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Analysis of the quality of bottled drinking water products through a Six Sigma approach and Failure Mode and Effect Analysis (FMEA) (Case Studies: PT. Sidogiri Mandiri Utama)

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Abstract

PT. Sidogiri Mandiri Utama is a company engaged in Bottled Drinking Water (AMDK) with the brand dangang "Santri" and has been operating since 1997. The raw materials used come from the Umbulan spring located in Mulyorejo hamlet, Pasuruan regency, East Java which is famous for its clarity. The results of the interview with the company, PT. Sidogiri Mandiri Utama currently has not implemented quality control methods. Currently the quality of AMDK products PT. Sidogiri Mandiri Utama has not been maximized, this is shown by the number of defective products that are greater than the established standards. Products with a packaging size of 240 ml are products with the highest percentage of defects. To overcome this problem, the Define, Measure, Analyze, Improve, and Control (DMAIC) approach is used in Six Sigma which is able to reduce defects and also with the FMEA method. Calculation with the Six Sigma method, there has been an increase in Sigma Level after improvement. Meanwhile, analysis using the FMEA method found that the RPN value decreased after the recommendations were implemented. This can be seen from the RPN value at the control stage is smaller than the RPN at the Analyze stage, thus showing the success of the corrective actions that have been taken.

Keywords: Product quality, bottled drinking water, Six Sigma, FMEA.

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1. Introduction

Industry players in the manufacturing sector play an important role in providing and increasing customer satisfaction. In realizing this role, the company requires several aspects that must be considered so that the sustainability of production activities can run more optimally, in this case, the production process (Lo, 2021; Sittisom & Srimarut, 2020). The production process is said to run well if the process can produce products that meet predetermined standards. But in fact in the production process there are still often irregularities and obstacles that result in defects in the products produced. Indirectly, this can reduce competitiveness against the industry which results in selective consumers in choosing products. This is what causes the high variation in the quality of the product (Ellyzabeth Sukmawati et al., 2022; C. Li et al., 2023; Lindenmeier et al., 2021; Sittisom & Srimarut, 2020).

One of the main needs of all living things is drinking water. In general, drinking water is water that has undergone a treatment process so that the water is by the requirements of Bottled Drinking Water quality standards (AMDK) (H. Li et al., 2019; Maneechaeye & Maneechaeye, 2022). AMDK is produced as an effort to meet the need of drinking water for the community. So the company must pay attention to quality aspects in ensuring that the products produced are safe and useful for consumers (Mahsyar & Surapati, 2020; Namjoshi et al., 2020; Stylidis et al., 2020). According to the regulation of the Minister of Industry No. 96/M-IND/PER/12/2011 about the Technical Requirements of the Bottled Water Industry, states that AMDK is water that has been processed without other food ingredients and food additives, packaged, and safe for drinking. The packaging material is a safe material to use for food packaging with the criteria of not causing toxins, not absorbing odors or tastes, rust resistant, and resistant to re-disinfection. In a business, the tighter competition, the more consumer expectations grow and trigger companies to focus more on efforts to retain their customers (Eka Erlinda et al., 2022; Moon & Armstrong, 2020; Simanjuntak et al., 2019).

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PT. Sidogiri Mandiri Utama is a company engaged in Bottled Drinking Water (AMDK) with the brand Dangang Santri and has been operating since 1997. In the process of water treatment into AMDK, it is necessary to carry out several stages so that quality and safe products can be produced for consumption. Santri products are packaged with hygienic processes in several sizes of plastic bottles measuring 330 ml, 600 ml and 1500 ml, plastic cup packaging sizes 240 ml and 120 ml and gallon packaging sizes of 19 liters. The raw materials used come from the Umbulan spring located in Mulyorejo, Pasuruan regency, East Java which is famous for its clarity, freshness and stable mineral content. Production process at PT. Sidogiri Mandiri Utama is carried out in a sustainable manner including the process of Sand Filter, Carbon Filter, sterilized using Ozone (O3), and ultra violet irradiation with Water Treatment technology according to the Indonesian National Standard (SNI).

The results of the interview with the company, PT. Sidogiri Mandiri Utama currently has not implemented quality control methods to maintain product quality. Activities carried out by the company in maintaining product quality include: giving reprimands to employees who have not carried out their duties optimally, submitting complaints to suppliers, returning cups that do not match the specifications to suppliers and getting return cups, collecting customer complaints, evaluation meetings for production parts by production managers and carrying out employee training.

