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Application of the DMAIC Method in Improving the Quality of Electric Power Steering Housing Products

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ABSTRACT

PT. ABC is a manufacturing company that produces Electric Power Steering (EPS) Housing components. For the past three months, there have been problems with the EPS production process. The problem is related to the finding of defective products which on average reached 3.9% of the total production, and has exceeded the maximum limit allowed by the company, which is 2%. This study aims to overcome these problems by making improvements using the DMAIC method in the hope of finding the root cause of the emergence of defects and making improvements to reduce the number of defects that occur. The improvement results have shown that the number of defects reduced from 3086 pcs to 1948 pcs per 22 working days or decreased by 0.54% with an increase in sigma level from 3.95 to 4.01 sigma. In this case, DMAIC implementation is effectively reduced defects by 1.5% based on the sigma level. To achieve a 6-sigma level equivalent to a world-class industry, companies must make continuous improvements by fixing other root causes.

INTRODUCTION

One way to compete in the industrial competition in this modern era is to continue improving product quality and rectify any deficiencies that exist in the product. It is very important to continuously improve and rectify any deficiencies that exist in the product. It is very important to continuously improve the manufacturing process. Companies that don't realize this idea will slowly disappear from the competition (Mitra, 2016).

PT. ABC is a company that produces car parts, namely Electric Power Steering (EPS) Housing. The increasing demand from customers requires companies to increase productivity, one way is to reduce the percentage of defects. During 2018, the EPS Housing line output in June was 96.4%, July was 95.5%, and August was 96.5%. However, the minimum allowed productivity percentage is 98%, or the maximum level of defects is 2% which means the current productivity is under the company's target. Therefore, companies need to develop comprehensive improvement efforts by applying systematic and proven methods that are also in accordance with the company's capabilities.

There are many process improvement methodologies available, one of which is quite popular in modern industry is the DMAIC method. DMAIC is a workflow to determine what you want (Define), then proceed with knowing the current condition, for example, the number of defects (Measure), next is to (Analyze) the significance of the problem and trace the source of the problem. After the source of the problem is identified, then proceed with finding ways to improve processes and statistically prove that improvements have been successful (Improve) and finally preparing procedure to maintain the improvement (Control) (Carroll, 2013; Shankar, 2009). DMAIC is a systematic method in the scope of six-sigma that can improve the production process. The focus of improvement is on reducing the variation in the production process and reducing the number of defects.

The DMAIC method has been successfully applied in various cases, including in the telecommunication industry (Abhilash & Thakkar, 2019) for reducing rejection rate in manufacturing of the doors in telecommunication cabinet, the automotive manufacturing industry to redesign tools to improve the welding process (Imtihan & Revino, 2019), engine boss drive face repair (Fithri & Yeni, 2016), muffler quality improvement for Colt Diesel FE 120 PS (Dharmawan & Ekawati, 2016), improving valve hole location in alloy wheel (Rijanto, 2014), reducing defective product in weaving department in the textile industry (Fithri, 2019), roof tile production process improvement (Dewi & Ummah, 2019), improving quality of apparel product industry (Tjandra et al., 2018), and (Subhan, 2018). DMAIC has also been successfully applied in government service offices by combining the lean office concept (Sukma et al., 2018), the personal care and home care industry (Nelfiyanti et al., 2018), the improvement of the concrete iron production process (Windarti, 2014), the weapons industry (Pakki et al., 2014), improving drilling ultra-shallow horizontal well (Wahyudi & Yudoko, 2019), improving the production quality of sandwich wall plate and roof panel (Usman, 2019) and also in bottling production (Kartini, 2019).

This study aims to apply the DMAIC method to improve the quality of the EPS Housing shown in Figure 1 and Figure 2 by reducing defects until they reach the level of defects that are still allowed by the company. The EPS Housing part is one of the components that is attached as well as a holder / housing for the motor / dynamo on the Electrical Power Steering component as a whole. The motor itself is a component that serves to help ease the rotation of the steering wheel on the vehicle. This motor will help turn the steering gear so that the steering system becomes lighter.

