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Quality Control of HDPE Bottles Production Processes based on Multivariate Attribute Data using T^2 Hotelling Control Chart as A Responds of Environment and Sustainability Issues

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Quality Control of HDPE Bottles Production Processes based on Multivariate Attribute Data using T^2 Hotelling Control Chart as A Responds of Environment and Sustainability Issues

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Abstract. This research was conducted to determine the current process capability in producing the M500 bottle, where the process capability index can be calculated from the results of a control chart whose data is considered to be statistically controlled. Multivariate control charts can be used in controlling the quality of the process at CV X because the quality characteristics of the products are more than one, and the controls must be carried out together. Correlated variables used in making multivariate control charts are different thicknesses, leaks, and dents. The results of the hotelling's T2 control chart show that the process has not been controlled because four observations are out of control. MYT decomposition results show that variables that cause observations to become uncontrolled are different thicknesses and dents. After revising the control chart, it is known that the current multivariate process capability index is 0.79, which means the process is said to be incapable and needs to be improved. The suggested improvement given to overcome the problem of different thicknesses is to position the die right in the middle so that the thickness on all sides is the same and for dented conditions can be reduced by adjusting the blowing temperature and pressure according to the standard.

1. Introduction

Control of product quality is an effort to reduce defective products produced by the company. Without quality control activities, it will cause enormous losses for the company because of irregularities that are unknown so that repairs cannot be done. Eventually, deviations will occur on an ongoing basis. If quality control can be appropriately implemented, any deviation can be used to improve the production process in the future. Thus, the production process that always pays attention to product quality will produce products that have high quality and are free from defects/damage. The use of plastic products nowadays almost meets all the needs of the community, because plastic products have advantages, including being more economical, flexible, and lightweight [1]. Data from Euromonitor also said, based on average growth (Compound Annual Growth Rate / CAGR) in Indonesia, the market for household plastic products will continue to increase in 2018. Growth in the market size for the category of purchasing products, food storage and dinnerware is 11.2% per year.

CV X is a medium-scale manufacturing industry that produces plastic products. CV X manufactures a wide range of plastic products with its superior products in the form of plastic bottles made from PET and HDPE plastic bottles, bottle caps, and plugs. Quality control activities at CV X have been carried out, starting from the receipt of raw materials to the process of sending products to consumers. Quality control activity is only in the form of a check (check sheet), whether the goods are received or not, and how many in each production period. The product that was the object of this research was the M500 bottle produced by the Extrusion Blow Moulding (EBM) machine. The M500 bottle is made from High-Density Polyethylene (HDPE) plastic raw material, which is the most requested HDPE product. Many reject products produced while producing M500 bottle exceed the target set by the company at 10%. Losses caused by high number of reject products are time wasted, production targets not reached, workforce planning is not appropriate, losses due to wasted material, and disrupted production schedules. Therefore, it is necessary to do quality control that can analyze the deviations in which variables are the cause of many rejected products so that deviations do not occur on an ongoing basis.

This study aims to control the production process of the M500 bottle on CV X. The most frequently used tool for multivariate methods is the same as in the univariate case, namely, the control chart [2]. Control of the process is carried out with a multivariate attribute control chart because the quality characteristics used are qualitative data classified as defective/non-defective products. The control chart used is a multivariate p map and the hotelling's T2 map. This study also compares the results of quality control from the control chart used. From the results of the calculation of the control chart where all data are controlled, the current process capability index is calculated, and an improvement proposal is given to reduce the number of reject products.

Multivariate analysis is a method of analyzing statistical data that is carried out simultaneously by paying attention to correlations/relationships between variables that exist or not [3]. In today's industrial world, sometimes in handling multivariate data, it usually uses one univariate control chart for each variable. This approach creates a lot of control charts and can confuse users/companies so that it can cause decision-making errors. Several quality characteristics that become variables which are correlated and controlled separately, they will cause some errors related to the out of control process [4].

