in the NC machine.

d. Machine

- Unsharpened blade of CNC Cutting machines causes the cut parts are not as expected. Old machine so that the machine becomes less precision also lead to errors in cutting the size of the part.
- Unsharpened drill in milling and drilling work station is no longer causing errors in the perforation.

- The existence of some old machines that causes processing raw materials error and uneven press tool resulting a cracked part.

e. Environment

- At forming work stations, hand tools that are used still scattered on the desk so disturbing other operators in doing their tasks.
- Manual perforation in hand forming station is done in untidy work environment.
- Lack accessibility of warehouse.

D. Improve Phase

Improve phase is done after knowing the cause of the product defect using FMEA analysis problems. The result shows that repairing old machines should be done first with RPN value reaches 200 as shown in Table IV.

TABLE IV
FMEA MANUFACTURING PROCESS OF PART EC MK-II

No.	CTQ	Severity	Causes of Failures	Occurrence	Control Recommendation	Detection	RPN
1	Wrong Dimension	8	work stations not meet 5s	3	creating a team to organize the work station according 5s	3	72
			less sharp cutting machines	4	sharpening the blade	3	96
			old machine	5	repair periodically and perform other preventive measures	5	200
			an error process sheet	3	more stringent inspections on the process sheet	2	48
			raw materials less than standard	3	more rigorous inspection on raw materials	3	72
			high difficulty in hand forming	6	training hand forming workers	4	192
2	Failure in Hole Process	7	operators error in hole placement	6	operator training in milling and drilling	2	84
			unsharpened drill	5	sharpening drill after used	3	105
			error in nc programming	3	operators more careful in entering the program	2	42
3	Cracked Part	6	storage areas are not arranged in a neat and stacked products	5	structuring the warehouse	4	120
			over pulling on the stretch	4	training operators in the process of stretching	3	72
			raw materials that stored in cold storage are not subsequently being processed	4	raw materials are subsequently processed	2	48
			there are scratch	5	more stringent inspections on raw materials	3	90
			uneven press tool	6	tool checking before production	4	144

On the other hand, the process of hand forming with RPN value of 192, uneven press tool with RPN value of 144, untidy warehouse with RPN value of 120 and unsharpened drill with RPN value of 105 needs to be improve. While the others causes of defects are only need to be monitored by the company.

E. Control Phase

Control is the final operational phase of the DMAIC cycle, a control mechanisms will be made based on six sigma implementation. It is expected that after application of this method the product defect rate can be decreased. At this stage, policies and procedures of quality improvement are documented to be used as a standard operational procedures in order to prevent similar problems or old practices reoccur and then six sigma team responsibilities of are being transferred to the person in charge in each manufacturing process.

V. CONCLUSION

Based on the research that has been done, it is concluded that the company's current position is at 4.30 sigma level, which means there is a product 2579.9254 disability in a million chance. The most dominant type of defect is the fault dimension (43.02 %), the error of making a hole (26.58 %) and cracked part (15.09 %). While the priority is to repair an old machine with RPN value of 200, the process of hand forming with RPN value of 192, uneven press tool with RPN value of 144, untidy warehouse with RPN value of 120 and unsharpened drill with RPN value of 105. So, that corrective actions recommendation are regular engine maintenance, arranging work stations according 5S, re - sharpening blades and more stringent inspection in process sheet.

Acknowledgment

Researcher thank to the support of Manufacturing System Laboratory, Industrial Engineering Department, Universitas Islam Indonesia.

References

[1] C. Valmohammadi and M. Beladpas, "A survey on the six sigma implementation in the Iranian service organization, *Technical Journal of Engineering and Applied Sciences*, Vol.3, 2013pp 1095-1099.

[2] J. Susetyo, Winarni, and C. Hartanto, "Six sigma application DMAIC and kaizen as product quality control and improvement", *Journal of Technology*, Vol. 4, 2011, pp 53-61.

[3] A.S. Nooramin, V.R. Ahouei and J. Sayareh, "A systematic framework for implemanting six sigma in the landside of marine container terminals, *Journal of the Persians Gulf*, Vol.3, 2012, pp 55-66.

[4] K.D. Prasad, K.V. Subbaiah, and G. Padmavathi, "application of six sigma methodology in an engineering educational instution", *International Journal of Emerging Sciences*, 2012, pp 210-221.

[5] W.R. Dewi, N.W. Setyanto, and T.C.F. Mada, "Implementation of six sigma to minimize iste in PT Prime Line International", *Journal of Industrial System Engineering and Management*, Vol 1., 2013, pp 47-56.

[6] W. Wahyani, A. Chobir, and D. Rahmanto, "Six sigma implementation Penerapan with DMAIC concept as quality control tools", *Industrial Engineering Journal ITATS* , 2010.

[7] S.B. Paramesh, "Lean six sigma implementation in cable harness manufacturing", *International Journal of Mechanical and Production Engineering*, Vol 1, 2013pp 49-56.

[8] T. Pyzdek and P. Keller, *The Six Sigma Handbook 3rd Edition*, Mc Graw-Hill Professional, 2009.

[9] R.U. Sambhe, "Six sigma practice for quality improvement – a case study of Indian auto ancillary unit", *Journal of Mechanical and Civil Engineering*, Vol. 4, 2012, pp 26-42.

[10] P.S. Peter, N.P. Robert and C.R Roland, *The Six Sigma Way*, Andi Publishing, 2002.

[11] S. Dey, S. Sharma and S. Dutt, "Application of six sigma in electronics industry-a case sudy", *International Journal of Engineering Science and Innovative Technology*, 2013, pp 302-315.

[12] M.D. Burlikowska, "Application of FMEA method in enterprise focused on quality", *Journal of Achievements in Materials and Manufacturing Engineering*, Vol. 45, 2011, pp 89-102.

[13] R.J. Mikulak, R. McDermott and M. Beauregard, *The Basic of FMEA 2nd Edition*, Productivity Press, 2008.

[14] M. Namdari, Sh. Rafiee and A. Jafari, "Using FMEA method to optimize fuel consumption in Tillage by Moldboard Plow, *International Journal of Applied Engineering Research*, Vol.1, 2011, pp 734-742.

[15] H.S. Rukmi, Rispianda and A. Sulistyobudhi, "filling lithos production line improvement in PT Pertamina LOBP PUG using failure mode and effect analysis method", *Teknoin Proceeding*, Vol 1, 2012, pp B117-B124.