THE MIXED UNIVARIATE CONTROL CHART EWMA AND CUSUM FOR FLOUR PRODUCTION QUALITY PROCESS MONITORING

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Abstract. *Control charts are an important statistical technique used to monitor process average quality or dispersion. Shewhart control diagram used to detect larger disturbances in process parameters. As time progressed, more sensitive univariate control charts were created, namely EWMA and CUSUM. The control chart is developed again into a Mixed EWMA-CUSUM control chart to detect smaller changes. Based on the univariate control diagram that has been mentioned, research was carried out to test which control diagram was more sensitive. A more sensitive control chart means a control chart that detects more observations out of control. A very sensitive control chart is a diagram more efficient control because it detects many out of control observations in one control phase. This research uses secondary data on wheat flour production with a total of 1,472 observations, consisting of 32 subgroups with 46 observations per subgroup. The quality variables used for wheat flour production data are moisture, ash and gluten. Based on the research results, the most sensitive control diagram was obtained, namely Mixed EWMA CUSUM control diagram for univariate control diagram with 15 out of control data on variable X_1, 43 out of control data on variable X_2, 34 out of control data on variable X_3.*

Keywords: CUSUM, EWMA, Mixed EWMA–CUSUM

1. Introduction

Although wheat flour is not the main meal of the Indonesian people, it is a commodity with a growing strategic importance. The evolution of the country's needs for wheat flour has altered the way that different government initiatives impact the growth of the wheat flour sector. The domestic industry has made significant investments, particularly to control the annual variations in the price of wheat flour in the country. Along with the rising popularity of instant noodles, bread, biscuits, and

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cookies, wheat flour consumption is also rising in Indonesia. Due to this phenomena, wheat flour has become a basic necessity, requiring the expensive purchase of raw materials from overseas markets.Therefore, the domestic industry has a critical function for the sustainability of wheat flour production and trade in Indonesia [1].

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A popular method for process monitoring in the production process is the control chart. The control chart not only monitors but also offers useful data for enhancing operations. A Center Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) are present on every control chart. A process is considered to be in control if the data plot remains within the control limits; otherwise, it is said to be out of control [2]. The control chart is made up of a multivariate control chart that keeps an eye on multiple quality variables and a univariate control chart that tracks just one [3].

A new, more sensitive control chart was found by comparing two previously existing control charts, coinciding with the advancement of research on univariate control charts. The EWMA and CUSUM control charts, also known as the Mixed EMWA CUSUM control charts, are used for univariate quality factors. The purpose of the Mixed EWMA-CUSUM control diagram is to make the control visual structure more sensitive, particularly to tiny process mean shifts. In order to offer a quick signal to identify out-of-control conditions, the Mixed EWMA CUSUM control graph's performance is dependent on both current observations and data gathered from prior observations [4].

2. EWMA Control Chart

The primary purpose of this EWMA control chart is to identify even the slightest change in a process's average value. The following is the definition of the exponentially weighted moving average value [5].

$$Z_i = \lambda x_i + (1 - \lambda)Z_{i-1}. \tag{2.1}$$

The EWMA control chart is constructed by plotting Z_i against the center line and control limits as follows.

$$UCL_i = \mu_0 + L\sigma\sqrt{\frac{\lambda}{2 - \lambda}[1 - (1 - \lambda)^{2i}]}, \tag{2.2}$$

$$CL = \mu_0, \tag{2.3}$$

$$LCL_i = \mu_0 - L\sigma\sqrt{\frac{\lambda}{2 - \lambda}[1 - (1 - \lambda)^{2i}]}. \tag{2.4}$$

3. CUSUM Control Chart

In the CUSUM method, two methods are used to monitor the production process. One of them is tabular CUSUM. For example, x_i is the i-th observation on the production process. When the process is under control, x_i is normally distributed with a target mean μ_0 and standard deviation. The CUSUM value is defined as follows [2].

$$C_i = \sum_{j=1}^{i} (x_j - \mu_0). \tag{3.1}$$

Upper CUSUM and Lower CUSUM for i-th observation, where $i = 1, 2, \cdots, n$ are:

$$C_i^+ = \max[0, x_i - (\mu_0 + K) + C_{i-1}^+], \tag{3.2}$$
$$C_i^- = \max[0, -(\mu_0 - K) - x_i + C_{i-1}^-], \tag{3.3}$$

where:

$$C_0^+ = C - 0^- = 0, \tag{3.4}$$
$$K = k\sigma = \frac{1}{2}\delta\sigma. \tag{3.5}$$

