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THE APPLICATION OF SIX SIGMA-DMAIC METHOD TO REDUCE DEFECTS AND IMPROVE THE CARTRIDGE CASE PROCESS IN AMMUNITION COMPANY

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Abstract *PT. Pindad has a superior product, namely the 5.56 mm ammunition MU5-TJ. The product performance and quality, to be better, need changes in manufacturing processes and stricter quality control. In the MU5-TJ manufacturing process, defects in the cartridge case significantly contribute to defective products, reaching 48.6%. This study aimed to evaluate the causes of the defects and improve thequality of the MU5-TJ cartridge case production line. The method used in this study was Six Sigma - DMAIC (Define, Measure, Analyze, Improve, Control). The quality identification showed that the gauging process contributes to 67.8% of total defects in all production lines of cartridge cases. The critical factors were inspection methods and machine settings. Improvements were made by implementing auto- control every 15 minutes by the operators, setting the heading and necking, edge turning, and gauging machine speed. The improvements were shown to increase the sigma level from 3.24 to 3.45 and save the cost by IDR62.372.824,00.*

Keywords*: Six Sigma, DMAIC, quality, defects, 5.56 mm ammunition, MU5-TJ cartridge case*

1. Introduction

PT. Pindad (Persero) is an Indonesian state-owned enterprise specializing in providing products for the state's defense and security capabilities. One of its superior products is ammunitions. The most sought-after ammunition is 5.56 mm caliber ammunition, accounting for 74.3% of demands for all small-caliber ammunitions in the last six years [1]. Of the figure, from 2018 to 2020, the MU5-TJ variant reached 86.6%. PT. Pindad, for this reason, continues to maintain and oversee the quality of its products to survive in the competitive market [2]. According to the construction and assembling process, ammunitions are classified into three types: fixed, semi-fixed, and separated [3]. Ammunition for a firearm comprises a projectile, a cartridge case, a propellant, and a primer mixture [4]. Ammunition is composed of metals, including lead (Pb), chromium (Cr), nickel (Ni), zinc (Zn), and copper (Cu) [5]. The production process involves manufacturing cartridge cases, bullets, and primers, and preparing munitions. During the process, defects occur in the cartridge case, bullets, and primers of the 5.56 mm caliber ammunitions, reaching 74.4% is the highest defects as shown in Figure 1, especially in those of the MU5-TJ cartridge cases variant, reaching 48.6%. Hence, we would focus on the MU5-TJ cartridge case to evaluate the factors causing defects in the production process using the Six Sigma-DMAIC method. Six Sigma focuses on customer needs, defect prevention, cycle time reduction, and cost savings to improve product quality which affects customer satisfaction. In this method, process stability is critical to consider by reviewing the control chart; a process is stable when all fall within limits. So is process capability, which means the ability of the process to produce a product according to the expected specifications [6]. DMAIC is a structured problem-solving procedure widely used in quality and process improvement by implementing solutions designed to solve quality problems.

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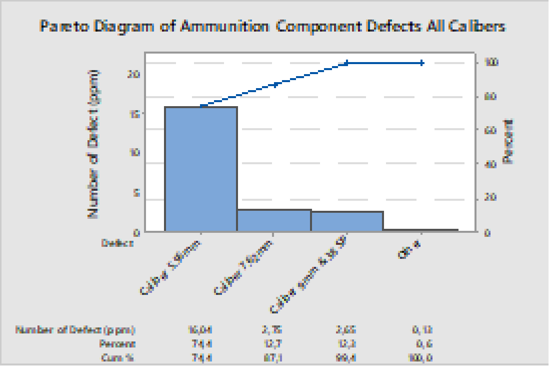


Figure 1. Pareto Diagram of Ammunition Component Defects of All Calibers

Jiraksupraset *et al*. suggested that the Six Sigma-DMAIC method was very effective in reducing defects in the production of rubber gloves. The data collected showed the defect level reached 19.51%, the DPMO value was 195,095, and the sigma level was 2.4. Two process factors, namely the oven temperature and the conveyor speed, were the primary defect-causing factors that directly affected the number of leaky gloves produced. Optimizing these two variables could reduce defects by about 50% so that the DPMO value decreased to 83,750, while the sigma level increased to 2.9 [7]. Indrawati used the DMAI approach to improve product quality and reduce waste at the iron ore plant, where the company's losses reached IDR588.801.463 [8]. By using FMEA analysis, an improvement was proposed based on the highest RPN value to overcome the main problems that cause waste in inappropriate processing and defects, namely by redesigning the dust collector, establishing standard operating procedures for weighing, and installing BC-05, vibrometer, and nitrogen plant.

