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Quality Control of Glass Bottle Drinking Water Products Using the Six Sigma Method

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***Abstract*— This study aims to enhance production performance and product quality, thereby achieving various financial and strategic objectives, including market share, competitiveness, and profitability. The problem faced by this company is in product quality control, where there are still defective products that arise during the production process. Therefore, this study uses Six Sigma with the concept of Define, Measure, Analyze, Improve, and Control (DMAIC) as a step to optimize production procedures at UD. NUSAQU, whose product is bottled drinking water. The focus of this study is on the visual of product defects in the form of cups, which are divided into two grades, namely Grade A and Grade B, which are distinguished based on the plastic cup material used. The results of data testing show that in Grade A and Grade B, slanted lid damage has the highest level of damage, but in Grade B, the results are the same as those of leaking cups. The DPMO value produced in Grade A is 62,633.914, while in Grade B it is 130,961.47. The smaller the DPMO value, the better the product quality. The average value of Six-Sigma for Grade A is 3.03, while Grade B is 2.63. Based on these values, it can be concluded that Grade A has better quality than Grade B, but both require improvement and enhancement efforts to achieve 6 sigma.**

***Keyword*: defect, quality control, six-sigma**

I. INTRODUCTION

One of the primary needs of society is water, which is a very important source of energy for the survival of society. This makes many entrepreneurs take advantage of opportunities in their businesses and efforts, such as making practical and healthy packaged mineral water products. However, the vast opportunities that exist create tight and sharp competition in the packaged mineral water business both in the local and national markets. Tight competition requires entrepreneurs to provide good products and in accordance with consumer desires in terms of quality, starting from raw materials, labor, machine tools used, packaging, and finished products.

Several industries are dedicated to improving production performance and product quality to achieve various financial and strategic goals, such as market share, competitiveness, and profitability (Fersini, 2019; Aytekin et al., 2023; Samanta et al., 2023). To achieve this, Lean Six Sigma (LSS) applies the DMAIC framework, which consists of five stages: 1) Define; 2) Measure; 3) Analyze; 4) Improve; and Control [4]. In addition to its strategic advantages, LSS seeks to clarify manufacturing processes by identifying opportunities for waste reduction, process variability reduction, and problem solving (Mandal, 2012; Chen et al., 2023).

Several previous studies have stated that in quality control, DMAIC still needs to be applied more adequately (Hakimi, 2018; Tsarouhas & Sidiropoulou, 2024). In this study, Pareto analysis is used to determine the process in production that causes the most defects, and to evaluate by identifying the part of the production process that is a significant cause of defects, among many other causes (Kartika, 2020; Can et al., 2021).

The case study chosen in this study is Glass Bottle UD. Nasaqu, which has been operating since 2019 in Pegantenan District, Pamekasan Regency, East Java, especially for 240 ml glass packaging. This company often produces defective products in large quantities, which are generally caused by factors such as raw materials for its glass packaging, human error, and the machines used. The Six-Sigma method is used to identify and eliminate defects in the production process, thereby improving the quality of the final product. With this research, it is hoped that business owners will get sufficient guidelines and knowledge in implementing effective and efficient production by reducing product defects that occur.

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II. Method

This study uses the DMAIC methodology, which is the basis of the Six Sigma process improvement initiative (Sajjaad et al., 2021; Elnaby et al., 2023). The following procedures describe a problem-solving methodology in which specific tools are used to transform practical problems into statistical formats, build solutions based on statistical models, and transform those solutions into practical solutions (Orbak et al., 2023).

Several stages in this study are as follows (Chen et al, 2023):

a. *Define*

At this stage, significant causes of failures that occur during the production process are determined, and the methods used are:

1) Defining the problem of quality standards in producing products that have been determined by the company.
2) Defining the action plan that must be carried out based on the results of observations and research analysis.
3) Determining the targets and objectives for improving Six Sigma quality based on the results of observations.

b. *Measure*

At this stage, the accuracy and feasibility of the measurement system or data collection system must be verified. The measurement phase identifies problems that require resolution through statistical graphs, such as a Pareto chart. Because the data studied is attribute data, the following stages are carried out in its measurement:

