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Product Quality Improvement in the Assembly Process of the 5.56 mm Ammunitions (Variant MU5-TJ) at PT.X Using the Six Sigma Method

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***Abstract*—Quality is one of the essential indicators for companies to exist amid strong competition. The 5.56 mm ammunition, especially variant MU5-TJ, is the primary commodity of PT. X. The process in ammunition production includes making cartridge cases, making bullets, making primers, and assembling ammunitions. The highest cost of defective products is led by defects in the preparation of the 5.56 mm ammunition, reaching 32.3%. In the process of preparing this kind of ammunition, most of the defects came from variant MU5-TJ, which accounted for 64%. This study aimed to improve the quality of the MU5-TJ ammunition preparation process by increasing its level of sigma. The method used in this study was the Six Sigma method through the Define, Measure, Analyze, Improve, and Control (DMAIC) phases. The quality identification results showed that the weighing and gauging process was the most contributing factor to the defects in the preparation of MU5-TJ ammunitions. The main defect found was the improper weight of the munitions due to the underfilling of propellant powder. The results of the chi-square test showed that the defect-causing factors with significant effects included the presence of sensor filling, varnish composition, tool material, and inspection methods. To reduce the defects, further improvements were made by installing the filling sensor on the ammunition assembly machine, changing the composition of the cartridge case mouth varnish, the use of tools made of hartmetall, and auto-control by the operator every 15 minutes. The results of the implementation of the improvements made resulted in an increase in sigma level from 3.69 to 3.79.**

***Keywords*—Chi Square, Defect, Quality, Sigma Level, Weighing and Gauging.**

I. INTRODUCTION

IN global business competition, quality becomes an essential factor leading a product to be valuable, following its production objectives. It also reflects a company's success, in the eyes of consumers, in carrying out its production business. In the efforts of overcoming quality-related problems, PT.X, as the defense industry in Indonesia, always needs to try to carry out intensive quality control on its products' basic components, production processes, and final products. Quality control is an activity to ascertain whether or not policies in terms of quality (standards) can be reflected in the final results [1]. The products, in this stage, are inspected according to the applicable standard specifications, and all irregularities are recorded and analyzed, the results of which will be used as feedback for implementers in carrying out corrective actions in the future. Small-caliber ammunition is the primary commodity of PT. X, consisting of 5.56 mm; 7.62 mm; 9 mm; 12.7 mm; and 9.652 mm ammunitions. The process of ammunition production includes making cartridge cases, making bullets, making primers, and assembling munitions. The biggest failure occurs in the process of ammunition assembling, especially in the 5.56 mm one, which has the highest demand every year. Most of the losses due to product failures come from 5.56 mm ammunition products, which is about 32.3%. Meanwhile, of the 15 variants of 5.56 mm ammunitions, most of the value of losses due to product failure as much as 64% comes from the assembly of variant MU5-TJ. The ammunition components are shown in Figure 1.

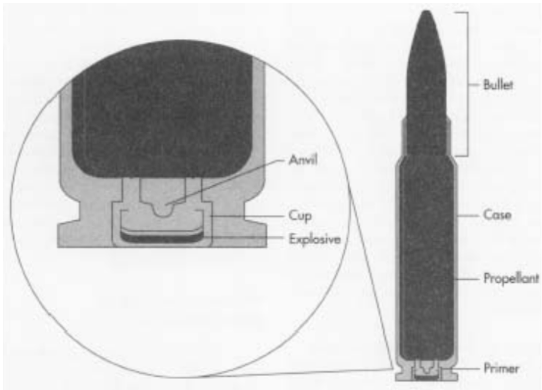


Figure 1. Ammunition components.

Six Sigma is recognized as a problem-solving method that uses statistical tools and quality to improve basic processes. It is now widely accepted as a high-performance strategy to eliminate defects from the company's quality system. It is defined as a set of statistical tools adopted in quality management to build a framework for process improvement (Goh and Xie, 2004; McAdam and Evans, 2004). The Six Sigma methodology is used to make efforts to improve the process continuously (Continuous Improvement). In this recent study, it consisted of Define, Measure, Analyze Improve, and Control (DMAIC) [2]. In its application, defect or failure targeted was controlled by 3.4 DPMO (Defects per Million Opportunities), which means that in 1 million units produced, there are only 3.4 defective products. This study aimed to identify the types of product defects in the production process, identify parts of the process that affect product defects, provide potential solutions to improve quality to minimize product defects in the MU5-TJ assembly process, and determine the sigma level of the MU5-TJ assembly process before and after improvement [3].