Plastic is one of the primary pollutants among various pollutants that often discharge into the environment. Plastics need more time to be degraded in the soil. Plastic burning release chemicals such as phosgene and dioxide, which are harmful to the ecosystem. It is estimated that 65% - 70% of plastics are produced ends up as waste disposal [5]. Plastic sized less than 5 mm is categorized as microplastic and is one of the biggest potential threats to the marine environment for the whole world. There are two types of microplastic, namely primary microplastic and secondary microplastic. Primary microplastic is a by-product of particle emissions released from industrial production or the release of plastic dust from plastic products. Secondary microplastics are the material of larger plastic particles. Microplastic can also act as a pollutant transport medium for other toxic elements such as DDT and hexachlorobenzene, which end up in the body of living organisms that consume them [6].

2. Research method

2.1 Quality control

The meaning of quality can vary depending on the series of words or sentences in which the term quality used and the people who use it [7]. Quality is a number of attributes or traits as described in the product or service concerned with the use of existing products [8]. Quality control is an essential tool for management to improve product quality (if needed), maintain quality -which is already high, and reduces the number of damaged goods [9]. Quality control is an integrated activity in controlling material quality standards, production process standards, semi-finished goods, finished goods, and delivery standard of the final product to consumers so that the goods/services produced are by planned quality specifications [10].

2.2 Production process extrusion blow moulding

Blow moulding covers three main thermoplastic processes, namely extrusion blow moulding, stretch blow moulding, and injection blow moulding. Blow moulding is the process of making or forming hollow products by inflating or blowing a liquid thermoplastic tube commonly called "parison" or using a preform made of polyethylene terephthalate (PET) material. The following stages are in the extrusion moulding process [11]:

1. In the engine cylinder, plastic material (plastic going) is heated at a specific temperature until it becomes soft (semi-fluid).
2. The softened plastic will be removed through a forming die (a mould hole or mould with a certain profile), using a certain pressure.
3. The plastic that has been formed then produces a product that is still hot and cools.
4. After the product has the desired length, it will be cut afterwards with a special cutting tool on the extrusion machine.

2.3 Attribute data

Attribute data is qualitative data that can be calculated for recording and analysis [12]. The attribute data is discrete, which means its value is always in the form of integers. Examples of quality characteristics attribute data are the absence of labels on product packaging, administrative errors in the customer's savings book, many types of defects in the product, and so on because they are obtained from the defects number calculation of each variable/quality characteristic. Discrete data has several statistical distributions, such as binomial distribution and multinomial distribution.

2.4 Correlation analysis

Correlation analysis is a set of statistical techniques used to measure the closeness of a relationship (correlation) between two variables. The primary function of correlation analysis is to determine how close the relationship is between two variables. One measure that states the closeness of a relationship is the correlation coefficient.

2.5 Multivariate normal distribution

A multivariate normal test is an analytical method used in cases where the quality of a product is measured by more than one variable which is carried out to test the assumption that the distribution of data to be analyzed has a multivariate normal distribution. Before the data are analyzed using a multivariate control diagram, the data must meet the assumption of a multivariate normal distribution test. Data is said to be multivariate in normal distribution if the plot of qi (*chi-square*) and di^2 values (mahalanobis distance) tends to form a straight line [13]. The principle of Mahalanobis distance is to calculate the distance between a variable and the centre from all observations [14].

2.6 Multivariate p-control charts

A multivariate p control chart is a control chart that has a multinomial random distribution with parameters (n, p) where n is the sample size and p is a probability vector of defects [15]. With k sample in the size of the n sample from the multinomial X process with parameters (n, p) so that C_i is the number of items from the jth sample classified in the defect category D_j. The parameter estimator is not biased from p_j as follows.

$$\overline{\hat{p}_i} = \frac{1}{k}\sum_{j=1}^{k}\hat{p}_{ij} \qquad i= 0, 1, 2, …, m \tag{1}$$