1) Analysis with a P-chart control diagram with the following steps:
   a) Data collection used for P-chart analysis, namely, the amount of production and the number of defective products produced.
   b) Calculating the mean product nonconformity with the equation:

   $$\bar{p} = \frac{np}{n} \quad (1)$$

   Where p̄ is the average nonconformity, n indicates the number of samples, and np is the number of defective products.
2) Determining the control limit for supervision is carried out by calculating the UCL (Upper Control Limit) value as the upper limit, LCL (Lower Control Limit) as the lower limit, and CL (Control Limit) as the linear limit. The equation is as follows:

   $$CL = \bar{p} = \frac{\sum np}{\sum n} \quad (2)$$

   $$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \quad (3)$$

   $$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \quad (4)$$

3) Calculating Sigma Capability, by:
   a) Determining the number of units to be measured
   b) Identifying Opportunities
   c) Calculating the number of defects
   d) Calculating the sigma capability value (baseline process)
   This capability value calculation uses DPMO measurement units to determine the sigma level.

c. *Analyze*

At this stage, an analysis of the causes of quality problems is carried out using:

1) Pareto Diagram
   In this study, after obtaining product failure information data. An analysis of the causes or dominant factors that cause the failure of a product is carried out by sorting the possibility of defects based on the type of failure from the largest to the smallest.
2) Cause-Effect Diagram
   After the dominant cause of the defect is known, an analysis of the relationship between an effect and a number of causes that may result in the occurrence of product failure is carried out. This is done by determining five problem areas, namely methods, materials, machines, environments, and workers.

d. *Improve*

After identifying the root cause, conducting measurements (looking at opportunities, damage, current capability processes), reviewing recommendations for improvement, analyzing, and then taking corrective actions. In this phase, solutions to eliminate the causes of variation are developed, verified, and standardized. This phase consists of:

1) Design-based solutions.
2) Assessing the accuracy of the proposed solution.

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3) Risk assessment and mitigation strategies

e. *Control*

During this phase, it is critical to maintain process control through error checking. This phase immediately identifies the root cause of any out-of-control process and restores the level of process control. At this phase, Statistical Quality Control (SQC) is critical to monitor and assess process performance and stability. To maintain good results, it is critical to stabilize the process that has been improved during the previous phase.

III. RESULTS AND DISCUSSION

1. Control Chart Analysis Stage (P-Chart)

Data taken from UD AMDK Nusaqu, namely, quality control measured by the number of final products. Measurements were carried out using statistical quality control type P-Chart on final products from September 2023 to August 2024, namely a sample size of 12. The type of product that will be used in this study is Bottled Drinking Water.

The amount of glass bottled drinking water produced during September 2023 to August 2024 was 374,400 glasses, and it was found that products suspected of being defective, originating from three main causes of defects, were 7813 glasses.

The amount of glass bottle drinking water produced during September 2023 to August 2024 was 374,400 glasses, and it was found that the products suspected of being defective, originating from three main causes of defects, were 7813 glasses. The following is a measurement sheet for taking samples from September 2023 to December 2023 to determine the LCL (Upper Control Limit) and LCL (Lower Control Limit) values. UD AMDK Nusaqu Packaged Drinking Water. The calculation of CL, UCL, and LCL Grade A values is shown in Table 1.

Table 1. Determining CL, UCL, LCL Grade A value

Period	Number of products	Number of defects	Proportion	CL	UCL	LCL
1	30.000	698	0.02327	0.02087	0.02334	0.01839
2	28.800	611	0.02122	0.02087	0.02339	0.01834
3	32.400	676	0.02086	0.02087	0.02325	0.01849
4	31.200	586	0.01878	0.02087	0.0233	0.01844
5	31.200	654	0.02096	0.02087	0.0233	0.01844
6	31.200	701	0.02247	0.02087	0.0233	0.01844
7	32.400	689	0.02127	0.02087	0.02325	0.01849
8	31.200	597	0.01913	0.02087	0.0233	0.01844
9	31.200	638	0.02045	0.02087	0.0233	0.01844
10	31.200	688	0.02205	0.02087	0.0233	0.01844
11	31.200	620	0.01987	0.02087	0.0233	0.01844
12	32.400	655	0.02023	0.02087	0.02325	0.01849
Total	374.400	7813				
$\bar{p}$	0,0208681					
1-$\bar{p}$	0.9791319					

As a rule of thumb (Prawirosentono, 2002), the following criteria are used:

a. If P < LCL, it means that all samples are in the acceptance area (LCL), then check the cause.
b. If LCL < P > UCL, it means that all samples are in the acceptance area, called normal behavior samples or good process capability.
c. If P > UCL, it means that the sample jumps up outside the acceptance (UCL), or it can be said that the process capability is low; then, check the cause and take corrective action by

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improving performance in the production process activities. The P-Chart Grade A control chart is shown in Figure 3.