The ammunition assembly process consists of inserting, varnishing, and crimping the primer, charging the case with propellant powder and assembling process, weighing and gauging process, visual process, and tip varnishing process.

Table 1.
Visual defects of MU5-TJ based on NATO standards (MIL-STD-636, 1958)

Nr	Defect and Method of Inspection	Critical	Major	Minor	Major or Minor
Visual Defect					
	Cartridge				
1	Discolored, dirty, Oily, Smeared			X	
2	Corrode or stained, if etched cas		X		
3	Mixed ammunition types	X			
	Case				
4	Round Head		X		
5	Dent				X
6	Split Case				
	in K, L, or M location	X			
	in I, S, or J location		X		
7	Perforated case	X			
8	Draw scratch				X
9	Scratch			X	
10	Beveled underside of head		X		
11	Case mouth not crimped in cannelure		X		
12	Scaly metal				X
13	No chamfer on head (rim)		X		
14	Fold			X	
15	Wrinkle			X	
16	Buckle			X	
17	Bulge			X	
18	Illegible or missing head stamp			X	
19	Defective head			X	
21	No visible evidence of mouth annual		X		
	Bullet				
22	Dent			X	
23	Scratch			X	
24	Split bullet jacket		X		
25	Loose bullet		X		
26	Missing cannelure		X		
27	Scaly metal (bullet)				X
28	Upset (crooked) point			X	
29	Exposed steel (clad jacket)			X	
30	Blunt point			X	
31	Defective cannelure			X	
	Primer				
32	No primer	X			
33	Cocked primer	X			
34	Inverted primer	X			
35	Loose primer		X		
36	Nicked or dented primer			X	
37	No waterproofing material (primer pocket joint)			X	
38	Defective crimp			X	

MU5-TJ specifications refer to NATO Standards (NATO 5.56x45 mm). Visual inspection standards for small-caliber ammunition refer to MIL-STD-636, according to Table 1 [4].

II. METHOD

Data was obtained based on monthly reports from January to August 2019, followed by the implementation of improvements from September 2019 to January 2020. Phases in this study include:

A. Define

The stages in the define phase included identifying quality-related problems, identifying the quality expected by consumers (based on NATO Standards), determining quality targets to be achieved (increased sigma level), defining processes to be improved (using Pareto chart tools), and defining valid and reliable measurement system (MIL-STD-105E).

B. Measure

The stages in the measure phase included determining the current sigma level (before improvement) and measuring process capability and making a control chart before improvement. Data normality test was required before statistical calculations. The number of samples taken followed MIL-STD-105E AQL Sampling Special Inspection Level S-3 Single Sampling Plans for Normal Inspections with

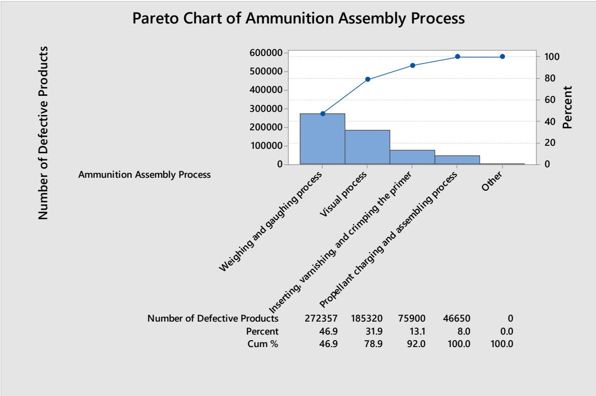


Figure 2. Pareto chart of the ammunition assembly process.

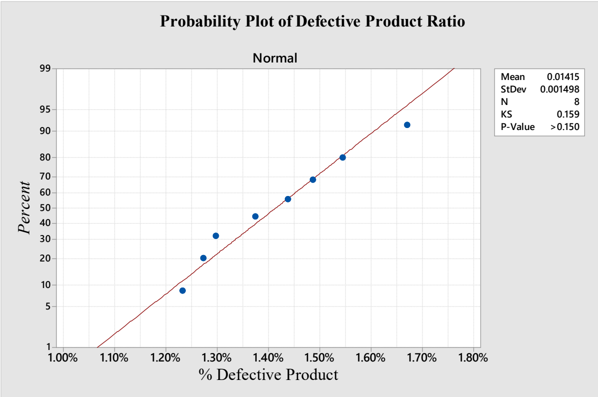


Figure 3. Normality test of defective product ratio.

acceptance criteria following AQL 1.5. This means that if one lot of MU5-TJ contains 201,600 cartridges, then the number of samples representing the population, based on these standards, is as much as 50 cartridges.