Costa *et al*. conducted research on an automotive company to reduce the number of defective units in the Printed Circuit Boards (PCB) pin insertion process using Six Sigma-DMAIC where the pin insertion force above the maximum (180N) resulted in the breaking of copper and loss of PCB electrical function, resulting in high rejecting costs and production line termination time [9]. A series of improvements could increase the level of process quality and stability with less variability, reduce the value of the pin insertion force to close to the nominal value, increase the sigma level from 4.22 to 4.92, reduce the number of defective units from 3231 PPM to 312 PPM, and save up the cost by around euro 122,000. The Six Sigma-DMAIC method could reduce the number of rejected units in the manufacture of telecommunication cabinet doors caused by variations in the dimensions of hinges, padlocks, and pole positions that resulted in misaligned doors on the cabinets [10]. A brainstorming found that the fixture was the primary culprit. After an improvement, the number of rejected units decreased from 136 from a total production of 5,844 door panels to 67 from a total production of 4,221, the DPMO value decreased from 23,271.73 to 15,873.01, rework costs decreased from 56,666,662.55 to 38,650,779, and the sigma level increased from 3.49 to 3.64.

Research on defects in ammunitions products by Wardani related to improving product quality in the assembly process of the 5.56 mm calibre MU5-TJ ammunitions using Six Sigma DMAIC raised the sigma level from 3.69 to 3.79. The processes that significantly affected the emergence of quality problems were the weighing, gauging, and visual processes [11]. Research on a tire manufacturing company to improve the extrusion process of rubber tires, namely the tread and sidewalls, by adopting the Six Sigma DMAIC method was conducted by T. Costa *et al*. where work-off generation was defined as an indicator of production performance above the target specification, namely 13% for tread extrusions and 26% for sidewall extrusions. The improvements implemented contributed to a significant reduction in non-conforming material by around five tons per day and a work-off reduction by 0.89% [12]. The Six Sigma-DMAIC concept was also applied in the process of connecting blocks and covers on the Kolbus BF 511 engine. The brainstorming conducted showed four main factors, namely work organization, machine, method, and man. Improvements were proposed to be done through implementing SMED (Single Minute Exchange of Die), developing training for employees, standardizing work and Total Productive Maintenance, and then carrying out continuous control regarding process efficiency on the machine [13].

2. Method

2.1 Research Phases

The phases of research using the DMAIC method carried out in this study were as shown in Table 1.

Table 1. Detail of DMAIC Tools

Phase	Objective	Activity	Output	Tools and Technique
Define	Identification of quality problems that are the main cause of defects in the MU5-TJ cartridge case.	Defining the production process	- MU5-TJ cartridge case production processflowchart - Pareto Diagram	Interview and brainstorming
Measure	Measuring quality parameters	- Measuring initial sigma level - Measuring initial process capability - Creating an initial control chart - Calculating DPMO value - Measuring the value of losses due to defects	- Initial sigma level - Cp and Cpk values - Xbar-R graphics - DPMO Value - Value of losses due to defects	- Process Capability - Control chart - DPMO value calculation - Sigma value calculation - Calculation of loss value
Analyze	Identifying and verifying root cause	- Data collection of root causes of cartridge case defects - Determination of the critical factor or CTQ that causes defects - Determination of the cause-and-effect relationship of the critical factor or CTQ	- Factors or root causes of defects	- Interview and brainstorming - Cause-and-effect diagram - Failure Mode and Effect Analysis
Improve	Improvement of the MU5-TJ production process with the most defects based on critical factors	- Hypothesis test - Implementation of improvenent results	- Chi-square value and *p*-value - Significance relationship between critical factors and cartridge case defects - Good product and the defect in the process with the most defects	- Chi-square test - Experiment
Control	Continuous improvement process development, avoiding returning to the initial state	- Measuring process capability after improvement - Making control chart after improvement - Calculating sigma level after improvement - Calculating DPMO value after improvement - Calculating cost saving	- Cp and Cpk values after improvement - Xbar-R graphics after improvement - Xbar-R chart comparison before and after improvement - Sigma value after improvement - DPMO value after improvement - Cost saving value	- Process capability - Control chart - Sigma level calculation - DPMO value calculation - Cost-saving calculation