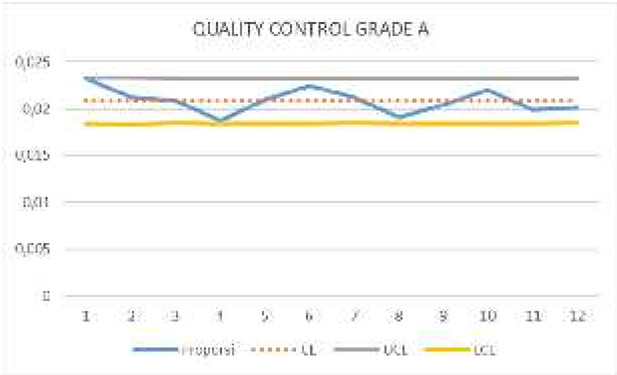

Figure 1: P-Chart Control of Grade A

From Fig. 3, it can be seen that not all lines cross the upper limit of the UCL, but from all there are still defects caused by machine factors that are not in accordance with the machine temperature settings that have been determined by the company. Human Error also greatly affects the quality of glass bottles, starting from packaging to the removal of products that are thrown, so that the product packaging is torn.

Table 2. Determining CL, UCL, LCL Grade B value

Period	Number of products	Number of defects	Proportion	CL	UCL	LCL
1	30.000	1200	0.04	0.04365	0.04719	0.04011
2	28.800	1152	0.04	0.04365	0.04726	0.04004
3	32.400	1296	0.04	0.04365	0.04706	0.04025
4	31.200	1134	0.0635	0.04365	0.04712	0.04018
5	31.200	1456	0.04667	0.04365	0.04712	0.04018
6	31.200	1346	0.04314	0.04365	0.04712	0.04018
7	32.400	1296	0.04	0.04365	0.04706	0.04025
8	31.200	1948	0.06244	0.04365	0.04712	0.04018
9	31.200	1256	0.040226	0.04365	0.04712	0.04018
10	31.200	1425	0.04567	0.04365	0.04712	0.04018
11	31.200	1567	0.05022	0.04365	0.04712	0.04018
12	32.400	1267	0.0391	0.04365	0.04706	0.04025
Total	374.400	16343				
$\bar{p}$	0.0436512					
1-$\bar{p}$	0.9563488					

The P-Chart Grade B image is shown in Figure 4. From Figure 4, it can be seen that there is still a line that passes the upper limit of UCL in August and also in November 2023 which is caused by the improper setting of the machine temperature so that many defective products such as leaking Cups with tilted Lids and also when the packaging of the goods is thrown which causes the product packaging to tear.

2. Sigma and Defect Level Measurement Stage

The Sigma and Defect per Million Opportunities (DPMO) measurement stage, as well as Grade A sampling from September 2023 to August 2024, can be seen in Table 3.

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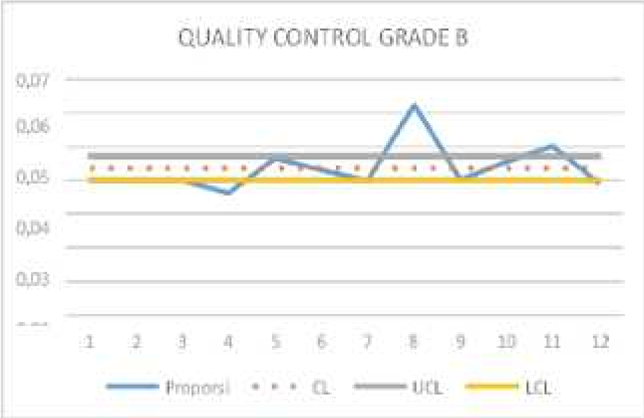

Figure 2: P-Chart Control of Grade B

Based on the sigma level measurement above, the DPMO pattern of the failure of bottled drinking water products (glasses) and the inconsistent sigma achievement still vary up and down throughout the 2023 period. It is known that the sigma level from September 2023 to August 2024 has exceeded the average sigma value in Indonesia, and an average DPMO value of 62633.914 was found with an average sigma level of 3.03. The Sigma Level Measurement Stage and Defects Per Million Opportunities Grade B from September 2023 to December 2023 can be seen in Table 4.