C. *Analyze*

The stages in the analyze phase included analyzing the types and causes of defects that have a significant influence on quality-related problems by grouping the types of defects as well as interviewing and brainstorming with six respondents consisting of field managers and field expert staff, making fishbone diagrams to find out the root causes of the problems, and determining the critical factors of the quality-related issues in the MU5-TJ ammunition assembly line.

D. *Improve*

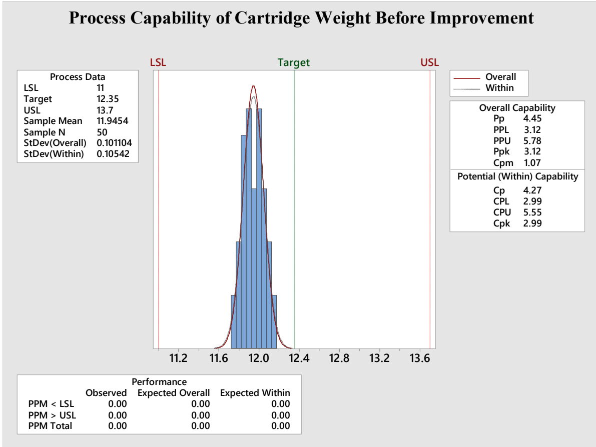
The stages in the improve phase consisted of testing the critical factors that had been determined in the Analyze phase by using a chi-square statistical test, implementing the improvement results based on critical factors that had been proven to have a significant effect on quality-related problems, and comparing the process capability and control chart before and after improvement.

E. *Control*

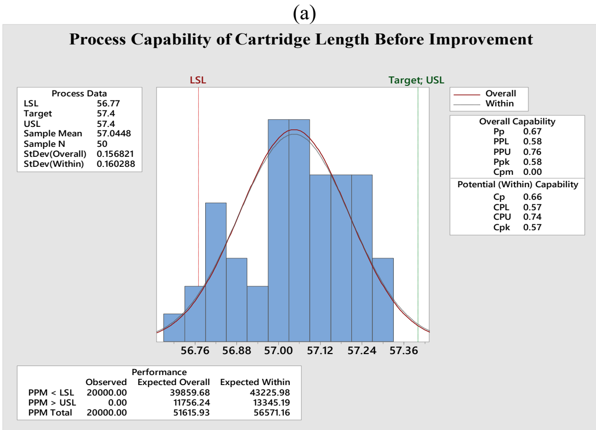
In the control phase, the sigma level is determined after implementing the improvement results.

III. RESULT AND DISCUSSION

The results of this study, by stage of DMAIC, are as



(a)



(b)

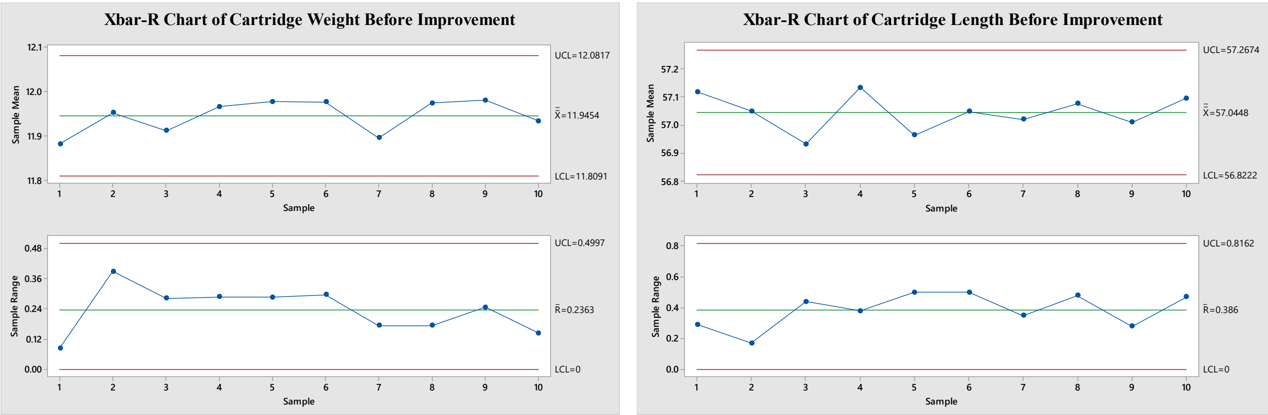
Figures 4. (a) Process capability of cartridge weight before improvement; (b) Process capability of cartridge length before improvement.