2.2 Data Collection

The data collected comprised two types, namely primary data and secondary data. The former was obtained directly through observation, experimentation, brainstorming, and interviews. In this study, it included data on the MU5-TJ cartridge case production process sequence, data on the number of defective products and the types of defects in the MU5-TJ cartridge case production process from the Quality Control department, data on the frequency or number of defective units of cartridge case according to defective types, data on the frequency or number of failure occurrences based on the factors causing defects in each process, and data on the factors causing defects in the cartridge case obtained from brainstorming and interviews with related parties. Meanwhile, secondary data was obtained through library research such as literature studies from books or previous research.

3. Six Sigma and DMAIC Application

This section presents the practical application of Six Sigma-DMAIC in the MU5-TJ cartridge case production process at PT. Pindad with stages systematically, according to the DMAIC model for manufacturing process improvement and problem solving.

3.1 Define

In this phase, the analysis focused on the MU5-TJ cartridge case production line, where operations, as shown in the process flowchart in Figure 2, ran. Brass cups as raw material went through drawing, trimming, heading-and-necking, fire hole piercing, and edge turning processes. Subsequently, the dimensions were measured using a gauging machine before going through mouth annealing and varnish-visual processes. Pareto analysis was carried out on the MU5-TJ cartridge case production line from July 2020 to February 2021. Data on the total defects in the MU5-TJ cartridge case production line are shown in Figure 3. The highest level of defects occurred in the gauging process, reaching 67.8%. This process sorted the dimensions using a gauging machine, including the cartridge case length, rim diameter, the height of the anvil, the primer hole diameter, the flash hole diameter, the extractor diameter, mouth diameter, rim thickness, and the headspace. Each of these dimensions has a maximum and minimum value limit. The Pareto diagram in Figure 4 shows the dimensional defects in the gauging process from July 2020 to February 2021. Most defects occurred in the headspace of 37.6% and rim thickness of 18.6%.