Where $\hat{p}_{ij} = \frac{C_{ij}}{n}$ with j= 1, 2, …,k and i = 0, 1, …,m. with sampling statistics $\hat{\delta}_i = \sum_{i=0}^{m} d_i\hat{p}_{ij}$ so the control limit values for multivariate p-Control charts are as follows.

$$UCL = \sum_{i=0}^{m} d_i \overline{\overline{p}}_i + \sqrt{x_{m,\alpha}^2} \sqrt{\frac{1}{n} \left[\left(\sum_{i=0}^{m} d_i^2 \overline{\overline{p}}_i \right) \right] - \left[\left(\sum_{i=0}^{m} d_i \overline{\overline{p}}_i \right)^2 \right]} \qquad (2)$$

$$CL = \sum_{i=1}^{m} d_i \overline{\overline{p}}_i \qquad (3)$$

$$LCL = \sum_{i=0}^{m} d_i \overline{\overline{p}}_i - \sqrt{x_{m,\alpha}^2} \sqrt{\frac{1}{n} \left[\left(\sum_{i=0}^{m} d_i^2 \overline{\overline{p}}_i \right) \right] - \left[\left(\sum_{i=0}^{m} d_i \overline{\overline{p}}_i \right)^2 \right]} \qquad (4)$$

2.7 Hotelling's T^2 control chart

Hotelling's T^2 control chart is one of the multivariate control charts based on individual observations. This control chart is for observations with the number of samples in all variables being the same or n = 1. Use the individual hotelling's T^2 control chart to detect shifts in the process mean by using the sample mean vector ($\overline{p}$_ (. J)) and the covariance matrix (S).

$$\bar{p}_{.j} = \frac{1}{m} \sum_{i=1}^{m} p_{ij} \qquad (5)$$

$$S = \frac{1}{(m-1)} \sum_{i=1}^{m} (p_{.i} - \bar{p}_j)(p_{.i} - \bar{p}_j)' \qquad (6)$$

$$T_i^2 = (p_{ij} - \bar{p}_{.j})' S^{-1} (p_{ij} - \bar{p}_{.j}) \qquad (7)$$

$$UCL = \frac{p(m-1)}{m-p} F_{\alpha,p,m-p} \qquad (8)$$

$$LCL = 0 \qquad (9)$$

2.8 MYT decomposition

This method is the development of the decomposition method of hotelling's T^2 to determine the contribution of variables or relationships between variables that cause an out of control process into the multivariate control diagram arrangement. MYT decomposition was carried out after the uncontrolled ith observation was detected by hotelling's T^2 statistics. Upper control limits for unconditional forms:

$$Ti^2 = \frac{(xi - \overline{x})^2}{Si^2} \sim \frac{m+1}{m} F_{1,(m-1)} \qquad (10)$$

2.9 Process capability index

Measurement of process performance using the process capability index is an important thing to do. The process capability index is a statistical technique used to analyze variability relative to product specifications, and a process is said to be capable if the value of Cp ≥ 1 [12].

2.10 Data collection

Data collection is done through literature studies and using data held by the company. Data collection techniques used in this study are:
- Interview

   Interviews were conducted with the head of the department and QC staff to determine the quality characteristics that influence the decision that a product is declared as a reject product or not. In addition, interviews were also conducted with the head of the production to find out the percentage of reject products produced on EBM machines.
- Secondary data

After conducting interviews and knowing firsthand the existing conditions, the next step is to collect secondary data. The variables carried out are ten variables checked. In this study, the variables to be controlled by multivariate control maps are variables that meet the assumption that these variables have multivariate correlations and are normally distributed. Taken samples were obtained based on historical company data, namely data in the January-April 2019 period and amounted to ± 90 samples.

2.11 Sample and population

The population in this study is all products produced by extrusion blow moulding (EBM) machines. Sampling is done on a daily basis. In phase I, the samples taken were obtained based on historical data of the company, namely in the period January-February 2019 and amounted to ± 50 samples. The determination of this sampling based on processing phase I with sample (m) ≥ 20 [12]. Whereas for phase II the data used is the most recent data, which is the data for the period March-April 2019, amounting to ± 40 samples. Phase II aims to monitor the process, whether it is controlled or not.