follows:

A. *Define*

In defining a problem, this research identified quality-related problems, identified the quality expected by consumers, determined the quality target to be achieved, outlined the process to be improved, and defined a valid and reliable measurement system. The quality-related problems faced were the high number of defects in the MU5-TJ ammunition assembly line, as explained in the previous sub-chapter. Furthermore, the quality expected by consumers was based on the Product Specification Standards, namely NATO Standards (5.56x45 mm). The quality target to be achieved in this research was to increase the sigma level in the MU5-TJ ammunition assembly process. The process that would be improved was that having a significant contribution to the defects in the MU5-TJ ammunition assembly line. The measurement system was carried out by following the MIL-STD-105E AQL Sampling Special Inspection Levels S-3 Single Sampling Plans for Normal Inspections. Based on data on defective products in each ammunition assembly process from January to August 2019, the Pareto chart was then drawn, as shown in Figure 2.

Based on the Figure 2, it appears that most of the defects occurred in the weighing and gauging process, followed by those in the visual process. The number of defects got a proportion of 46.9% of the total defects in the weighing and gauging process and a proportion of 78.9% of the total defects



(a) (b)

Figures 5. (a) Control chart of cartridge weight before improvement; (b) Control chart of cartridge length before improvement.

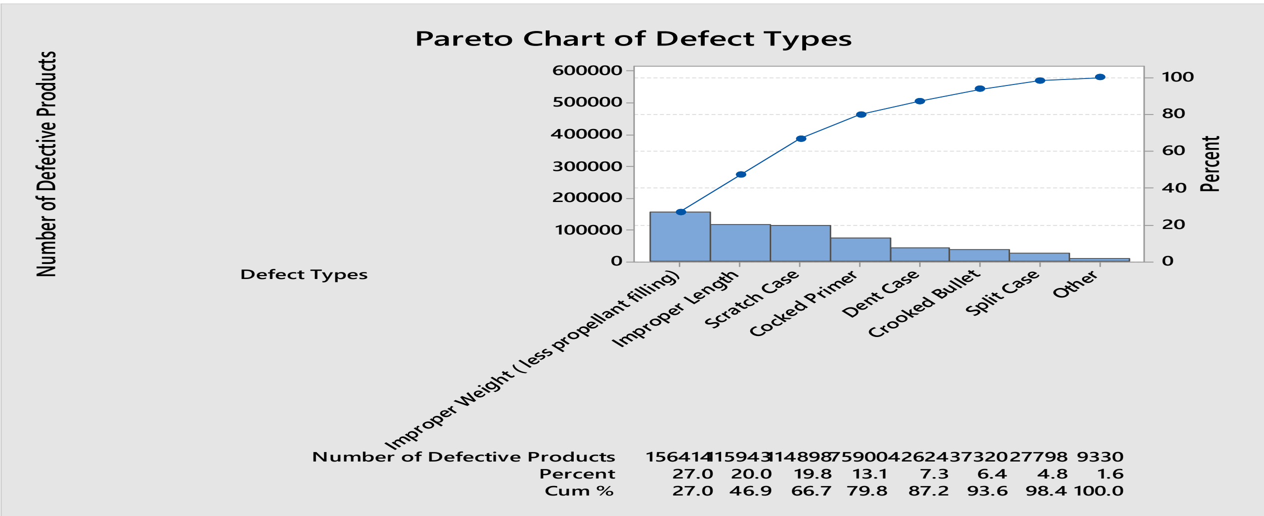


Figure 6. Pareto chart of defect types.

in the two processes, namely the weighing and gauging and visual processes. In the former process, the defects were generally in the form of the improperness of ammunition length and weight. The former improperness means that the ammunition produced could be too long or too short. The latter occurred due to the underfilling of the propellant powder. The latter one should be detected in the previous process, namely in the propellant filling process, since there was a filling sensor that functioned to check the filling of the ammunitions automatically on the machine. Therefore, the processes to be analyzed were charging the case with propellant powder and assembling, weighing and gauging, and visual processes.

B. Measure

In the measure phase, measurements of quality parameters were carried out. The current sigma level on the MU5-TJ ammunition assembly line process and the process capability and control chart on the MU5-TJ ammunition assembly line were measured before any improvement. The determination of the initial sigma level was done based on the defective product ratio data from January to August 2019. In the initial step, a normality test was conducted using Minitab 17 software, and it was found that the data were normally distributed, as shown in Figure 3, with an average defective product ratio of 1.41%.