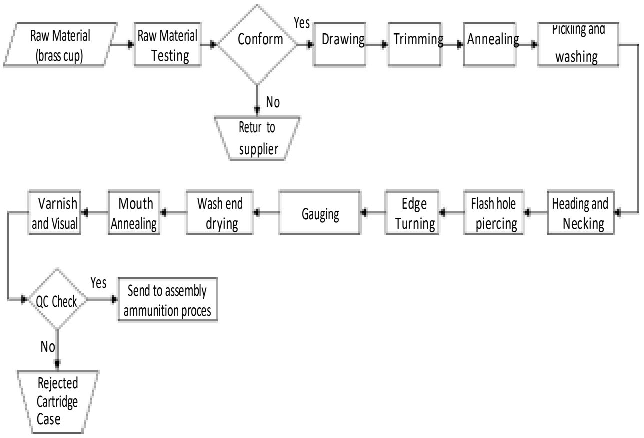


Figure 2. MU5-TJ Cartridge case Production Process Flowchart

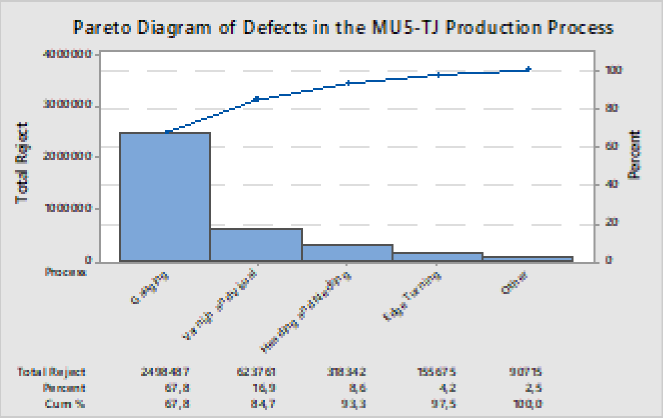


Figure 3. Pareto Diagram of Defects in the MU5-TJ Production Process

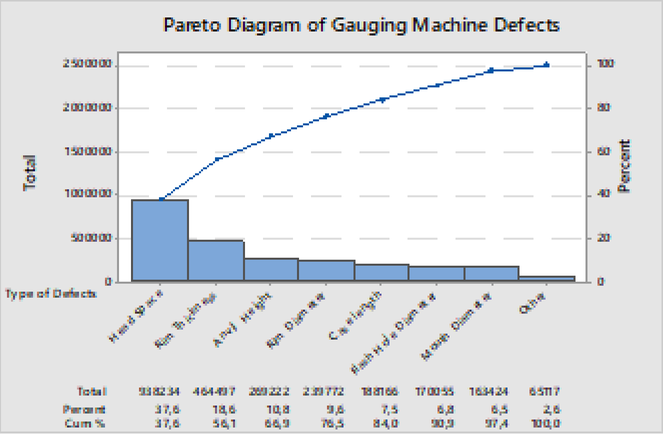


Figure 4. Pareto Diagram of Defects Due to the MU5-TJ Cartridge case Gauging Process

3.2 Measure

In this phase, the researchers performed the data normality test before analyzing the quality parameters, aiming to detect random characters from the sample data and outliers, assess whether the data obtained had a normal distribution, and assess the process capability indicators. If the data from July 2020 to February 2021 was distributed normally, then the data represented the entire defects in the MU5-TJ cartridge case production line. Using the Anderson-Darling test, the researchers obtained a *p*-value of 0.549 > α, where α was 0.05. So, the data was normally distributed. The average ratio of MU5-TJ production defects for the eight months was 4.97%. The calculation of the sigma level before the improvement was carried out using the Standard Normal Distribution equation as follows:

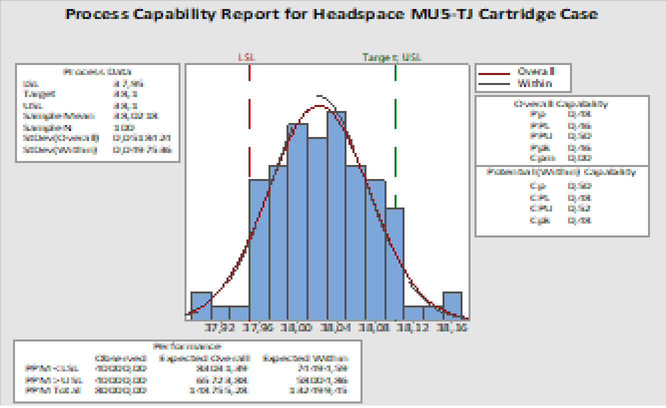
$$P\ (z \geq x) = NORM.S.INV\ (probability) + 1{,}5\sigma$$

$$z = NORM.S.INV\ (1\text{-}0{,}411) + 1{,}5\sigma$$

$$z = 3{,}238061\ \sigma \qquad (1)$$

The calculation above generated an initial sigma level of 3.238061. The DPMO value was 0.0411, meaning that in the MU5-TJ cartridge case production process, out of 1,000,000 units produced, 41,100 were potentially defective. The loss due to defects in the MU5-TJ cartridge case production from July 2020 to February2021 was IDR 1.728.085.731, reaching 1.67%.

The measurements of the process capability and the control chart of the MU5-TJ cartridge case production process should be on the heading and necking machines and the edge turning machines. Product defects occurred because the headspace and rim thickness were above the maximum specifications and/or below the minimum specifications. In one batch producing 20,000 units of MU5-TJ cartridge cases during an 8-hour shift, 100 units were taken as the sample to be tested using the Anderson-Darling test for the normality by analyzing the headspace and the rim thickness. The results showed that each of them had a *p*-value of 0.707 and 0.192, respectively, higher than the confidence level of 0.05. The two data, hence, were normally distributed. Figures 5 and 6 present the process capability of headspace and rim thickness data. The histograms for both are wide, meaning that the process generated a lot of variation and the process capability was low. Besides, the heading and necking machines' and the turning machines' capabilities to generate products that meet specifications with slight variations were still low, so that the Cp values were low at 0.50 for headspace and 0.58 for rim thickness (Cp < 1.33). The Cpk values were 0.48 for headspace and 0.35 for rim thickness. According to Romdhane, a Cp value of 0.67 indicates that the process is chaotic. For improvements, shutting down the process and analyzing the causes and corrective actions are recommended [14].