Total AMDK production at PT. Sidogiri Mandiri Utama has fluctuated in the last four years. Where, the total production in 2018 was 59,212 doses, in 2019 it was 61,739 doses, in 2020 it was 61,228 doses, and in 2021 it was 63,041 doses. Of the total production, the most widely produced packaging products are 240 ml glass packaging products with an average production of 14,389 doses over the last four years. As for the percentage of defects over the last four years, the percentage of defects produced are: in 120 ml packaging of 0.67%, in 240 ml packaging of 0.81%, in 330 ml packaging of 0.66%, in 600 ml packaging of 0.68%, in 1.5 liter packaging of 0.64%, and in 19 liter packaging of 0.66%.

PT. Sidogiri Mandiri Utama Set a standard for the percentage of defects at 0.70% of total production. Of the six packaging sizes, products with a packaging size of 240 ml are the products with the highest percentage of defects. Where the percentage has exceeded the standard limit set by the company. While the types of defects that have been identified, among others: Less Volume, Dirty Water, Damaged Packaging, and Untidy Cover. Therefore, this study will use quality improvement on 240 ml packaged AMDK products with the DMAIC method. This size selection is based on the consideration that this packaging has the highest percentage of defects. Thus, it is necessary to carry out quality control in the production process to be in accordance with the company's production goals.

Six Sigma is a method that consists of steps to improve the production process by focusing on finding the factors that cause defects and errors so that indirectly this method can improve not only product quality but also production quality (Graafmans et al., 2021; Tampubolon & Purba, 2021). The basic principle of Six Sigma is product improvement by making improvements to the process so that the process produces a perfect product. Six Sigma methods focus on defects and variations, starting with identifying critical quality elements of a process. The goal of Six Sigma is to reduce variation in output so that it will not exceed six standard deviations (Six Sigma) between the mean (mean) and the nearest specification limit (Byrne et al., 2021; Kaswan & Rathi, 2020; Laureani & Antony, 2019). In the Six Sigma Define, Measure, Analyze, Improve, and Control (DMAIC) method, researchers perform the Improve method using Failure Mode and Effect Analysis (FMEA) which is expected to identify the cause of the problem and provide suggestions for improvements in quality improvement. This research was conducted as a proposed improvement in reducing the risk of defects in AMDK products through the Six Sigma approach and Failure Mode and Effect Analysis (FMEA).

2. Method

The Six Sigma method is used to improve the production process which is focused on reducing defects in AMDK packaging "Santri" using intensive statistical techniques so that it can measure a process based on the defect reduction rate category. Six Sigma on DMAIC concept was used in this study to solve problems systematically. Collection of internal company data obtained from the observation process carried out from May 2022 to July 2022 until sufficient data is needed. The research was conducted at PT. Sidogiri Mandiri Utama. The following is internal data obtained from May to July 2022. Data analysis using FMEA (Failure Mode and Effect Analysis).

3. Results and Discussion

The percentage result of defects in AMDK Products PT. Sidogiri Mandiri Utama:

Table 1. Percentage of AMDK Product Defects PT. Sidogiri Mandiri Utama

Items	Average production		*Defect* (unit)	Defect percentage (%)
	Perdos	Unit		
Packaging 120 ml	8662	389779	2604	0.67
Packaging 240 ml	14389	690648	5570	0.81
Packaging 330 ml	7807	187368	1236	0.66
Packaging 600 ml	10023	240552	1644	0.68
Packaging 1,5 litre	9508	114099	732	0.64
Packaging 19 litre (gallons)	10917	10917	72	0.66

Table 1 shows that AMDK 240 ml products have the most defects of 0.81%.

The results of Six Sigma data processing use the DMAIC concept as follows:

3.1. Define

Identify AMDK products PT. Sidogiri Mandiri Utama. Four defects in the production process occur, namely less volume, dirty water, damaged packaging, and untidy covers. The defined results are set out in Table 2.