Because the data had a normal distribution, the next step was to determine the sigma level by using the Standard Normal Distribution Equation, i.e.

$$P(z \geq x) = NORM.S.INV\ (probability) + 1.5\sigma$$

$$z = NORM.S.INV\ (1 - 0.0141) + 1.5\sigma$$

$$\text{z} = 3.6945$$

The results of these calculations generated an initial sigma level of 3.6945. DPMO value for the sigma value with a probability value of 0.0141 was 14,100 product units. It means that the MU5-TJ ammunition assembly process had the opportunity to produce 14,100 units of defective products out of 1,000,000 units of product produced. Furthermore, the results of the measurement of process capability for cartridge weight and cartridge length are shown in Figures 4, and the control charts for cartridge weight and cartridge length are shown in Figures 5.

C. Analyze

In the analyze phase, the first step was to analyze the types and causes of defects that had a significant effect on quality.

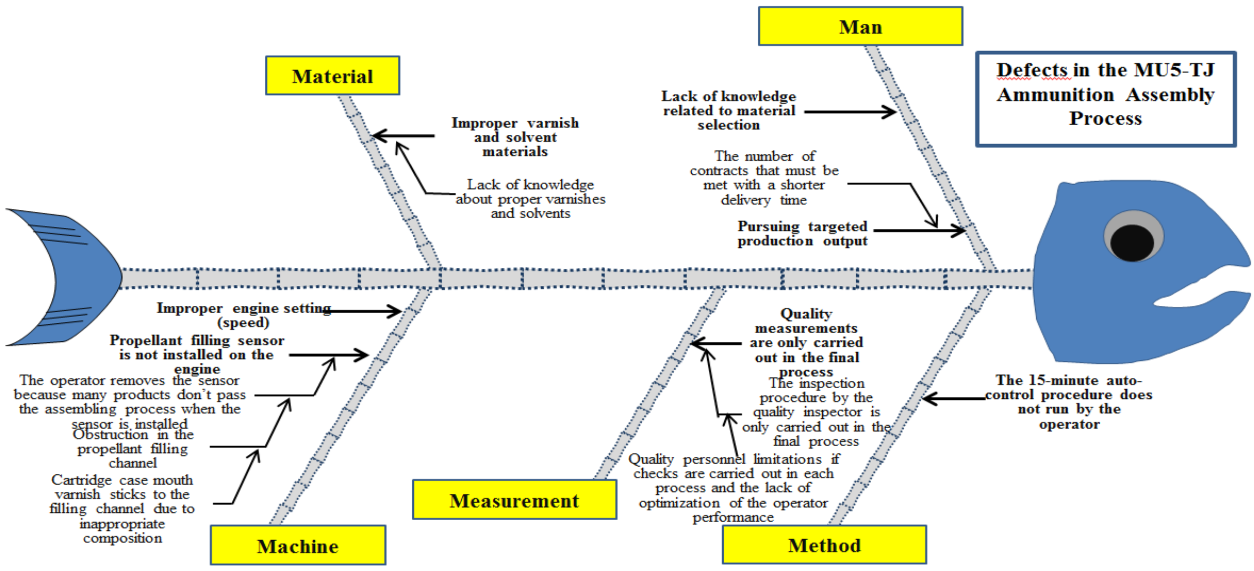


Figure 7. Fishbone diagram.

Table 2.
Results of critical factor 'engine setting' test using chi-square

Engine Setting	F_0		Total	Fh		Chi-Square		Total Chi-Square/P-Value
	Output	Defect		Output	Defect	Output	Defect	
120 rpm	3648	78	3726	3651.96	74.04	.00429	.21	0.449/0.799
95 rpm	2845	54	2899	2841.39	57.61	.00458	.23	
80 rpm	2385	48	2433	2384.65	48.35	.00005	.00	

Table 3.
Results of critical factor 'filling sensor' using chi-square

Sensor	F_0		Total	Fh		Chi-Square		Total Chi-Square/P-Value
	Output	Defect		Output	Defect	Output	Defect	
With sensor	3645	74	3719	3656.99	62.01	.0393	2.32	4.796/0.039
Without sensor	3550	48	3598	3538.01	59.99	.0406	2.40	

Table 4.
Results of the critical factor 'cartridge case mouth varnish composition' test using chi-square

Composition	F_0		Total	Fh		*Chi-Square*		Total Chi-Square/P-Value
	Output	Defect		Output	Defect	Output	Defect	
Composition 1	1848	58	1906	1859.84	46.16	.07537	3.04	6.590/0.037
Composition 2	1756	44	1800	1756.41	43.59	.00009	.0038	
Composition 3	1795	32	1827	1782.75	44.25	.08413	3.39	

Based on production data from January to August 2019, defects were grouped for each process in the MU5-TJ ammunition assembly line based on the types of defects according to MIL-STD 636. The results of the grouping of the defect types are shown in Figure 6.