Figurer 5. MU5-TJ Cartridge Case Headspace Process Capability Before Improvement

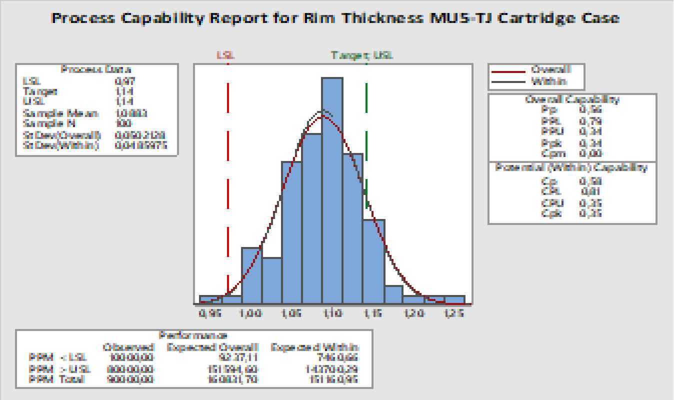


Figure 6. MU5-TJ Cartridge Case Rim Thickness Process Capability Before Improvement

3.3 Analyze

In this phase, the researchers analyzed critical factors that contributed to defects in the MU5-TJ production process. Based on brainstorming, field observations, and interviews with operators and production and quality managers, the causes of MU5-TJ cartridge case defects can be described in the cause-and-effect diagram in Figure 7. Ishikawa diagram or "Cause-Effect" diagram is a tool for analyzing and planning the relationship between a particular effect (e.g., variation in quality characteristics) and its probable cause [15]. After considering all possibilities and by conducting analysis using Root Cause Failure Analysis in each process, the researchers found the root causes of defects in the heading and necking, edge turning, and gauging processes, namely the inspection method that was not carried out in an orderly manner by operators and machines and speed that were not set appropriately.

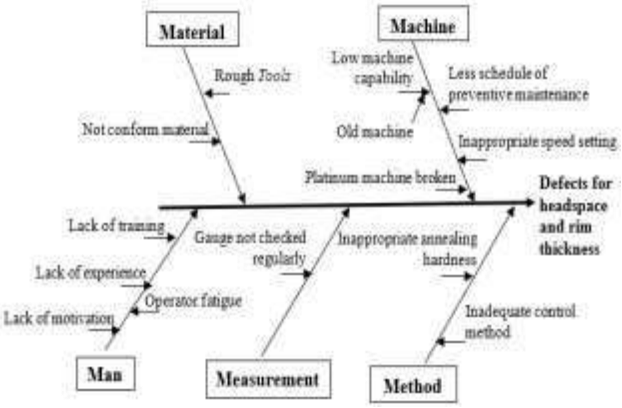


Figure 7. Cause-and-effect diagram

Determination of Cause-and-Effect Relationships based on critical factors:

1. Inspection Method

Based on PT Pindad regulation, operators should do inspections regularly every 15 minutes. However, this activity did not run optimally. Before this regulation, the QC personnel did patrol at each process line. When their number became limited, the operators took their tasks. However, this shift made the inspections work ineffectively, bringing the defective cartridge cases to accumulate at the end of the process.

2. Machine Setting

During the heading and necking, edge turning, and gauging processes, defects were possibly occurring for improper settings of speed and machines. In the gauging process, different machines and speed settings can affect the accuracy of the cartridge case's dimensional sorting and its visual inspection by the operators. In the heading and necking process and edge turning, machine and speed settings can affect the product's ability, accuracy, and size stability. The higher the machine speed, the more the products generated, but the higher the variation beyond tolerable specifications.

3.4 Improve

After the defect root causes were determined, this phase was done to identify solutions to reduce them by testing product defects in the heading and necking, edge turning, and gauging processes using the chi-square test. This test aimed to prove whether there was a significant relationship between the critical factors and defects in the related process. The results of data collection for the two critical factors are shown in Table 2.

