Statistical Quality Control of Plastic Spoon Production Process Using Laney Demerit Control Chart and Analytical Hierarchy Process-Integrated Statistical Process Control

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Abstract. The industrial sector is one of the crucial sectors in the period of development and economic growth in Indonesia. The plastic industry plays an important role in the supply chain for several strategic industrial sectors. To fulfill all of these needs, plastic companies produced plastics in large amounts. During the production, it is common to find the product defects and it is likely that the product defects will become plastic waste. One of the causes of environmental damage today is plastic waste, because plastic takes a long time to destroy naturally. Therefore, it is necessary to control the production of the plastic using statistical quality control to maintain the quality of plastic and fulfill the customer satisfaction. In this research, statistical quality control will be carried out using demerit, AHP-based demerit, Laney demerit, and AHP-based Laney demerit control charts. The results of the demerit and AHP-based demerit control charts shows that the plastic spoon production process was not statistically controlled. Meanwhile, the result of the Laney demerit and AHP-based Laney demerit control charts shows that the plastic spoon production process in phase I has been statistically controlled after being handle because of the out of control observation points. In phase II, it was obtained that the plastic spoon production process was not statistically controlled. Then for the process capability analysis results show that the production process was not capable.

Keywords: Analytical Hierarchy Process, Demerit Control Chart, Laney Demerit Control Chart, Statistical Quality Control, Plastic.

1 Introduction

Along with the times, the industrial sector has progressed rapidly, specifically in the plastic industry. Plastic was first introduced by Alexander Parkes in 1862 at International Exhibition in London. Furthermore, the development of plastic in the market has increased in 1974 when the retail companies in America used plastic bags as a substitute

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for paper bags. The plastic industry plays an important role in the supply chain of several sectors, such as the cosmetics, electronics, food and beverages, and pharmaceutical industries [1].

In general, there are four methods in plastic manufacturing process, namely injection molding, extrusion, thermoforming, and blow molding [1]. Several companies in Indonesia use injection molding machines in the plastic production process. However, in the implementation of injection molding machines, product defect often occurs. Product defect refer to the products that do not meet standards, specifications, or tolerance limits [2]. If a product defect reaches the customer's hands, it is possible that the products will be unused, discarded, or consider as trash or plastic waste.

Statistical process control is an effort to prevent the recurrence of the same error in the system [3]. The main objective of statistical quality control is to reduce process variability as much as possible. One method to perform statistical quality control is to use a control chart, which is used to determine whether a process has been statistically controlled. Control chart is divided into two types, namely variable control chart and attribute control chart. In this research, attribute control chart analysis will be used, specifically the demerit control chart. This is caused by the variation in the number of production inspection samples that change every day according to the production of spoons in a day, and each type of defect has a different level of seriousness. When the company produces many samples, the demerit control chart may be too sensitive and may result in many observation points being out of control. Therefore, additional analysis using Laney demerit control chart is required.

2 Literature Review

2.1 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a method used to solve complex and unstructured problems by compiling a hierarchy according to the level of priority based on the preferences of related experts [4]. AHP basically follows three fundamental principles, namely the creation of a hierarchy, the creation of a criteria and the assessment of alternative through pairwise comparison, and the calculation of the consistency ration (CR).

AHP is used to rank or prioritize various alternatives in solving problem. There are two main reasons why AHP is chosen as a method of dealing with problems rather than other methods [5]. First, AHP prioritizes a hierarchical structure, which means creating a hierarchy as a result of selecting criteria. Second, AHP takes into account validity or consistency, which means recognizing the limit of tolerance for inconsistencies in the selection of alternatives.

When evaluating criteria and alternatives using pairwise comparison assessment, comparisons are made based on the preferences of related experts regarding the level of seriousness between one criterion and another. Then, it can be represented in the form of a pairwise comparison matrix. In this research, the basic scale used for pairwise comparisons as shown in Table 1 [6].