2.12 Research variable

CV X has a variety of quality characteristics that are used as a determinant of whether a product is included in the product reject or not. There are ten variables (quality characteristics) checked, but not all of these variables are used in this study. Variables used are quality characteristics that are correlated and normally distributed, amounting to three variables, namely different thicknesses, leaks, and dents.

3. Result and discussion

3.1 Control chart

Characteristics can be known by using descriptive statistics to find the average, variance, minimum and maximum values of the M500 bottle production process data in CV X with 93 observations. The descriptive statistics for the January-April 2019 production data can be seen in Table 1.
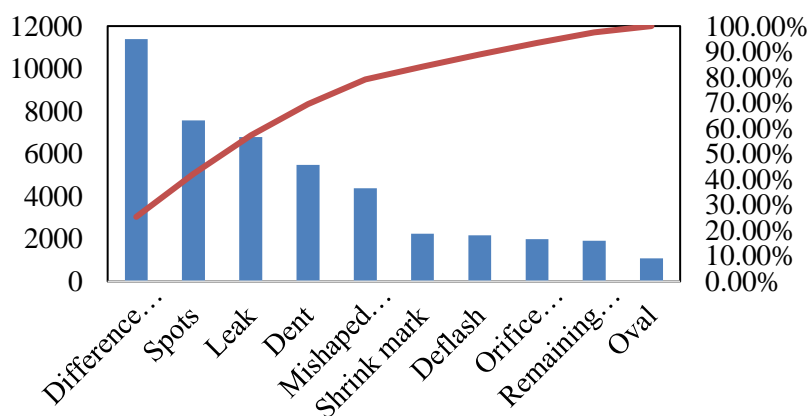

Figure 1. Pareto Chart of Product Reject (M500)

Based on the Pareto chart, it shows that the highest type of defect is different thickness, with the number of defects of 11,381 bottles while the types of defects with the least amount are oval as many as 1088 of the total production defects of 44,978 bottles. To create a multivariate control chart, two

assumptions that must be fulfilled are correlated variables and multivariate normal distributions. Here, multivariate correlation test uses Pearson's Correlation Coefficient. Correlation test conducted using Minitab software produces Pearson correlation value and p-value, where if the Pearson correlation value> 0.2 and p-value <0.05 means that there is a correlation between variables. There are three variables that are correlated, namely, different thicknesses, leak, and dent. Correlation test calculation values for each variable are, between different thicknesses with leaks (Pearson correlation = 0.306; p-value = 0.002), between different thicknesses with dents (Pearson correlation = 0.343; p-value = 0.001), and between leaks with dents (Pearson correlation = 0.279; p-value = 0.006). The results of multivariate normal distribution testing on plot data tend to form a straight line. The value of the mahalanobis distance correlation with a chi-square value of 0.947, meaning the correlation value is more than 0.5, it can be concluded that the multivariate normal distribution data.
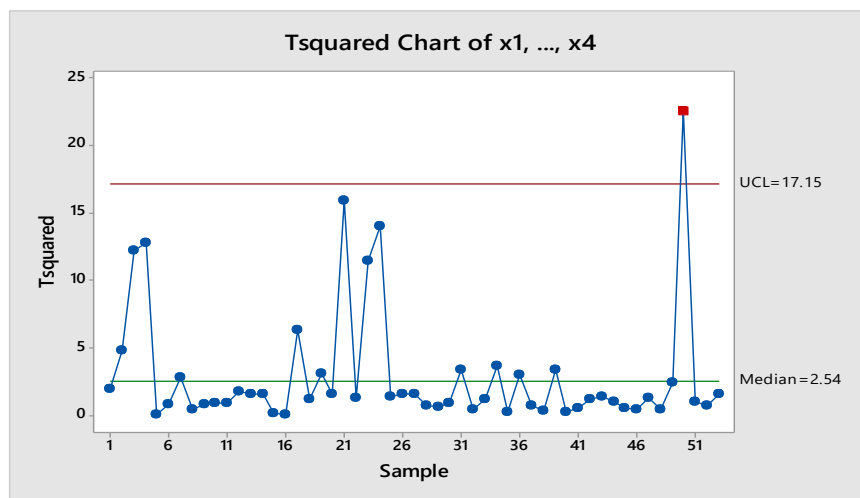