Based on the Pareto chart in Figure 6 above, it appears that the improper weight of the ammunition (underweight or less propellant filling) held the largest proportion of defects, which was 27%. Furthermore, the improper length (too long or too short) held the proportion of defects as much as 20% of the total defect types in the MU5-TJ ammunition production process. It means that 46.9% of the types of defects occurred in the weighing and gauging process. Meanwhile, defects in the visual process had a proportion of 31.94%, namely 19.8% in scratch case, 7.35% in dent case, and 4.79% in split case. Furthermore, defects in the form of cocked primer originating from inserting, varnishing, and crimping the primer processes held a proportion of 13.1%. In comparison, those in the propellant charging and assembling process reached 8.04%, namely 6.43% in crooked bullets and 1.61% in split bullets. Furthermore, the results of interviewing and brainstorming with the field manager and field expert staff to find out the root of the quality-related problems are depicted in the fishbone diagram, as shown in Figure 7.

Based on the fishbone diagram above, expert staff and related field managers concluded that four critical factors cause defects, especially in the weighing and gauging process, including the engine speed setting, the presence of propellant filling sensor, cartridge case mouth varnish composition, and inspection method.

D. Improve

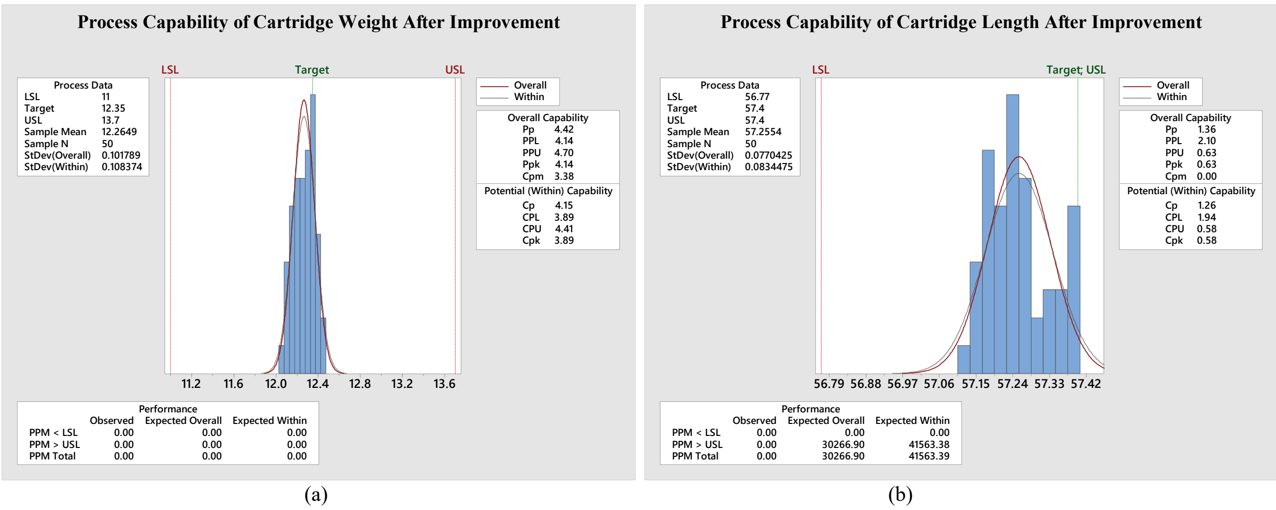
In the improve phase, the initial step was testing the four critical factors that caused defects in the weighing and gauging process that were previously determined at the Analyze phase using the chi-square statistical method. There were two hypotheses in chi-square testing, including: (1) H_0: There is no difference between the conditions A1, A2, and A3 in each factor. (2) H_1: There are differences between the

Table 5.
Results of the critical factor ‘inspection method’ test using chi-square

Inspection Method	F_0		Total	Fh		*Chi-Square*		Total Chi-Square/P-Value
	Output	Defect		Output	Defect	Output	Defect	
Method 1	2755	83	2838	2771.18	66.82	.0945	3.92	
Method 2	2845	64	2909	2840.51	68.49	.0071	.29	6.482/0.029
Method 3	2695	53	2748	2683.30	64.70	.0510	2.11	