Figure 1. EPS housing

Figure 2. EPS housing part

RESEARCH METHOD

This study uses production data from June, July, and August 2018 on the number of production defects. The DMAIC method is utilized to improve product quality and reduce defects hence it will increase productivity. The DMAIC method (Shankar, 2009) has five stages as follows.

Define

Define is the initial stage where the activities consist of defining the project, determining problems, objectives, and describing a SIPOC (supplier – input – process – output – customer) diagram. The SIPOC diagram is a map used to define project boundaries by identifying the process being studied. In this phase, identifying CTQ (Critical-to-quality) may be started. CTQs are the things that customers need and expect to get from services and products company provided (Carroll, 2013). Additionally, SIPOC could be developed to more detail through a process flow chart.

Measure

The purpose of this stage is to evaluate and determine the present process state. The activities include identifying key process input and output variables, defining the critical to quality (CTQ) through the Pareto chart, and measuring the stability and capability of the process by developing a p-chart and process capability (Shankar, 2009). The calculation of process capability is carried out by converting the sigma level into the process capability index then performing the calculation interpolation to get the closest sigma value. Table 1 shows the sigma level conversions.

Furthermore, calculating DPMO is also needed to determine the current quality of the product and to know what sigma level the process has reached. The steps that must be taken are calculating DPU (Defect per Unit), DPO (Defect per Opportunity), DPMO (Defect per Million Opportunity) as shown in Equation (1)-(3).

- Calculating DPU (Defect per Unit).

$$DPU = \frac{\text{Total Defect Amount}}{\text{Total Production Amount}} \tag{1}$$

- Calculating the DPO (Defect per Opportunity).

$$DPO = \frac{DPU}{CTQ} \tag{2}$$

- Calculation of DPMO (Defect per Million Opportunity).

$$DPMO = DPO\ x\ 1000000 \tag{3}$$

- Convert DPMO results to sigma values according to the Sigma Table 1.

Table 1. Sigma level conversion

DPMO	**Cpk**	**Σ level**
66.803	1.00	3
6.210	1.33	4
233	1.67	5
3.4	2.00	6

Analyze

The purpose of this phase is to develop a root causes analysis (RCA) to the situation found in the Measure phase. According to Gasperz (2002), Heuvel et al. (2008), and (Barsalou, 2015), for example, a fishbone diagram, would be very helpful in finding the root of the problem. Besides, analysis through Failure Mode Effect Analysis (FMEA) will be used to identify risk priority number (RPN). The higher RPN number indicates that the step in the process has a higher risk and should be prioritized.

Improve

The next phase after applying RCA and also FMEA, that shows identified quality problems, is preparing a corrective action plan. The corrective action plan by using the 5W+1H method will be used to propose improvements (Gasperz, 2002).

Control

Control is the last phase in DMAIC. The activity is to make sure that the process stays in control after the solution has been implemented. Another objective is to quickly detect the out-of-control situation and determine the associated special causes so that actions can be taken to correct the problem before nonconformances are produced (Carroll, 2013). SOP would be developed to maintain the improvements.

RESULTS AND DISCUSSION

Define

This project has proceeded in the EPS housing line. The project need to be done because defects found in the EPS housing have increased to a significant value above the acceptable level. The SIPOC diagram Fig. 3 and flow chart Fig. 4 explain the EPS Housing line production process. The process starts from blank casting EPS housing, then through some machining process, washing, inspection, and packaging a final product of EPS Housing will be completed.

Another task in this stage is identifying CTQ. It has been found there are five defect type which consists of M5 over-thread, hard spot, deform, chipping, and blowhole. These five defect types are summarized in the Pareto diagram Fig. 5. Based on the Pareto diagram shown, it can be seen that the M5 over-thread defect has the largest percentage.