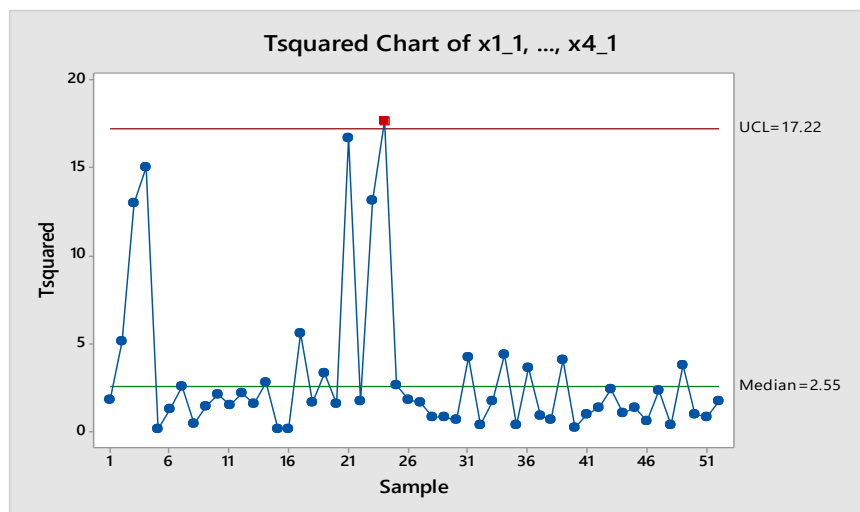**Figure 2.** Hotelling's T^2 Phase I Control Chart
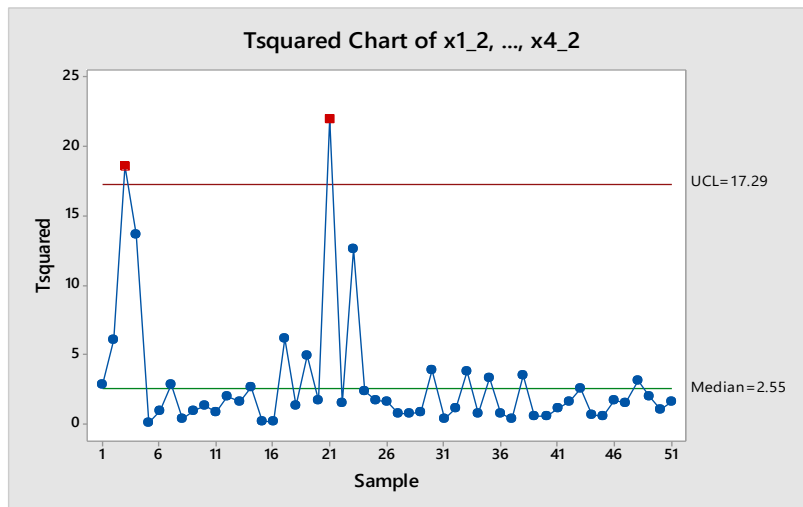