Table 3. Calculation of Sigma and DPMO Grade A

Period	Number of products	Number of defects	CTQ	DPO	DPMO	Six Sigma
1	30.000	698	3	0.0698	69.800	2.98
2	28.800	611	3	0,063645833	63.645.833	3.02
3	32.400	676	3	0.062592593	62.592.593	3.03
4	31.200	586	3	0.056346154	56346.154	3.09
5	31.200	654	3	0.062884615	62884.615	3.03
6	31.200	701	3	0.067403846	67403.846	3
7	32.400	689	3	0.063796296	63796.296	3.02
8	31.200	597	3	0.057403846	57403.846	3.08
9	31.200	638	3	0.061346154	61346.154	3.04
10	31.200	688	3	0.066153846	66153.846	3.01
11	31.200	620	3	0.059615385	59.615.385	3.06
12	32.400	655	3	0.060648148	60.648.148	3.05
sum	374.400	7813	3	0.062604167	62.604.167	3.03
average					62.633.914	3.03

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Table 4. Calculation of Sigma and DPMO Grade B

Period	Number of products	Number of defects	CTQ	DPO	DPMO	Six Sigma
1	30.000	1200	3	0.12	120.000	2..67
2	28.800	1152	3	0.12	120.000	2.67
3	32.400	1296	3	0.12	120.000	2.67
4	31.200	1134	3	0.109038462	109.038.46	2.73
5	31.200	1456	3	0.14	140.000	2.58
6	31.200	1346	3	0.29423077	129.423.08	2.63
7	32.400	1296	3	0.12	120.000	2.67
8	31.200	1948	3	0.187307692	187.307.69	2.39
9	31.200	1256	3	0.120769231	120.769.23	2.67
10	31.200	1425	3	0.137019231	137.019.23	2.59
11	31.200	1567	3	0.150673077	150.673.08	2.53
12	32.400	1267	3	0.117314815	117.314.81	2.69
sum	374.400	16343	3	0.130953526	130.953.53	2.62
average					130.961.47	2.63

Based on the sigma level measurements above, the DPMO pattern of the failure of packaged drinking water products (glasses) and the achievement of the sigma level is still inconsistent, fluctuating throughout the 2023 period. It is known that the sigma level from September 2023 to December 2023 that occurred included the average sigma value for Indonesia, which found an average DPMO value of 130961.47 with an average sigma level of 2.63.

3. Analysis of Causes of Poor Quality AMDK

Analyze is a stage for improving quality by clarifying the causes of damage, namely with a Pareto diagram and a cause-effect diagram. Damage to Grade A is explained in Table 5. The Pareto Diagram of Grade A glass is shown in Figure 5 in the following section.

Table 5. Level of Grade A Product Defect

Type of defect	**Total**	**Percentage**	**Cumulative Percentage**
Slanted Lid	3.173	41%	41%
Packaging	2.936	38%	78%
Leaking Cup	1.704	22%	100%
Total	7.813	100%	

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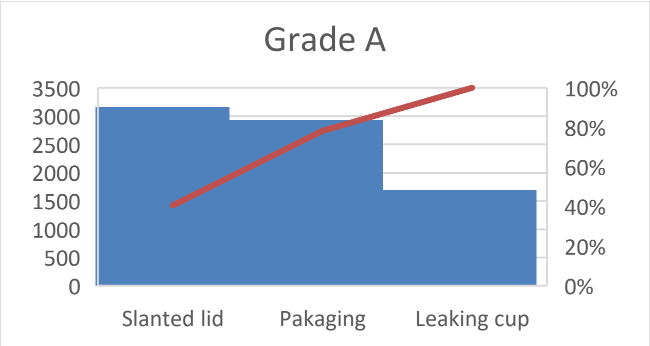

Figure 3: Pareto Diagram of Grade A

As for the amount of damage to glass bottled water products, the Grade B category can be explained in Table 6.