Table 1. Basic Scale of Pairwise Comparison

Basic Scale	Description
1	Both criteria are equally important.
3	One criterion is slightly more important than the other.
5	One criterion is more important that the other.
7	One criterion is clearly more important than the other.
9	One criterion is absolutely more important than the other,
2, 4, 6, 8	A value that falls between two adjacent comparisons.

After the pairwise comparison matrix has been compiled, the next step is to calculate the geometric mean of the assessments of the relevant experts. The geometric mean calculation is used to provide a more accurate average approach because it reduces the variation that may arise between the assessment of one expert and another in the AHP questionnaire [7]. The geometric mean formula can be calculated using equation (1).

$$G = \sqrt[r]{a_1 \times a_2 \times \ldots \times a_r} \tag{1}$$

where G is the geometric mean, a_1 is the result of the first expert's assessment, a_2 is the result of the second expert's assessment, and r is the number of experts who filled out the questionnaire.

The next step is to normalize the pairwise comparison matrix. Normalization of this matrix can be calculated using equation (2).

$$(\mathbf{t}_\mathrm{i}, \mathbf{t}_\mathrm{j}) = \frac{a_{ij}}{N_l} \tag{2}$$

where $(\boldsymbol{t_i}, \boldsymbol{t_j})$ is the normalization of the pairwise comparison matrix, a_{ij} is the element in the pairwise comparison matrix of the i-th row and j-th column, N_i is the sum of elements of the j-th column in the pairwise comparison matrix, and $i, j = 1,2,3, \ldots, l$. The next step is to weight the criteria by calculating the average of each row in the normalized pairwise comparison matrix using the formula as described in equation (3).

$$W_c = \frac{\sum_{j=1}^{l} a_{ij}}{l} \tag{3}$$

AHP analysis is considered valid if it is consistent in its results. To meet the consistency criteria, the Consistency Ratio (CR) value must be less than 10% [8]. The calculation of the Consistency Ratio (CR) value can be done using the formula given in equation (4).

$$CR = \frac{CI}{RI} \tag{4}$$

where RI is the Random Index value and CI is the Consistency Index value. In this research, the Consistency Index is obtained using the formula in equation (5).

$$CI = \frac{\lambda_{\max} - l}{l - 1} \tag{5}$$

with λ_{max} value is obtained using the formula in equation (6) and l is the number of criteria.

$$\lambda_{\max} = \frac{\sum_{i=1}^{l} W_{s_i}}{l} \tag{6}$$

where the value of W_{s_i} is obtained by multiplying the elements in the pairwise comparison matrix by the weight of the criteria, and the result is divided by the weight of the criteria in accordance with the order of the criteria.

2.2 Laney Demerit Control Chart

When monitoring the production process, we often find many types of defects. However, not all defects have the same level of seriousness. Defect A may be more serious than defect B, defect C, or even vice versa. Therefore, there needs to be an effort to categorize these different types of defects. One method used to perform classification based on their seriousness is through the use of demerit control chart.

If the number of sample data used exceeds 500, it is recommended to use the Laney demerit control chart. Laney demerit is an extension of the Demerit control chart that is used to measure the number of defects in each unit by categorizing different types of defects based on their seriousness when using a large sample.

In Laney demerit control chart, the weighted number of defects in each subgroup observation can be calculated using the formula in equation (7).

$$D_i = w_1 c_{i1} + w_2 c_{i2} + w_3 c_{i3} + w_4 c_{i4} \tag{7}$$

where c_1, c_2, c_3, c_4 is the number of defects in each class, w_1, w_2, w_3, w_4 is the weight of defects in each class, and $i = 1,2,3, \ldots, m$.

The average value of defects per unit (u_i) for each subgroup observation is obtained by dividing the weighted number of defects in each subgroup observation (D_i) by the number of samples in each subgroup observation (n_i). The u_i value can be calculated using the formula in equation (8).

$$u_i = \frac{D_i}{n_i} \tag{8}$$

where $i = 1,2,3, \ldots, m$.