Figure 3. Hotelling's T^2 Repair 1 Control Chart

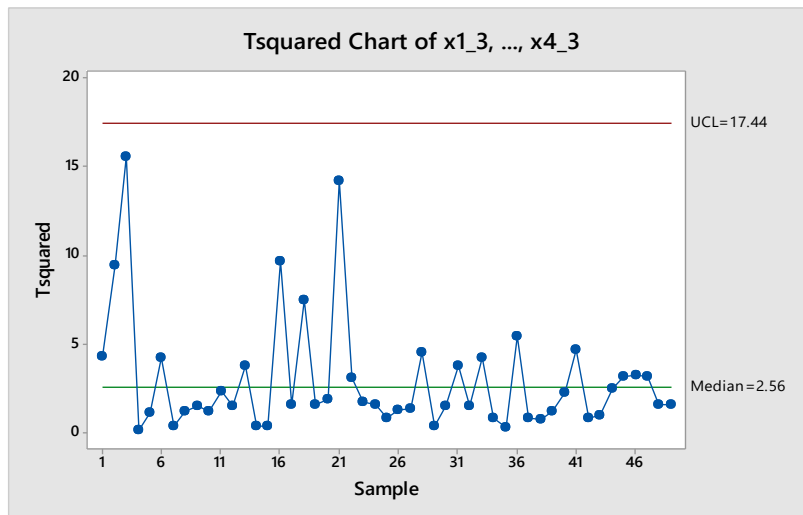**Figure 4.** Hotelling's T^2 Repair 2 Control Chart

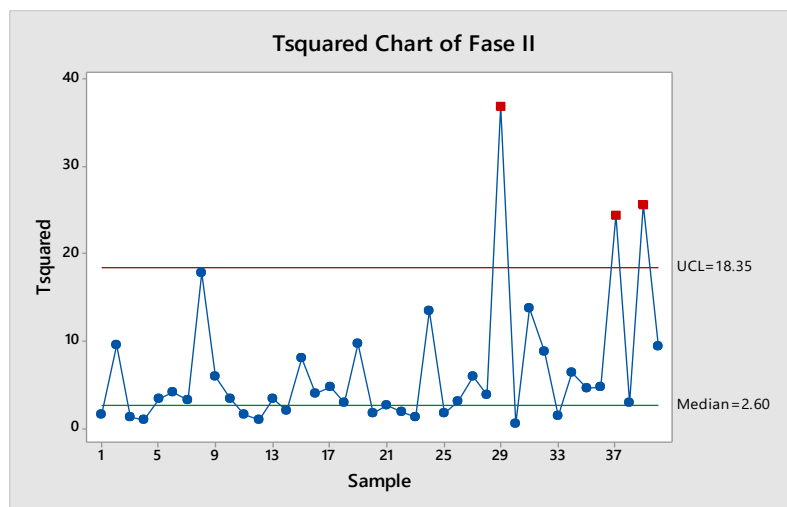**Figure 5.** Hotelling's T^2 Repair 3 Control Chart

Figure 6. Hotelling's T^2 Phase II Control Chart

In the pictures above, it appears that there are data out of control which means that the production process in phase II has not been controlled. Therefore, improvements are needed to make the production process more controlled.

3.2 MYT decomposition

Here are the results of MYT decomposition for all out of control data for different thickness variables (x1), leak (x2) and dents (x4) with an upper limit of 4.1026:

Table 1. T^2 decomposition

Data *Out*	T_i^2	MYT Decomposition		
		T_1^2	T_2^2	T_4^2
3	18,61	0.128656	0.141431	15.30983*
21	22,05	0.002992	4.099256	0.649486
24	17,67	9.448272*	0.911519	11.02163*
50	22,5	14.98479*	1.152392	2.489921
Total		2	-	2