Table 6.
Comparison between process capability and control chart before and after improvement

Parameter	Process Capability	Control Chart
Before Improvement		
Cartridge Weight	Cp = 4.27 Cpl = 2.99 Cpu = 5.55 Cpk = 2.99	UCL – LCL = 0.2726
Cartridge Length	Cp = 0.66 Cpl = 0.57 Cpu = 0.74 Cpk = 0.57	UCL – LCL = 0.4452
After Improvement		
Cartridge Weight	Cp = 4.15 Cpl = 3.89 Cpu = 4.49 Cpk = 3.89	UCL – LCL = 0.2923
Cartridge Length	Cp = 1.26 Cpl = 1.94 Cpu = 0.58 Cpk = 0.58	UCL – LCL = 0.2412



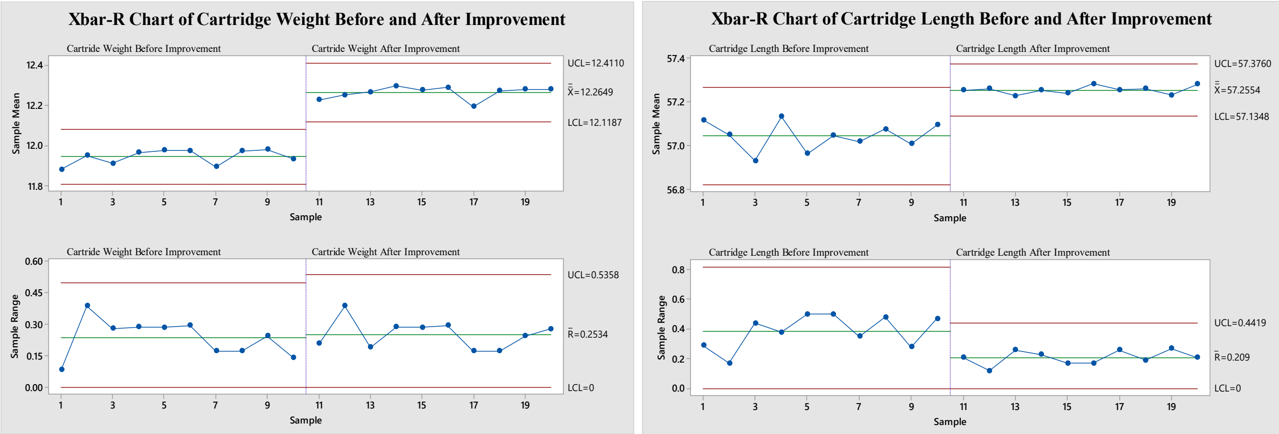
Figures 8. (a) Process capability of cartridge weight after improvement; (b) Process capability of cartridge length after improvement.

conditions A1, A2, and A3 in each factor. The first critical factor testing, namely the engine setting, was done by setting the engine at speeds of 120 rpm; 95 rpm; and 80 rpm and retrieving product defect data generated in the weighing and gauging process at each of these speeds for three days. The results of the critical factor ‘engine setting’ test is shown in Table 2.

In the same way, a critical factor test for the existence of filling sensor was carried out by taking product defect data generated in the weighing and gauging process, especially for the improper weight due to a lack of propellant powder when the filling sensor was installed and not installed for three days. The results of the critical factor ‘filling sensor’ test is shown in Table 3. Subsequently, the critical factor testing was performed for the cartridge case mouth varnish composition. The initial step before the test was to make three varnish compositions, including: (1) Composition 1: 79.5% asphalt; 18% SBP; 2.5% ethyl acetate (existing composition at PT.X). (2) Composition 2: 80% bitumen oil; 20% thinner A. (3) Composition 3 : 90% bitumen oil; 10% lacquer thinner.

The use of each composition was based on the specifications of the cartridge mouth case varnish, whose surface must be dry, while the inside remains moist. Less dry varnish, on its surface, can obstruct the propellant filling channel. Dry speed test on each of these compositions showed that composition 3 had the fastest surface dry speed, which was 5 minutes. In comparison, composition 2 needed 7 minutes while composition 1, which was the existing composition at PT. X, needed 20 minutes.

The next step was to retrieve product defect data generated in the weighing and gauging process for each composition for



(a) (b)

Figures 9. (a) Control chart of cartridge weight after improvement; (b) Control chart of cartridge length after improvement.

three days. The results of the critical factor ‘cartridge mouth case varnish composition’ test is shown in Table 4.