Table 2. AMDK Product Defect Type Data for May-July 2022

No	Production amount	Types of disability				Number of defect
		Less volume	Dirty/ cloudy water	Damaged/ crushed packaging	Logo prints/ untidy cover	
1	14900	11	2	68	24	105
2	13700	14	4	46	31	95
3	13300	7	1	89	38	135
4	16200	16	6	63	22	107
5	11350	9	3	70	27	109
6	12800	13	7	53	37	110
7	13100	17	5	58	28	108
8	17100	10	9	66	39	124
9	10400	15	4	79	40	138
10	15100	13	0	48	26	87
11	14100	11	3	82	34	130
12	12350	14	5	69	25	113
Total	**164400**	**150**	**49**	**791**	**371**	**1361**

Table 2. The above shows that the total defects that occurred in AMDK products during the last 12 weeks were 1361 units out of the total products produced of 164400 units. The types of defects that have been identified, among others: less volume with a total of 150 units, dirty water a total of 49 units, damaged packaging with a total of 791 units, and untidy covers with a total of 371 units.

3.2. Measure

The Measure stage is the measurement stage for the object of research, namely the AMDK product. Measurements are made in terms of defect levels based on DPMO (Defect Per Million Opportunity) values and Six Sigma levels.

3.2.1. Calculating the percentage of defects

Presentase *Defect* = $\frac{Total\ Defect}{Total\ defect\ product}$ x 100%

Presentase *Defect* = $\frac{150}{1361}$ x 100% = 11.021%

From the calculation above, it can be seen that the percentage of defects in the "less volume" category during May to July was 11.021%.

Table 3. Recapitulation of DPO, DPMO, and Sigma Level for May to July 2022

No	Production amount (unit)	Number of defect (unit)	CTQ	DPO	DPMO	Level Sigma
1	14900	105	4	0.001762	1762	4.42
2	13700	95	4	0.001734	1734	4.42
3	13300	135	4	0.002538	2538	4.30
4	16200	107	4	0.001651	1651	4.44
5	11350	109	4	0.002401	2401	4.32
6	12800	110	4	0.002148	2148	4.36
7	13100	108	4	0.002061	2061	4.37
8	17100	124	4	0.001813	1813	4.41
9	10400	138	4	0.003317	3317	4.17
10	15100	87	4	0.001440	1440	4.48
11	14100	130	4	0.002305	2305	4.33
12	12350	113	4	0.002287	2287	4.34
Average				**0.002121**	**2121**	**4.36**

Table 3 shows that the average DPO (Defect Per Opportunity) value was 0.002121, the Defect Per Million Opportunity (DPMO) value was 2121, and the sigma level value was 4.36 for the last 12 weeks from May to July.

3.3. Analyze

The Analyze stage is the third step in the six sigma method, which is to analyze the results of measurements that have been carried out in the previous stage and determine the root cause of CTQ using a fishbone diagram.

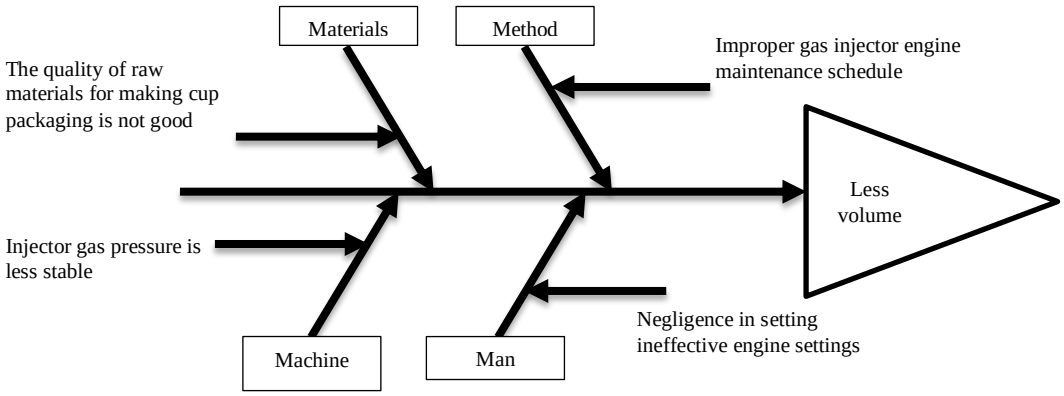

Figure 1. Fishbone Diagram Defect Less Volume

In Figure 1 fishbone diagram product defect volume is less occurs because the material in the quality of raw materials for making cup packaging is not good, plus the method in the gas injector engine maintenance schedule is not right, and human negligence in setting engine settings is less effective, and the engine releases gas injector pressure less stable.