Variables that cause observations to become out of control are variables that have a decomposition value higher than the upper limit. Based on the table above, the variables x1 and x4 are obtained, namely, different thicknesses and dents are the cause of out of control in the observation process. Therefore these variables are made as the main priority in the improvement process.
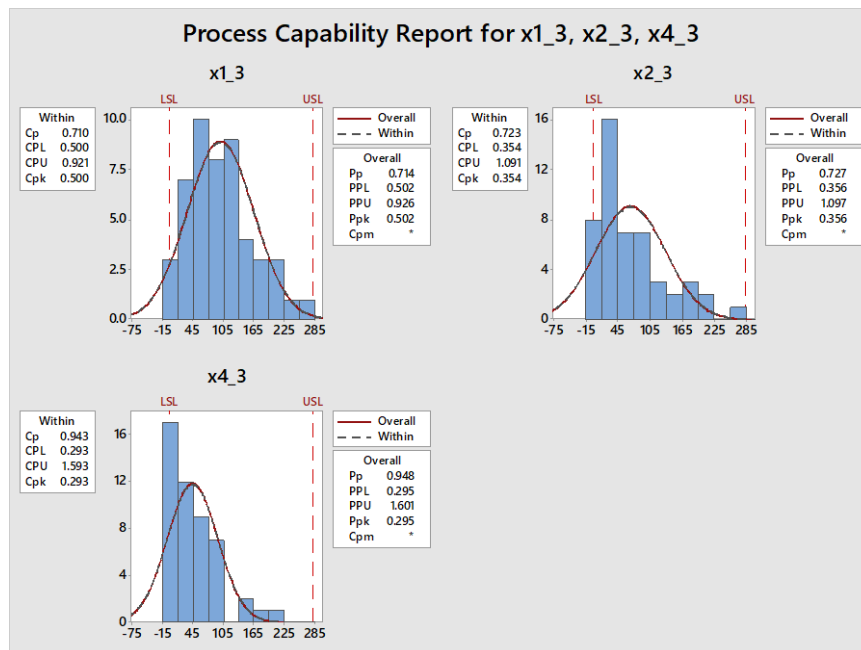

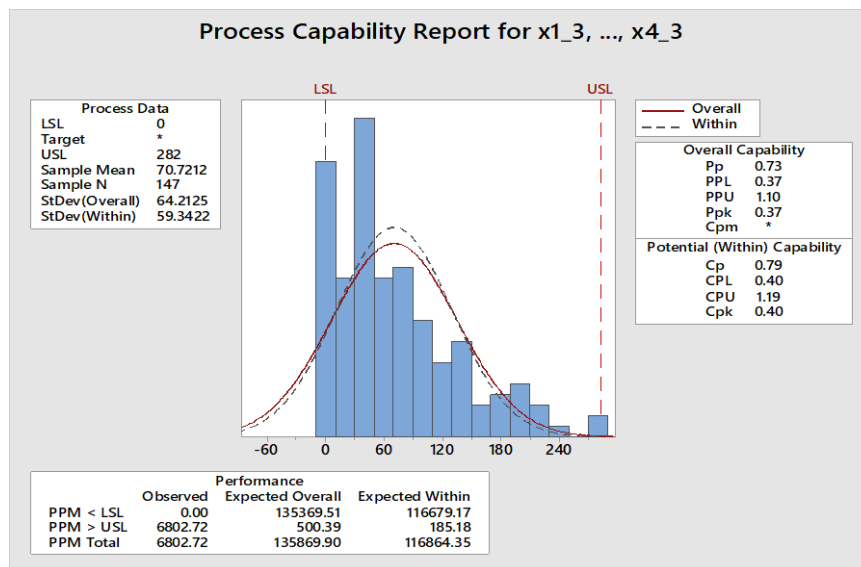**Figure 7.** Process Capability for Each Variable

Figure 8. Multivariate Process Capability

On figure 7 and 8, it shows that the value of Cp <1, where Cp X1 = 0.710; Cp X2 = 0.723; Cp X3 = 0.943. The multivariate Cp value obtained was 0.79, which means that the ability of the current production process is not capable.

3.3 Comparison of results between multivariate p-control charts with hotelling's T^2 control charts

On the multivariate p-Control charts, the statistical value of sampling the proportion of defects was used, while the hotelling's T^2 control chart used the distance of proportions to the sample mean vector and the covariance matrix for each observation. It is known that on the control map there are 40 observations that are outside the control boundary and on the hotelling's T^2 map. There are four observations that are outside the control boundary. The highest value before the control chart was improved for the multivariate p-control chart was the 24th observation of 0.1676 (UCL = 0.054), and the highest value on the Hotelling's T^2 control chart was the 50th observation of 22.5 (UCL = 17.15).