The next step is to calculate the average value of total defects per unit for all types of defects using the formula in equation (9) with the value of $\bar{u}_1, \bar{u}_2, \bar{u}_3, \bar{u}_4$ are the average defects per unit in each class.

$$\bar{U} = w_1\bar{u}_1 + w_2\bar{u}_2 + w_3\bar{u}_3 + w_4\bar{u}_4 \tag{9}$$

Then, after calculating all the values needed to determine the three limits on the Laney demerit control chart. These three values are obtained using the formula in equation (10) until (12).

$$LCL_i = \bar{U} - 3\hat{\sigma}_i \times \sigma_Z \tag{10}$$

$$CL = \bar{U} \tag{11}$$

$$UCL_i = \bar{U} + 3\hat{\sigma}_i \times \sigma_Z \tag{12}$$

where $\hat{\sigma}_i$ is obtained using the formula in equation (13).

$$\hat{\sigma}_i = \sqrt{\frac{w_1^2\bar{u}_1 + w_2^2\bar{u}_2 + w_3^2\bar{u}_3 + w_4^2\bar{u}_4}{n_i}} \tag{13}$$

The σ_Z value is the standardized value of the average value of defects per unit (u_i). The first step is to convert the value of u_i into a *z*-score using equation (14).

$$Z_i = \frac{(u_i - \bar{U})}{\sqrt{\frac{\bar{U}}{n_i}}} \tag{14}$$

The second step is to plot the *z*-score in an individual chart using equation (15) and (16).

$$R_i = |Z_i - Z_{i-1}| \tag{15}$$

$$\overline{MR} = \frac{1}{m-1}\sum_{i=2}^{m} R_i \tag{16}$$

Then, the σ_Z value is obtained using the formula in equation (17).

$$\sigma_Z = \frac{\overline{MR}}{1.128} \tag{17}$$

3 Methodology

The data used in this research is secondary data from the quality control division, namely the defect inspection data for the plastic spoon production process in 2022. There are 271 data in the form of subgroups, where subgroup represent daily data. The data used will be divided into phase I and phase II. Phase I is the first 150 data, which is production data from January 2, 2022 to July 19, 2022. Phase II is the last 121 data, which is production data from July 20, 2022 to December 29, 2022. In this dataset, there are ten types of defects found which are grouped based on their seriousness and have a weight on each group of defects.

4 Result and Discussion

4.1 Demerit and Laney Demerit Control Charts

In phase I of plastic spoon production process in 2022, statistical quality control was used to assess whether the observations were within the control limits. This research applies analysis using demerit control charts, as can be seen in Figure 1.

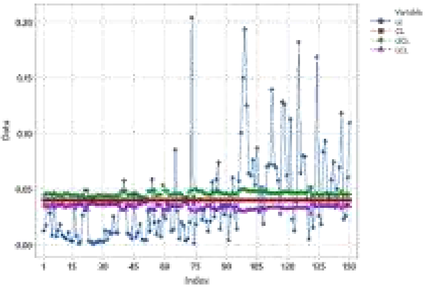
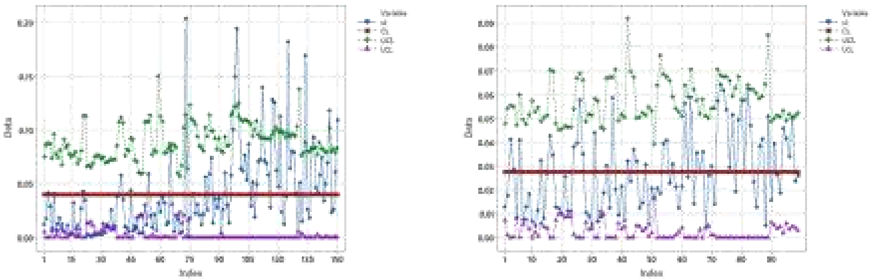


Fig. 1. Demerit Control Chart

Based on Figure 1, it can be seen that 130 observation points are outside the control limits. This indicates that the demerit control chart is very sensitive to the plastic spoon production data. This is due to the large number of production samples. Therefore, an additional approach is needed by applying the Laney demerit control chart.