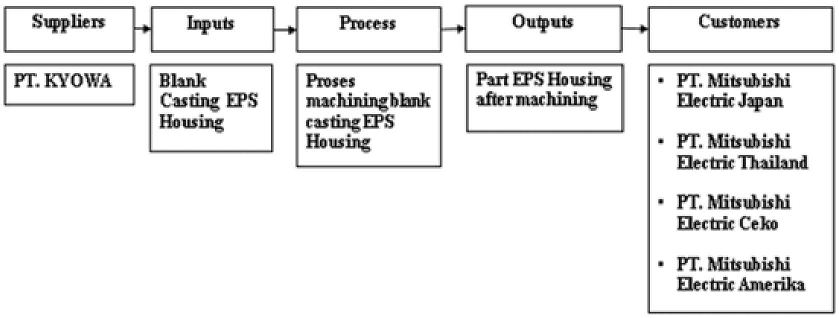

Figure 3. SIPOC diagram

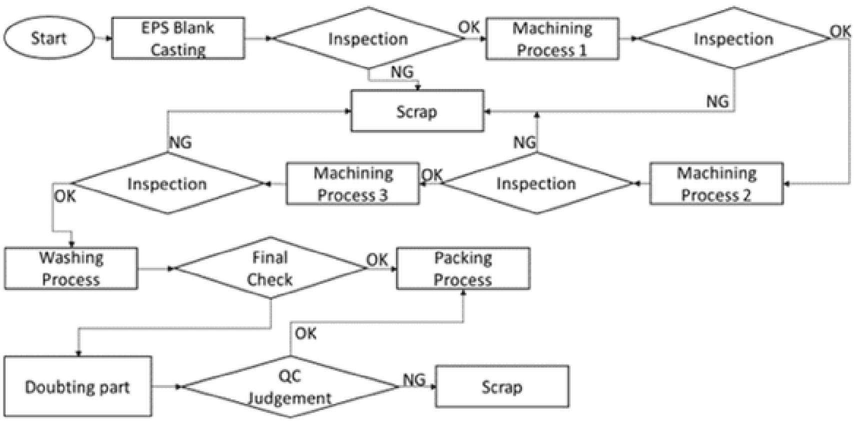

Figure 4. Process flow of the EPS housing line production process

Measure

In the Measure stage, CTQ will be defined based on the Pareto diagram that has been build in the previous stage, Fig 5. The company decided to focus on a major defect first which is the M5 over-thread defect that influences the product quality due to current company capability. Then CTQ will refer to this defect.

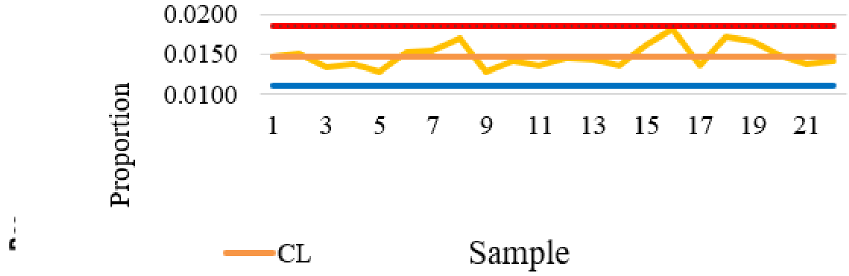

Figure 6. P-chart of M5 over thread defect products

	Thread Defect	t Defect	Defect	Defect	e Defect
Qty	7205	4760	4352	3563	3272
Percentage	31.10%	21.00%	18.90%	14.90%	14.10%
Cum Percentage	31.10%	52.10%	71.00%	85.90%	100.0%

Figure 5. Pareto diagram of defect

DPU, DPO, and DPMO were calculated by using equation (1)-(3). Then p-chart was developed to examine current process stability. Conversion of DPMO to sigma level also important to easily identify the current condition. The process capability will also be calculated.

- Calculation of Defects per Unit (DPU)

$$DPU = \frac{23152}{593790} = 0{,}0389902154$$

- Calculation of Defect per Opportunity (DPO),

$$DPO = \frac{0{,}0389902154}{5} = 0{,}0077980431$$

- Calculation of DPMO (Defects per Million Opportunity)

$$DPMO = 0{,}0077980431 \ \times 1.000.000 = 7798{,}0$$

- Converting DPMO to sigma level with the sigma table, the result is 3.92 sigma.