Table 6. Level of Grade B Product Defect

Type of damage	Total	Percentage	Cumulative Percentage
Slanted Lid	6.095	37%	37%
Packaging	6.019	37%	74%
Leaking Cup	4.229	26%	100%
Total	16.343	100%	

Next, the Pareto diagram for the product of glass mineral water packaging with Grade B quality is shown in Figure 6 as follows.

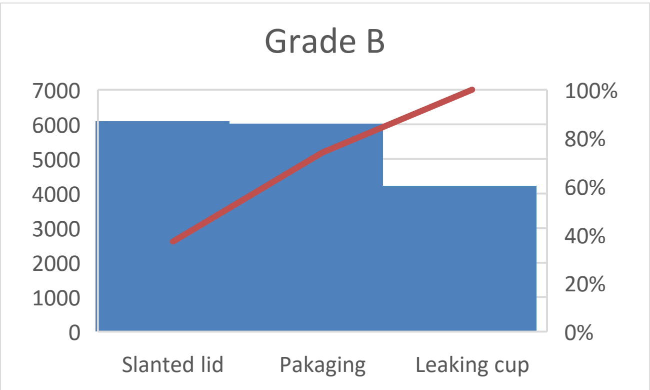

Figure 4: Pareto Diagram of Grade B

4. Cause-and-Effect Diagram

A cause-effect diagram is useful for showing factors that influence quality and have an impact on the problem we are studying. In addition, we can also see more detailed factors that influence and have an impact on the main factor, which we can see from the arrows in the shape of fishbones in the fishbone diagram.

Based on sample data, histograms, and Pareto diagrams, it can be seen that the number of broken cup defects, tilted lids, and packaging for cup products are still outside the standard, and the most dominant is the broken cup defect. The factors causing the broken cup defect can be described using a cause-and-effect diagram. The cause-and-effect diagram of the broken cup defect can be seen in Figure 5.

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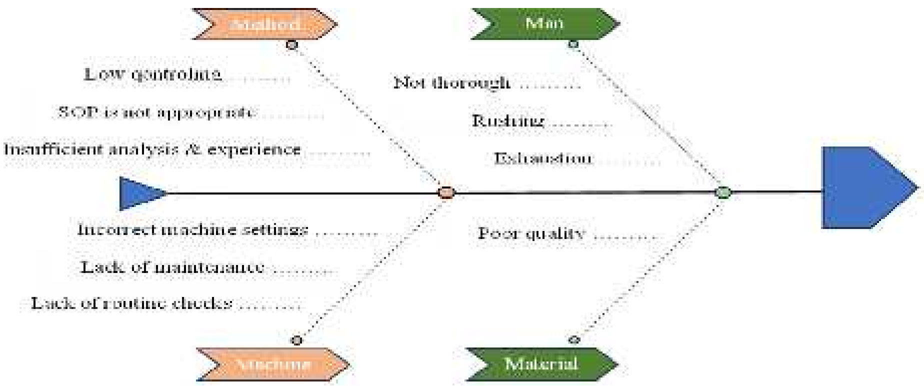

Figure 5: Fish Bone Diagram

Based on the observation results above, the main product defects are caused by raw materials, humans, machines, and methods as follows:

a. Machines, imperfect machine settings in adjusting the thickness of raw materials and machine temperature, lack of machine temperature maintenance, lack of machine temperature maintenance and machine elements, namely molds, compressors, cooling towers, loose panbelts resulting in products that are not in accordance, and lack of routine checks before production so that the machine is damaged during the production process causing a lack of machines
b. Humans, fatigue of thermoforming machine operators due to the large workload given, lack of concentration, lack of thoroughness, being in a hurry when working, and chasing targets, resulting in the production process not running optimally.
c. Methods, lack of analysis and operator experience in machine settings, lack of supervision of performance, incomplete and poorly adhered SOPs, and lack of training for machine operators, causing inconsistencies in machine settings.
d. Materials, poor quality raw materials due to limited raw materials, and raw materials that do not comply with raw material standards, which cause several product defects.