1. Inspection Method

   There were three inspection methods, namely:

   a. Method 1: Without auto-control by the operators and patrolling by the quality inspectors in the heading and necking, edge turning, and gauging processes.
   b. Method 2: The quality inspectors patrol around the heading and necking, edge turning, and gauging processes every 120 minutes.
   c. Method 3: Auto-control by the operators once every 15 minutes on heading and necking, edge turning, and gauging processes.

   The hypotheses are:

   H_0: There is no interaction between inspection methods, namely the frequency of inspections and the number of defects.

   H_1: There is an interaction between inspection methods, namely the frequency of inspections and the number of defects.

2. Machine Setting

   a. The heading and necking process, the hypotheses are:

      H_0: There is no interaction between the increase in machine speed and the number of headspace defects in the heading and necking process.

      H_1: There is an interaction between the increase in machine speed and the number of headspace defects in the heading and necking process.

   b. The edge turning process, the hypotheses are:

      H_0: There is no interaction between the increase in machine speed and the number of rim thickness defects in the edge turning process.

H_1: There is an interaction between the increase in machine speed and the number of rim thickness defects in the edge turning process.

c. The gauging process, the hypotheses are:

H_0: There is no interaction between the increase in machine speed and the accuracy in the dimentional sorting.

H_1: There is an interaction between the increase in machine speed and the accuracy in the dimentional sorting.

Table 2. Data of Defects Affected by Inspection Method and Machine Setting

No.	Critical Factor	Number of Good (pcs)	Number of Defective (pcs)
1.	**Inspection Method:**		
	Method 1	865	160
	Method 2	899	133
	Method 3	945	111
2.	**Machine Setting:**		
	a. Heading and necking:	**Good Units**	**Defective Units**
	125 rpm	1,825	155
	100 rpm	1,470	130
	75 rpm	1,055	123
	b. Turning:	**Good Units**	**Defective Units**
	62.5 rpm	1,775	150
	60 rpm	1,710	110
	57.5 rpm	1,673	100
	c. Gauging:	**Defective units entering good unit box**	**Defective unitss entering defective unit box**
	10 rpm	185	1,315
	20 rpm	193	1,307
	30 rpm	207	1,293
	40 rpm	218	1,282
	50 rpm	403	1,097

The results of the critical factor test causing defects in the heading and necking, edge turning, and gauging process with the chi-square test are shown in Table 3. These results indicate that the inspection method and machine settings significantly affect the defects in the heading and necking, turning, and gauging processes.

Table 3. Results of the Chi-Square test of Defect-causing Critical Factors

Critical Factor	Chi-Square Test	Table Chi-Square	*P*-value Pearson	Results	Annotation
Inspection Method	11.983	5.99	0.003	H_1 Acceptable	Significant
Machine Setting:					
a. Heading and Necking	7.056	5.99	0.029	H_1 Acceptable	Significant
b. Edge Turning	8.036	5.99	0.018	H_1 Acceptable	Significant
c. Gauging	164.853	9.49	0.000	H_1 Acceptable	Significant

3.5 Improvement Result Implementation

The implementation of improvements to the MU5-TJ cartridge case production line was carried out for 5 months from June to October 2021 with the acquisition of the optimal parameters obtained based on experiments and a chi-square test as follows:

1. The inspection method 3; the operators did auto-control every 15 minutes on the heading and necking, edge turning, and gauging processes. This method was chosen because it resulted in a total number of defects less than that when using methods 1 and 2.
2. Machine speed setting:
   a. 100 rpm for the heading and necking process.
   b. 60 rpm for the edge turning process.
   c. 40 rpm for the gauging process.
   The lower the machine speed, the less the headspace and rim thickness defects and the better the dimensional sorting accuracy. With moderate speed, because the defects occuring were not too high and the resulting outputs were not too low.

3.6 Control

The control phase aimed to maintain, monitor, and ensure that the improvement process remained under control [7]. After implementing the improvement process, 100 units generated from the heading and necking and edge turning processes were measured for their headspace and rim thickness. To assess whether the two processes were controlled or not, a control chart with Xbar & R charts was used. The process capability was calculated to determine whether the process capability in achieving quality targets increased after improvement and whether it produced a more stable and more efficient process with a lower variation of outputs, compared to those before the improvement. Process capability values of headspace and rim thickness are shown in Figures 8 and 9.