Based on these results, the current situation is far from a 6-sigma level buat higher than 3-sigma. Next is measuring Process Stability and Capability.

- Calculating the value *CL* (P)

$$CL = \bar{p} = \frac{3086}{208582} = 0{,}0148$$

- Calculating the value *UCL*

$$UCL = 0{,}0148 + 3\sqrt{\frac{0{,}0148(1 - 0{,}0148)}{9481}} = 0{,}0185$$

- Calculating the value *LCL*

$$LCL = 0{,}0148 - 3\sqrt{\frac{0{,}0148(1 - 0{,}0148)}{9481}} = 0{,}0111$$

It can be seen in Fig. 6 that all data are already within control limits, so there is no need to revise the p-chart. Next, calculate the process capability presented in the calculation below.

Calculation of process capability, namely:

Cp = 1 - *p* bar
= 1 – 0,015
= 0.0985

The calculation of the process capability index (*Cpk*) is obtained from the results of the interpolation of Table 1 sigma level conversion regarding the sigma value which is at the 3.95 sigma level.

$$\frac{3.95\text{-}3}{4\text{-}3} = \frac{x\text{-}1.0}{0.833\text{-}1.0}$$

$$X = 1.32$$

$$Cpk = X = 1.32 < 1.5,$$

Base on the rule of thumb, the current *Cpk* is too small because of less than 1.5. Thus, the improvements must be made to increase the value of *Cpk*.

Analyze

Causal diagrams are made based on brainstorming with line leaders, sub-leaders, and fellow operators. As a summary of the discussion, the fishbone analysis is shown in Fig. 7. The diagram shows that four-factor (man, machine, material, and method) contribute to the defective. Then actions need to be taken to overcome every root of cause.

Man factor, the dimensions of the EPS Housing product are varying due to frequent program input errors or dimensional input errors in the machine program. This happens due to the operator's lack of understanding the machine operation. Method factor, the rotation of the M5 tap tool and 4.6 drill is unstable or the tool shakes during the cutting process. This is because the installation of the tap and drill tool is not centered. After being traced, the main cause is when changing the tool the operator only centers the tool based on feeling. Material factor, there are differences in the dimensions of the blanks sent by the supplier. This happens because there is a new cavity sent by the supplier.

Machine factor, the cutting process is hampered by a large number of chips. When the cutting process takes place there are a lot of chips in the product and the coolant that should be white turns gray. This is because the coolant emitted from the nozzle has mixed with the chip. After exploring the main cause, the filter in the coolant tank is loose. The cutting process sounds loud and rough, this is because the tool wears out prematurely. Tools that wear out quickly are due to the cooling during the cutting process is not optimal (air coolant does not lead to the tool). After being traced, the main cause is the distance between the coolant nozzle and the tool is too far, so the coolant water does not radiate right into the tool. Part vibrates during the cutting process, this happens because the clamp pressure on the jig is not strong enough to hold the part during the cutting process. After being traced, the main cause is a clamp that is too small.

After reviewing the fishbone analysis then continue with the FMEA analysis as shown inTable 2. the FMEA analysis shows the most prioritized problem that has the largest RPN score to the least priority problem that has the smallest RPN. From this FMEA table, it is shown that there are three most potential failures which have an RPN score of more than 200. They are too small clamp, bad filter, and unavailable tools for changing.