5. Improvement

Some actions in the measurement process that can be taken are:

a. Opportunities: Reduce the number of defective products by implementing more precise Control.
b. Damage: Of the 374,400 products produced from September 2023 to December 2024, there were 7,813 defective products.

Grade A and Grade B capability processes. The Six Sigma Values in Grade A and Grade B are explained in Table 7.

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Table 7. Value of Six Sigma Grade A and Grade B

Periode	Grade A		Grade B	
	DPMO	*Six Sigma*	DPMO	*Six Sigma*
1	69.800,00	2.977	120.000,00	2.67
2	63.645,83	3.025	120.000,00	2.67
3	62.592,59	3.033	120.000,00	2.67
4	56.346,15	3.086	109.038,46	2.73
5	62.884,62	3.031	140.000,00	2.58
6	67.403,85	2.995	129.423,08	2.63
7	63.796,30	3.024	120.000,00	2.67
8	57.403,85	3.077	187.307,69	2.39
9	61.346,15	3.044	120.769,23	2.67
10	66.153,85	3.005	137.019,23	2.59
11	59.615,38	3.058	150.673,08	2.53
12	60.648,15	3.049	117.314,81	2.69
Average value	**62.604,17**	**3.033**	**130.961,47**	**2.63**

The results of the comparison of production process data for grade A and grade B can be seen in Figure 8. From the figure, it can be seen that the comparison of production process data for grade A and grade B shows more damage to grade B, so the production process (quality control) that must be paid more attention to is grade B,wherealldamageisreduced.

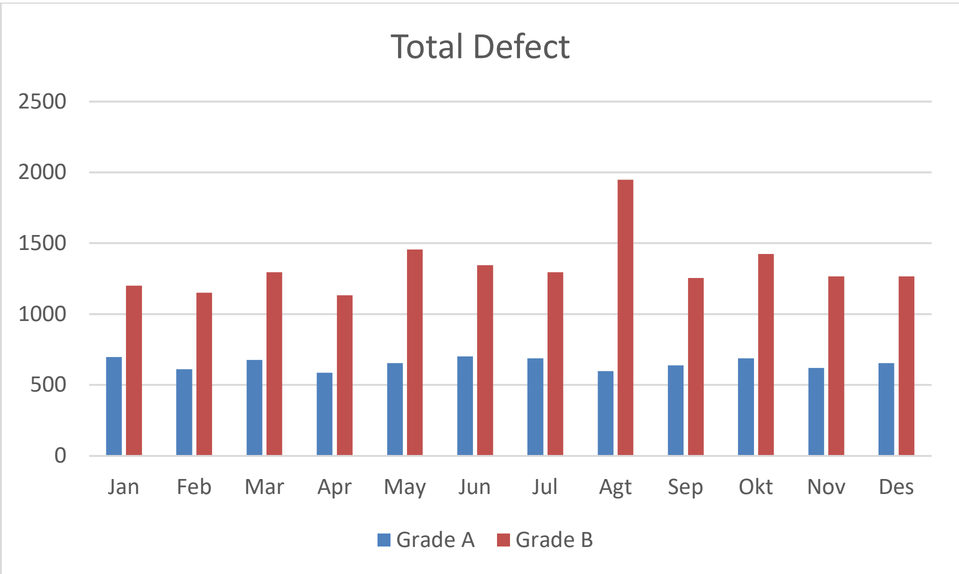

Figure 6: Data Comparison of Grade A and Grade B Production

IV. CONCLUSION

Based on the results of the research and discussion, several conclusions can be drawn as follows.

1. The application of the Six Sigma method can improve performance and reduce the possibility of errors. And in the end, the Six Sigma method is able to improve the quality of its production to be better and can increase profits for the AMDK NUSAQU company.
2. The selection of Cup Grade A raw materials is more recommended than Cup Grade B, given the fewer defective products. Cup Grade A is recommended because the percentage value of Cup Grade A damage reaches 22%. While the

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percentage value of Cup Grade B reaches 37%. The Six Sigma value of Cup Grade A reaches 3.033. While the Six Sigma value of Cup Grade B reaches 2.63. So, Cup Grade A was chosen because its value is better than the value of Cup Grade B

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