The figures show that the histogram shape in the process was narrower and the standard deviation value was smaller than those before the improvement. For headspace, Cp = 1.89 and Cpk = 1.0, while for rim thickness, Cp = 1.47 and Cpk = 0.58. The process capability of the heading and necking and edge turning processes after the improvement was better because it resulted in better distribution and centralization of data, indicating that the process was more accurate and stable and had less variation. A Cp value > 1.67 indicates that the process is highly capable and has no concerns, while a value of 1.33 < Cp 1.67 indicates that the process is capable and is in a comfortable situation [14]. Furthermore, the control charts for headspace and rim thickness before and after improvement were compared to the results shown in Figures 10 and 11.

The control charts show that the entire process was statistically controlled. In the post-improvement phase, it produced a more uniform process with minor variation and no value exceeded the UCL limit or approached the LCL limit, as shown by the differences in the UCL (Upper Control Limit) and LCL (Lower Control Limit) on the Xbar-R chart that was narrower, namely 0.03172 for headspace and 0.05306 for rim thickness. All points were between the control limit and on each side of the centerline, so no intervention was needed [14]. Before the improvement, all processes, both heading and necking and edge turning, were not statistically controlled because the headspace value was above UCL and the rim thickness value was close to UCL and LCL. Comparison of the values of process capability Cp and Cpk and control chart before and after improvement is shown in Table 4.

After improvement, the process became more uniform, with only minor variations. The sigma level was again measured. Based on production defect data from June to October 2021, the MU5-TJ cartridge case defect ratio was 2.58%, the final sigma level was 3.446456. The DPMO for the sigma value was 25,800. The percentage of the loss due to the MU5-TJ cartridge case defects after improvement was 1.11%, with a loss value of IDR 124.670.009. The calculation of cost saving is by multiplying the average percentage before the improvement, which is 1.67% and after the improvement, which is 1.11% with the total value of the product in the period after the improvement. Calculation of cost saving, the cost contained in the period before the improvement is an approach using the average value of losses due to defects caused to the product in the period after the improvement, if the process is carried out without improvement steps. The resulting cost saving is shown in Table 5. The cost saving after the improvement of the MU5-TJ cartridge case production line was IDR 62.372.824.

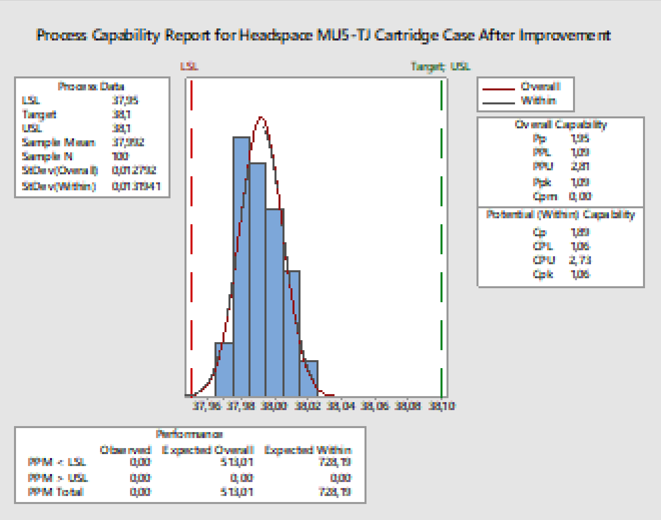


Figure 8. Process Capability of the MU5-TJ Cartridge Case Headspace after the Improvement