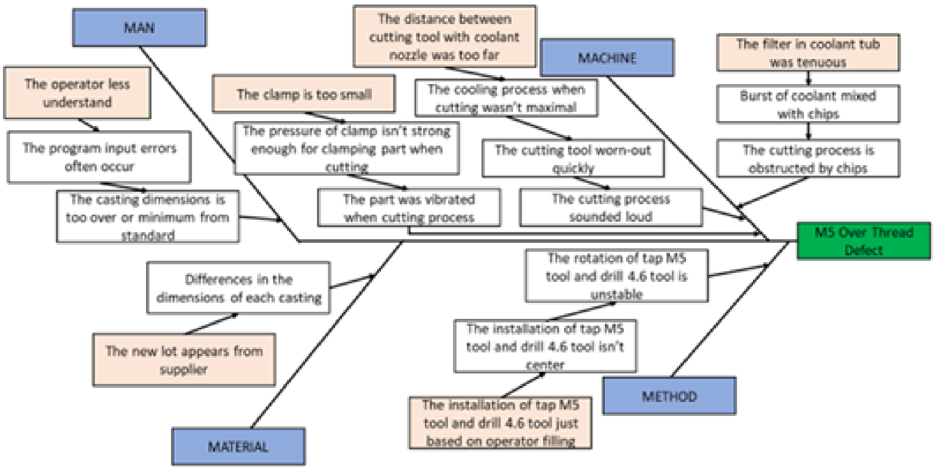

Figure 7. Cause and effect diagram

Table 2. FMEA results

Expected product	Potential failure mode	Cause of failure	Potential effect of failure	Severity	Occurrence	Detection	RPN
High-quality EPS Housing products (low defect rate)	*The clamp is too small*	There was no analysis from the engineering department regarding the M5 over thread regarding the vibration during processing	Ulir M5 *Over*	7	7	7	343
	The filter in the coolant tube is tenuous	The filter has been used for too long	Ulir M5 *Over*	6	7	7	294
	Center tool installation when changing tools is only done based on operator feeling	No tools are provided for the center tool when changing the tool	Ulir M5 *Over*	5	7	7	245
	The distance between the coolant nozzle and the tool is too far	*Short coolant nozzle*	Ulir M5 *Over*	4	7	7	196
	Lack of operator understanding	Refresh training is rare	Ulir M5 *Over*	3	7	7	141
	There is a new cavity from the supplier	The need to replace the use of mold from the supplier	Ulir M5 *Over*	2	7	7	98

Improve

Based on the FMEA analysis, it can be seen the importance of a failure mode. The higher the value, the more priority it is to be repaired immediately. In this case, the priority order of failure mode is obtained namely, the clamp is too small, the filter in the coolant tank is loose, the center tool installation when replacing the tool is only done based on the operator's feelings, the distance between the coolant and tool nozzles is too far, the operator lacks understanding and the presence of a new cavity from the supplier. From the sequence of problems, successive improvements will be made using the 5W + 1H method. Based on root cause analysis and FMEA. Some actions would be planned and executed. Repair begins by making Table 5W + 1H as shown in Table 3. After preparing the improvement proposal, repairs are carried out referring to the date and each PIC that has been decided. The repair process has an impact on all four factors. Figure 8 – 13 the situation of before and after improvement based on Table 3.

Figure 8. *Clamp* before and after

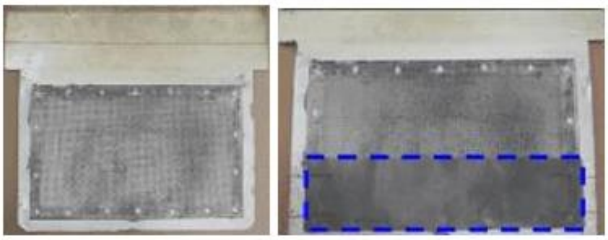

Figure 9. Filter before and after

Figure 10. Round out and check sheet round out

Figure 11. Nozzle coolant before and after

Figure 12. Refreshment training

Figure 13. Measuring tools and measurements made in incoming

Control

At this stage, the standardization of the EPS Housing production process is carried out based on the improvements that have been made. The improved standard operating procedure:

1. *Revising IK (Work Instruction) on TC machines*. IK-PRD-PPP-015-03-032 on TC 1 machines and IK-PRD-PPP-015-03-033 on TC machines 2. By adding center round- machines. Shows in Fig. 14.

2. *Revise the incoming IK (Work Instruction).* IK-PRD-PPP-015-03-060, by adding a dimension checking point for each blank pallet from the supplier. Shows in Fig. 15.