Upper CUSUM and lower CUSUM which has been standardized for the i-th observation, where $i = 1, 2, \cdots, n$ becomes:

$$C_i^+ = \max[0, y_i - K + C_{i-1}^+], \tag{3.6}$$
$$C_i^- = \max[0, -K - y_i + C_{i-1}^-]. \tag{3.7}$$

The upper control limit for the CUSUM control chart is:

$$UCL = H = h\sigma. \tag{3.8}$$

4. Mixed EWMA–CUSUM Control Chart

The upper control limit for the CUSUM control chart is [4]. The EWMA statistical value Z_i is combined with the CUSUM structure. The mixed EWMA–CUSUM control chart is defined by two statistics, namely upper CUSUM, M_i^+ and lower CUSUM, M_i^-. The two statistical values are set to zero in the classic mixed EWMA-CUSUM, and their values depend on the EWMA statistical, which is Z_i. So that it is obtained [6]:

$$M_i^+ = \max[0, (Z_i + \mu_0) - a_i + M_{i-1}^+], \tag{4.1}$$
$$M_i^- = \max[0, -(Z_i + \mu_0) - a_i + M_{i-1}^-], \tag{4.2}$$

where a_i is the time-varying value for the mixed EWMA–CUSUM control chart structure, given by:

$$a_i = a^* \sqrt{var(Z_i)}, \tag{4.3}$$

where

$$var(Z_i) = \sigma^2 \frac{\lambda}{2 - \lambda}(1 - (1 - \lambda)^2), \tag{4.4}$$

and $a^* = k$ as in the classic CUSUM control chart. The control limit value is given by:

$$b_i = b^* \sqrt{var(Z_i)} = b^* \sigma \sqrt{\frac{\lambda}{2 - \lambda}(1 - (1 - \lambda)^{2i})}, \qquad (4.5)$$

where $b^* = h$ like in the classic CUSUM control chart. The M_i^+ and M_i^- plotted against the control limit b_i.

5. Data and Variables

This research uses secondary data on flour production at PT. Pioneer Flour Mill with a total of 1,472 observations. The data consists of 32 subgroups with 46 observations per subgroup. This research uses three quality variables, namely [7]:

- Moisture ($X1$)
  Moisture shows the water content in wheat flour. If the amount of moisture exceeds the maximum standard, it can reduce the shelf life of flour wheat. Because it will spoil more quickly, become moldy and smell musty. Limit The moisture specification for wheat flour is 13.15%-13.9% .
- Ash ($X2$)
  Ash or ash content in flour affects the process and final product results, including product color (colour of crumb in bread, color of noodles) and level of dough stability. The lower the ash content, the better the wheat flour. Ash content more than 0.57% indicates the product has failed.
- Gluten ($X3$).
  Gluten is a compound in wheat flour that is chewy and elastic, which plays a role in determining the quality of the food it produces. The higher the gluten content, the higher the protein content in the wheat flour. The gluten specification limit in wheat flour is 22%-26%.

6. Results dan Discussion

In this study, the EWMA, CUSUM, and mixed EWMA–CUSUM univariate control charts were applied to wheat flour production data with three variables, namely Moisture (X1) show the water level, Ash (X2) or ash content in flour, and Gluten (X3). Gluten is a compound in wheat flour that is chewy and elastic. The following compares the results of the control chart application using the EWMA, CUSUM, and mixed EWMA–CUSUM univariate control chart.