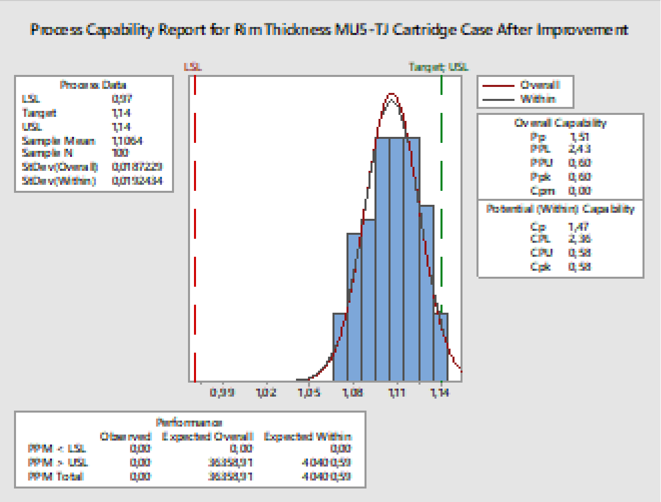


Figure 9. Process Capability of the MU5-TJ Cartridge Case Rim Thickness after the Improvement

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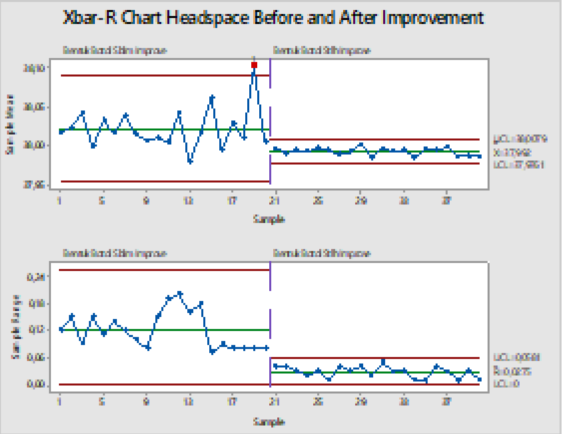

Figure 10. Process Capability of the MU5-TJ Cartridge Case Headspace before and after the Improvement

Figure 11. Control Charts of of the MU5-TJ Cartridge Case Rim Thickness before and after the Improvement

Table 4. Comparison Between Before and After the Improvement

Measurement parameter	**Process Capability**	**Control Chart**	**Difference between UCL-LCL**
Before the Improvement			
Headspace	Cp: 0.50 Cpk: 0.48	UCL: 38.0916 LCL: 37.9520	0.1396
Rim Thickness	Cp: 0.58 Cpk: 0.35	UCL: 1.1526 LCL: 1.0240	0.1286
After Improvement			
Headspace	Cp: 1.89 Cpk: 1.06	UCL: 38.00786 LCL: 37.97614	0.03172
Rim Thickness	Cp: 1.47 Cpk: 0.,58	UCL: 1.13293 LCL: 1.07987	0.05306

Table 5. Cost Savings After Improvement

Condition	**% Loss Value of Cartridge Case**	**Good Product Value (IDR)**	**Loss Values of Cartridge Case Defect (IDR)**
Without Improvement	1.67%	11.138.004.373	186.004.676,03 3
By Improvement	1.11%	11.138.004.373	123.631.848,54
Cost Savings			62.372.824,49

4. Conclusion

This paper presented a case study of defect reduction in the MU5-TJ cartridge case manufacturing process by applying Six Sigma principles and the DMAIC problem-solving methodology. The analyze and improve phases showed that the inspection method and machine settings had a statistically significant effect on headspace and rim thickness defects and the accuracy in the dimensional sorting of the MU5-TJ cartridge case. The reduction in the number of defective products was obtained by determining the optimal inspection method, namely auto-control by the operators every 15 minutes and setting the heading and necking machine at 100 rpm, the edge turning machine at 60 rpm, and the gauging machine at 40 rpm. The result of the improvement implementation was an increase in the sigma level from 3.24 to 3.45. The percentage of losses due to the MU5-TJ cartridge case defects decreased from 1.67% to 1.11%. The DPMO decreased from 41,100 to 25,800. The cost-saving was calculated by multiplying the average percentage before the improvement, which is 1.67% and after the improvement, which is 1.11% with the total value of the product in the period after the improvement. The value generated by improvements from June to October 2021 reached IDR 62.372.824. This research was considered a pilot project to demonstrate that the ammunition manufacturing industry that uses Six Sigma and DMAIC as problem-solving methods can improve the MU5-TJ cartridge case manufacturing process by reducing the number of defective products. These show that as long as the company continues to implement Six Sigma in a culture of continuous improvement and apply its concepts and principles to solve quality problems systematically, it can gain benefits such as cost savings, product quality improvement, and customer satisfaction.

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