Table 3. 5W + 1H Results

What	Factor	Why	How	When	Where	Who
Ulir M5 *Over*	*Machine*	*The clamp is too small*	The replacement of the clamp is wider	25/09/2018	*Line EPS Housing*	*Engineering*
	Machine	The filter in the coolant tube is tenuous	Add layers to the filter	26/09/2018		*Engineering*
	Method	Center tool installation when changing tools is only done based on operator feeling	Tool replacement is performed checking the center round out ± 0.03	25/09/2018		*Leader*
	Machine	The distance between the coolant nozzle and the tool is too far	Attach a nozzle and point to the tool	27/09/2018		*Engineering*
	Man	Lack of operator understanding	Hold refresh training	26/09/2018		*Leader*
	Material	There is a new cavity from the supplier	Add checking in the form of measurement by incoming	26/09/2018		*Quality*

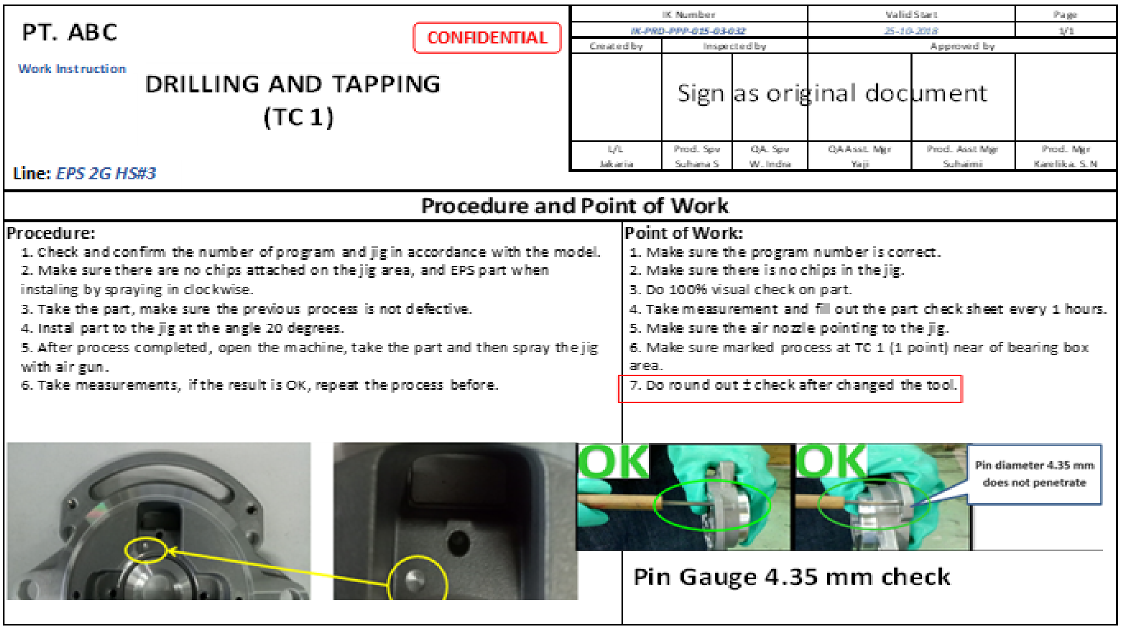

Figure 14. SOP: IK-PRD-PPP-015-03-032

After the repair is completely done, the results are compared to previous data (before improvement). The results show improvement as follows: (1) As shown in Table 4, the defect reduces by 0.54%. (2) Table 5 also shows a comparison of calculations, DPU, DPO, PMO, and Sigma level. It shows that the sigma level increase from 3.95 to 4.01. (3) Process capability after improvement can be computed by the following:

$$Cp = 1 – 0{,}00934 = 0{,}99066$$

Furthermore, the calculation of the process capability index (*Cpk*) is obtained from the interpolation results in the sigma level table regarding the sigma value which is at the 4.01 sigma level.