We will compare the nine control chart results after creating the EWMA, CUSUM, and mixed EWMA-CUSUM control diagrams on the three quality variables. To find out which control chart is better at identifying out-of-control observations, EWMA, CUSUM, and mixed EWMA-CUSUM control charts are compared. The amount of observations that are out of control shows how the control chart compares. The control chart will be more sensitive the more out-of-control observations it is able to identify. A comparison of the EWMA, CUSUM, and Mixed EWMA-CUSUM control charts can be found below.
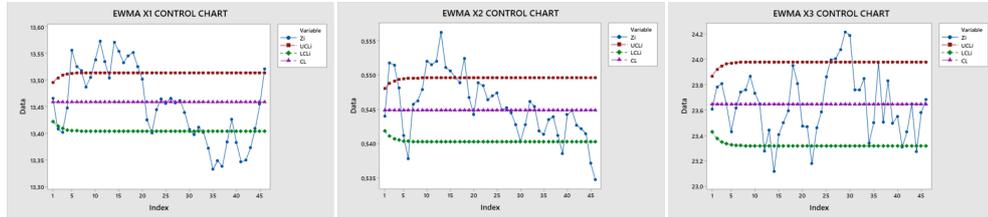
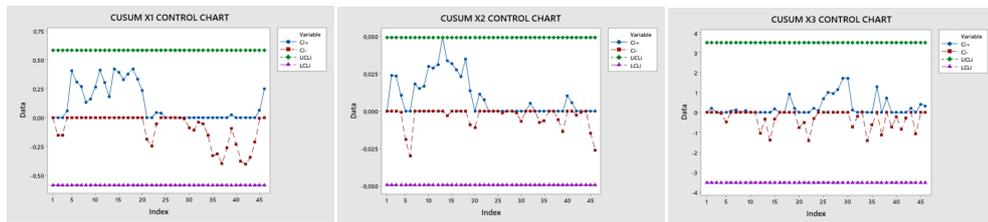Figure. 1. Application of EWMA Control Diagram on variable X1, variable X2, variable X3 (from left to right)

Figure. 2. Application of CUSUM Control Diagram on variable X1, variable X2, variable X3 (from left to right)
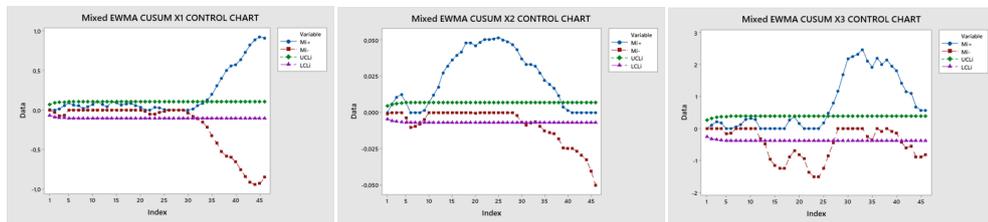

Figure. 3. Application of MIXED–EWMA CUSUM Control Diagram on variable X1, variable X2, variable X3 (from left to right)

Based on Table 1, it is known that all quality variables in the CUSUM control diagram have no out of control observations. However, after identifying the C_i value, a data plot was obtained which illustrates that the process is not under control. This shows that the CUSUM control diagram is not sensitive in identifying process shifts. Meanwhile, the EWMA and mixed EWMA–CUSUM control charts both have out of control observations. But the EWMA–CUSUM mixed control chart has more out of control observations. Thus, the mixed EWMA–CUSUM control chart can be said to be more sensitive than the EWMA control chart, both to quality variables with a normal distribution and quality variables that are not normally distributed.

Therefore, the EWMA–CUSUM mixed control chart was chosen as the most efficient control chart for controlling univariate data rather than the EWMA control chart and CUSUM control chart. The resulting differences in patterns mean that there should be confirmation to the company regarding the state of the production

Table 1. Comparison of Out of Control Observations on EWMA, CUSUM, and Mixed EWMA–CUSUM Control Diagrams

Control Chart	Quality Variable	Total Observations Out of Control	Control Chart Pattern
EWMA	X1	27	Irregular
	X2	14	Gradual Change
	X3	10	Mix
CUSUM	X1	0	-
	X2	0	-
	X3	0	-
Mixed EWMA–CUSUM	X1	15	Stratification and trend
	X2	43	Sudden change and gradual change
	X3	34	Mix

process so that the cause of the uncontrolled process can be properly identified.

7. Conclusion

Based on the discussion of the univariate model and its combination with flour production data, it was obtained that the Mixed EWMA–CUSUM control chart is the most sensitive control chart for the univariate model. The Mixed EWMA–CUSUM control chart is more sensitive than the EWMA control chart and the CUSUM control chart as proven by the greater number of out of control observations detected on the Mixed EWMA–CUSUM control chart compared to the EWMA control chart and the CUSUM control chart.

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