The quality of a product greatly determines customer satisfaction, food or beverage products that taste bad, expired, the amount of contents that do not match the packaging writing, unattractive packaging makes customers disappointed and there is no desire to buy the product again (Lo, 2021; Nasution et al., 2021; Tampubolon & Purba, 2021).

Figure 2 is fishbone diagram Dirty water:

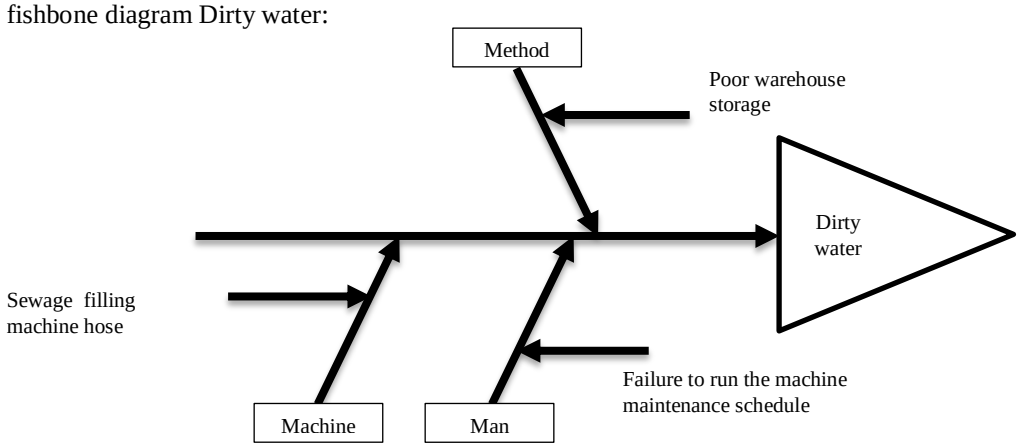

Figure 2. Fishbone Diagram Defect Air Kotor

In Figure 2 fishbone diagram of dirty water product defects occur due to poor warehouse storage methods, dirty filling machine hoses, and human negligence in carrying out machine maintenance schedules.

Quality mineral drinking water products sold in packaging must pay attention to water color, odor, and taste. The color of the water changes not only due to temperature, packaging, storage, but also the tools used to fill water into the packaging must also be clean (Hussein et al., 2022; Tan et al., 2022; Zavarzina et al., 2022). Jadwal perawatan mesin harus sangat diperhatikan untuk mencegah terjadinya mesin rusak dan produk tidak berkualitas (Fuadiya & Widjajati, 2022; Hossayni et al., 2020).

Figure 3 is diagram of fishbone damaged packaging:

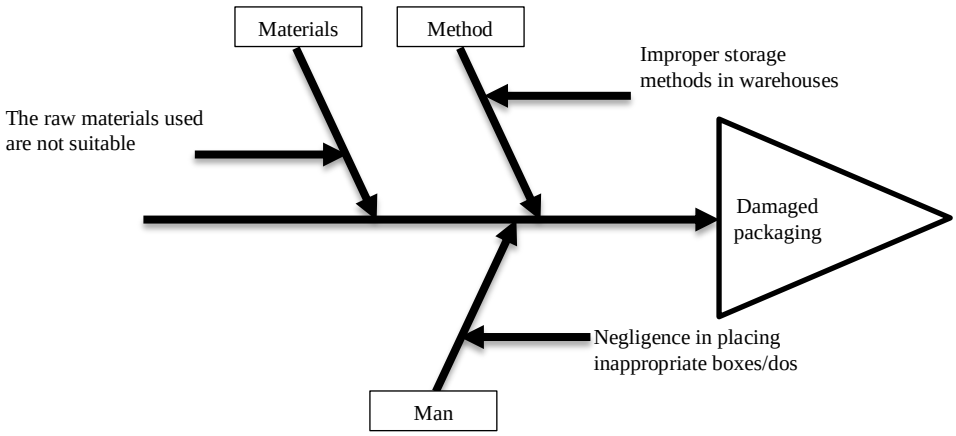

Figure 3. Fishbone Diagram Defect Damaged Packaging

In Figure 3 fishbone diagram defects damaged packaging occurs because the material from the raw materials used is not appropriate, the method in storage methods in warehouses is not right, warehouse storage methods are not right, and human negligence in placing boxes / doses that are not appropriate.