In the same way, critical factor testing is carried out by the inspection method using variations of three methods, including: (1) Method 1: Without auto-control by operators and quality inspector patrols (inspection by quality inspectors only on the final product). (2) Method 2 : Inspection patrols on the ammunition assembly process by quality inspectors every 2 hours. (3) Method 3 : Auto-control by the operator every 15 minutes and inspection by the quality inspector on the final product.

The next step is to retrieve product defect data generated in the weighing and gauging process for each of these methods for three days. The results of the critical factor ‘inspection method’ are shown in Table 5.

Based on the results of these tests, it can be concluded that the factors that have a significant effect on quality problems are the presence of filling sensor, cartridge case mouth varnish composition, and inspection method, each of which has a *p*-value <confidence level of 0.05.

The next step was implementing improvements on the MU5-TJ ammunition assembly line by installing the filling sensor on the propellant filling machine and ammunition assembly, changing the cartridge case mouth varnish composition using composition 3 (90% bitumen oil with 10% lacquer thinner), and running the auto-control system by the production operator every 15 minutes and inspection by quality inspectors on the final products.

Furthermore, measurements were made on the process capability and control chart after improvement, the results of which can be seen in Figures 8 and Figures 9. A comparison of conditions before and after improvement for the cartridge weight and cartridge length parameters is shown in Table 6.

Based on the results of Table 6, the comparison between the process capability and control chart, it appears that after improvement, the process capability became better, resulting in better distribution and centering of data, indicating that the process was more accurate and approached the target as marked by a higher Cpk value for cartridge weight parameters, though the difference in Cp in the ammunition weight in the two phases was not too significant. Meanwhile, in the cartridge length parameter, the values of Cp and Cpk were higher in the phase after improvement, especially the value of Cp, which indicated that process capability became better after improvement.

It is notable that because measurements were taken by sampling so, especially when measuring the weight of the munitions, the samples taken at the time before and after the overall improvement were according to specifications. However, the use of tools in the form of a Pareto chart was more appropriate in describing quality-related problems in the pre-improvement stages. The results of the control chart showed that overall the process was statistically controlled both in the pre- and post-improvement phases. However, in the post-improvement phase, it produced a more stable process with less variation. So, as a whole, it can be concluded that the MU5-TJ ammunition assembly line assembly after improvement produced better quality products.

E. Control

In the control phase, the sigma level was determined after improvement. Future sigma level determination was done based on data from September 2019 to January 2020. Data normality test was carried out in the same way as in the Measure phase, using Minitab software 17, and it was found that the data were normally distributed, according to the average defect product ratio of 1.08 %.

Furthermore, in the same way, as in the Measure stage, by using the normal distribution equation (equation 1), the final sigma level of 3.7977 was obtained. The DPMO value for the sigma value was 0.0108, namely 10,800 product units. It means that the MU5-TJ ammunition assembly line had the opportunity to produce defective products of 10,800 units out of 1,000,000 units produced.

IV. CONCLUSION

The results of the identification of quality-related problems in the 5.56 mm ammunition assembly line, namely variant MU5-TJ, indicated that the part of the process that had a significant effect on the emergence of quality-related problems was the weighing and gauging process. It accounted for 46.9% of the defects in the MU5-TJ ammunition assembly line. The types of product defects that existed in the MU5-TJ production process at PT. X included the improper length of the ammunition (too long or too short) and the improper weight due to the underfilling of propellant powder, scratch case, split case, dent case, cocked primer, split bullet, and crooked bullet.

Based on the identification of the types of product defects, it can be shown that the improper weight of the ammunitions due to the underfilling of propellant powder was the most influencing factor of defects in the assembly of MU5-TJ ammunition, reaching 26.96%, followed by the improper length of the ammunition (too long or too short), reaching 19.98%. The analysis of the causes of defects found four critical factors, namely the engine setting, the presence of the propellant filling sensor, cartridge case mouth varnish composition, and inspection method.

The results of chi-square testing of the four critical factors indicated that the factors that led significantly to the defects in the weighing and gauging process were the presence of the filling sensor, cartridge case mouth varnish composition, and inspection method.

Based on these findings, the improvement made included installing the propellant powder filling sensor on the MU5-TJ ammunition assembly machine, changing the cartridge case mouth varnish composition (90% bitumen oil with 10% lacquer thinner), running the auto-control system by the production operator every 15 minutes and inspection by quality inspectors on the final products. From the results of improvements that have been made, an increase in sigma level was obtained, from 3.69 to 3.79.

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