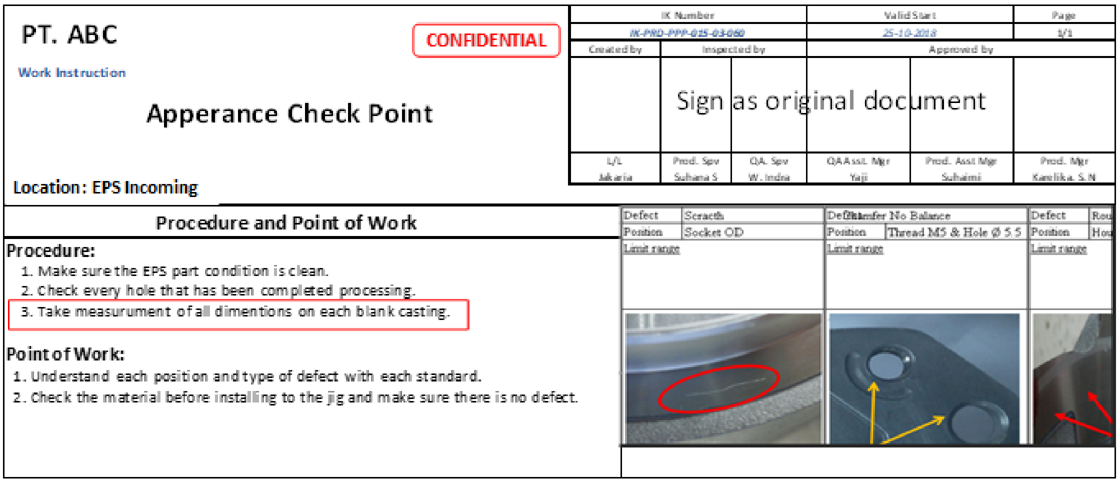

Figure 15. SOP: IK-PRD-PPP-015-03-060

$$\frac{4.01-3}{5-3} = \frac{x-1.0}{1.67-1.0}$$

$$\frac{1.01}{2} = \frac{x-1.0}{0.67}$$

$$Cpk = x = (1{,}01 \text{ x } 0.67) + 1.0 = 1{,}68$$

(4). The results of the t-test as shown in Table 6 tell us that by looking at column t = 17.552, then compared with the T value in the T-test table with a Df-1 value and a 95% confidence level. The value in the table is 1,725, which means 17,552> 1,725, so the improvement is significant. Besides, it can also be seen that the mean = 52,182 is positive, meaning that there is a tendency for a decrease in the number of defective products.

The results of this study show that based on sigma level the improvement is still small (1.5%) compare to 13% in (Girmanová et al., 2017), 29.1% in (Yadav & Sukhwani, 2016), 6% in (Usman, 2019), 37.6% in (Imtihan & Revino, 2019), but almost similar to (Dewi & Ummah, 2019) which is only 2%. However, based on this comparison, how far the improvement depends on the effort of the organization and the capability of its resources.

Table 4. Comparison of the number of threads M5 over.

Description	Observation Time	Number of Prod	Num of Defects	Percentage (%)
Before repair	22 Hari	208582	3086	1,47%
After repair	22 Hari	208582	1948	0,93%

Table 5. Comparison Six-sigma level

Description	Observation Time	Number of Prod	Num of Defects	DPU	DPO	DPMO	Level Sigma
Before repair	22 Day	208582	7430	0,035621482	0,007124	7124,3	3,95
After repair	22 Day	208582	6292	0,030165594	0,006033	6033,1	4,01

Table 6. t-Test.

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Differences Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Before Improvement After Improvement	52.182	13.944	2.973	45.999	58.364	17.552	21	0.000

CONCLUSION

Based on improvements made to the EPS Housing line production process, the number of thread defective M5 over products decreased from 3086 pcs to 1948 pcs per 22 days or a 36.88% reduction. The sigma level increased from 3.95 to 4.01. Then the sigma capability value increased from 1.32 to 1.68. Finally, the results of the t-test, the value of the t calculation results is greater than the value in the t-table, which means that the improvements made have been significant. For further research, a deeper analysis of the critical quality characteristics (CTQ) is needed so that the company can reach the highest sigma level, which is 6 sigma or equivalent to the world-class industry average.

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