The process of packaging and storing products affects product quality. Even though the product is in a quality condition, the packaging is not appropriate, including the room, the treatment of the product after packing, and the position of the goods that are not suitable, for example the room is too hot or stacking or goods are thrown or slammed (Herdian & Cokki, 2022; Tumanggor et al., 2020; Wang, 2013).

Figure 4 is the fishbone diagram of the untidy cover:

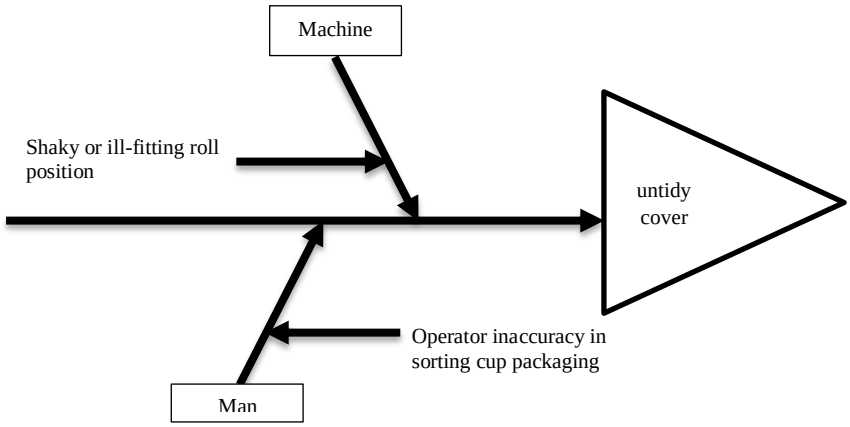

Figure 4. Fishbone Diagram Defect Untidy Cover

In Figure 4 fishbone diagram the defect of the cover is not neat because the cover machine occurs a shaky or improper roll position and human inaccuracy in sorting the cup packaging.

Packaging goods is an important job so that a product can be neatly packaged, not open, and does not damage the quality of the contents of the product (Duka et al., 2023; Misbachul Munir, 2021; Weyer et al., 2014). To minimize the presence of defects in a product can be done with the accuracy and supervision of good packaging workers, and repeated checking of tools such as cover seals or closing machines consistently (Drago et al., 2020; Yulianingsih et al., 2019).

3.4. Improve with metode Failure Mode and Effect Analyze (FMEA)

This stage calculates the Risk Priority Number (RPN) to determine recommendations for improvements that can be proposed from various defects that occur. This method can analyze system reliability and the causes of non-compliance with the system, design, process requirements, and safety by providing basic information about system reliability, design, and process predictions. The results of the FMEA volume category are less contained in Table 4.

Table 4. FMEA Volume Less

Modes of Failure	Effect of Failure	S	Causes of Failure		O	Current Controls	D	**RPN**
Less volume	The resulting cup packaging products have varying volume portions	6	*Materials*	Poor quality of raw materials	5	Rigorous selection and inspection of raw materials	3	**90**
			Method	Improper gas injector engine maintenance schedule	2	Rescheduling by management	6	**72**
			Machine	Injector gas pressure is less stable in the filling process	4	Perform maintenance on filler machines	5	**120**
			Man	Negligence in setting ineffective engine settings	3	The operator increases accuracy in setting machine settings	3	**54**

Table 4 shows that the factors causing volume defects include poor quality of raw materials, improper gas injector engine maintenance schedules, unstable gas injector pressure in the filling process, and negligence in setting ineffective engine settings. For the improvement proposals, namely strict selection and inspection of raw materials according to the company's SOP, rescheduling is carried out by the management which is carried out at least once a month, repairs and machine inspections in the filling process periodically and carried out at least once a month, and operators further increase accuracy in adjusting machine settings.

Table 5. FMEA Dirty Water

Modes of Failure	Effect of Failure	S	Causes of Failure		O	Current Controls	D	**RPN**
Dirty water	The resulting content water is cloudy or dirty so it is less hygienic	8	*Method*	Poor warehouse storage	3	Cleaning the warehouse and always checking the shelf life	3	**72**
			Machine	Dirty filling machine hose	5	Inspection of filling machines before production	2	**80**
			Man	Negligence in carrying out the machine maintenance schedule	5	Granting a reprimand to the officer/operator on duty	4	**160**

Table 5 can be seen that the factors causing dirty water defects include poor warehouse storage quality, dirty filling machine hoses, and negligence in carrying out machine maintenance schedules. For proposed improvements, namely routine and scheduled warehouse cleaning and always checking the shelf life and expiration period of products, checking filling machines before and after production, and giving reprimands and strict sanctions are imposed on the officer/ operator responsible.