Prior to the improvement of the control map, points on the multivariate p-control chart indicate that out of control data was dominated by data that crossed the lower boundary (LCL), and on the hotelling's T2 control chart, the data that were within the control boundary were more than the median value (2,54). Based on the control chart that has been obtained, it shows that for the case of quality control in the M500 bottle production process in CV X; the multivariate p-control chart is more sensitive because more observations are out of control. But in terms of the components of the control chart, the hotelling's T^2 is more complex because it uses the mean vector and also the covariance matrix. On the chart, hotelling's T2 can easily see patterns that show shifts in mean and variance because on the chart; there is also a median of all observations.

3.4 Suggested improvement of the M500 bottle production process

Based on the causes mentioned above, the following is a suggested improvement that management/operators might be able to do to reduce errors during the production process so that the number of reject products can be reduced:

• Machine

Reject products caused by engine performance can be improved by doing several methods such as increasing the temperature of the material, reducing the loading time of the material, reducing the die temperature, using a die with better heat conductivity, and increasing the material flow velocity.

• Setting

Reject products caused by improper settings can be improved by doing methods such as standardizing the thickness of the wall in each cavity, resetting the clamping pressure, resetting the temperature between the core and cavity, reducing the screw rotation, improving the system gas ventilation on the mould, adding cooling time, and checking cavity for the right location and adequate size.

- Material

Reject products caused by materials can be improved by doing several methods such as replacing materials with better grades, checking the material, drying the material beforehand, and making sure that the hopper, barrel, and screw are clean from the previous material.

- Mould

Reject products caused by moulds can be improved by doing several methods such as maintaining or replacing worn moulds, increasing mould temperature, increasing the speed of opening the mould, and checking the mould release mechanism for proper design and operation.

Table 2. Descriptive statistics of product defects

Num	Types of Defects	Total	Average	Variant	Min	Max
1	Difference of Thickness (X1)	11381	117.33	11075.34	0	558
2	Leak (X2)	6788	69.98	5139.02	0	350
3	Spots (X3)	7561	77.95	9261.53	0	536
4	Dent (X4)	5483	56.53	4545.82	0	279
5	*Deflash* (X5)	2166	22.33	2116.06	0	254
6	*Shrink mark* (X6)	2243	23.13	1761.00	0	272
7	Mishaped Orifice (X7)	4378	45.14	6908.05	0	421
8	Remaining Material (X8)	1907	19.66	1321.60	0	185
9	Orifice Defects (X9)	1981	20.43	1588.87	0	169
10	Oval (X10)	1088	11.22	766.27	0	148

4.   Conclusion

Based on the results and discussion above, conclusions can be drawn regarding the quality control of the Doff M500 bottle process at CV X. Quality control using a multivariate attribute control chart was done based on the amount of production and rejected produced. It shows that there are only three correlated quality characteristics used in making the hotelling's T2 control chart, namely, the characteristics of different thicknesses, leaks, and dents.

Based on the hotelling's T2 control chart obtained, it is known that the current production process has not been controlled because there are samples (observations) that are outside the control limits (out of control).MYT decomposition results show that the dominant variable causing the data to become out of control is different thickness and dent. Univariate process capability values obtained for x1 is 0.71, for x2 variables is 0.72, and for x3 is 0.943. While the multivariate process capability is 0.79. All capabilities of this process capability are less than one, which indicates that the current process is not yet capable and must be improved so that the production process becomes capable and can meet specifications precisely.

Based on the control chart that has been obtained, it can be seen that for the case of quality control in the M500 bottle production process in CV X; the multivariate p-Control charts are more sensitive because more observations are out of control. Suggested improvements given to reduce the number of

reject products include regulating engine temperature, increasing material flow velocity, paying attention to the position of engine and mould components, using the right blow pressure, adding a cooling system, using the right material, checking material so its not contaminated, clean the material flowing place, perform maintenance or replace worn mould, and improve mould performance such as when opening and closing.

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