Table 6. FMEA Packaging Damaged

Modes of Failure	Effect of Failure	S	Causes of Failure		O	Current Controls	D	**RPN**
Damaged Packaging	Cup packaging products produced have a less-than-perfect shape (dents, thin layers, and leaks)	7	*Materials*	The raw materials used in making cup packaging are not in accordance with SOPs	6	Buy and choose raw materials that are better than standard specifications	3	**126**
			Method	Improper placement or storage of warehouses	4	Arranging and rearranging boxes and periodic checks	4	**112**
			Man	Negligence in placing boxes/dos that are not following standards	5	Pay more attention to the maximum fulcrum load limit of box placement	2	**70**

Table 6 shows that the factors causing defects in damaged packaging include raw materials used in making cup packaging not by SOPs, improper placement or storage of warehouses, and negligence in placing boxes/doses that are not by standards. For the proposed improvements, namely 1) buying and choosing suppliers of raw materials that are better than standard specifications, 2) paying more attention to the accuracy of the company's QC when taking and examining samples, 3) Making a track record of raw material problems for QC parties in improving quality, checking stored goods regularly and expanding the storage warehouse area, and paying more attention to the maximum fulcrum load limit for box placement.

Table 7 can be seen that the factors causing untidy cover defects include a shaky or ill-fitting roll position and an oil-lubricated roll machine, and the operator's inaccuracy in sorting the cup packaging that will pass through the cup sealer machine. For the proposed improvement, namely giving a certain pause or interval in the production process and checking the machine, and checking the filling machine before and after production, and training employees on the importance of paying attention to sorting good cup packaging.

Table 7. FMEA Untidy Cover

Modes of Failure	Effect of Failure	S	Causes of Failure		O	Current Controls	D	RPN
Untidy Cover	The final product results are not perfect and not feasible in terms of product aesthetics it affects the company's brand image	6	Machine	Shaky or ill-fitting roll position and oil-lubricated roll engine	4	Giving a certain pause or time lapse in the production process	4	**96**
			Man	Inaccuracy of the operator in sorting the cup packaging that will pass through the cup sealer machine	3	Employees pay more attention to sorting cup packaging	5	**90**

3.5. Control

At this stage, RPN recalculation is carried out after the Improve stage. This recalculation is done to determine the extent to which the improvement progress is made if the recommendations are implemented. After recalculating the RPN, it can be seen that progress has occurred after the improvement recommendations are applied. The RPN in the Control stage is smaller than the RPN in the Analyze stage, this indicates the success of the corrective actions that have been taken.

4. Conclusions and Recommendation

The conclusions based on this study are as follows:

a) Based on the results of AMDK product data processing from May to July 2022, the types of defects in mineral water packaging products identified are 4 CTQs, including less volume, dirty water, damaged packaging, and untidy covers. Based on the results of data processing in Table 3, it is known that the failure of every one million opportunities (DPMO) produced is 2121 products from the average total amount of production from May to July 2022. So that AMDK products produce an average sigma value of 4.36 which means that it still does not meet the target, which is towards world-class company standards or 6σ (sigma).

b) Proposals or recommendations for improvements that can minimize the risk of defects in bottled mineral water products in the company include: strict selection and inspection of raw materials according to company SOPs, repair and inspection of machines in the filling process periodically and carried out at least once a month, routine and scheduled warehouse cleaning and always checking the shelf life and expiration period of products, Inspection of filling machines before and after production. Granting reprimands and imposing strict sanctions on responsible officers, making a track record of raw material problems for Quality Control (QC) parties in improving quality, checking stored goods regularly and expanding the storage warehouse area, and paying more attention to the maximum fulcrum load limit for box placement and the need to provide certain pauses or time intervals in the production process and check the machine.

Recommendation that can be given at the end of the study as consideration for further researchers are that the company is expected to improve product quality by considering recommendations and making improvements during the production process.

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