(a) (b)

Fig. 2. Laney Demerit Control Chart in Phase I
(a) out of control, (b) in control

Based on Figure 2. (a), analysis using Laney demerit control chart in phase I using $\sigma_Z = 8.2713$ and $CL = 0.0399$ shows that 33 data are out of control. In response to the large number of data that crossed the control limits, a step was taken to deal with the data that crossed the control limits. To do this, the observation data that was furthest from the control limits was removed.

Based on Figure 2. (b), the Laney demerit control after 51 iterations of removing the data that are out of control and using the value $\sigma_Z = 5.7358$. From these results, it can be concluded that the plastic spoon production process in phase I has been statistically controlled. Therefore, the analysis can proceed to phase II using a $CL = 0.0276$.

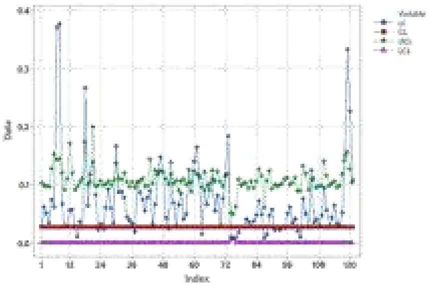


Fig. 3. Laney Demerit Control Chart in Phase II

Figure 3 is the Laney demerit control chart for phase II using $\sigma_Z = 13.2092$ and $CL = 0.0276$. Phase II was conducted to evaluate whether there were any shifts in the process between phase I and phase II, as well as to monitor the next run of the process. The results of the analysis showed that 19 data were out of control. From the results, it can be concluded that the plastic spoon production process in phase II has not been statistically controlled, and there is a shift in the process between phase I and phase II.

4.2 AHP-Based Demerit and AHP-Based Laney Demerit Control Charts

The analysis in this AHP method will be said to be consistent if the Consistency Ratio (CR) value has a number below 10%. This research uses a Random Index (RI) value is 0.900 because there are 4 defect classes. The calculation results show a CR value is 0.093, which indicates the consistency of defect weight calculations using the AHP method.

In the first phase, statistical analysis of quality control is used to identify observations that are within limits. Figure 4 shows the results of using AHP-based demerit control charts in the plastic spoon production process in phase I.

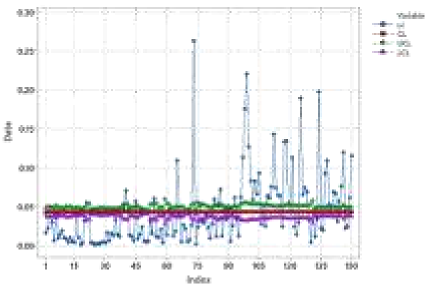
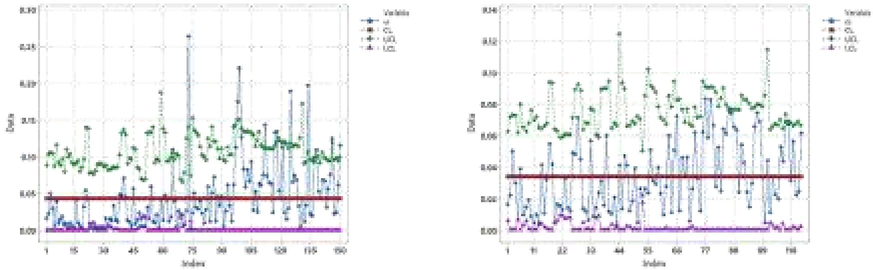


Fig. 4. AHP-Based Demerit Control Chart

From the Figure 4, it can be seen that there are 132 observations that are outside the control limits. This shows that the AHP-based demerit control chart is very sensitive to the plastic spoon production process data. This happens because of the large number of production samples. Therefore, an additional approach is needed by applying AHP-based Laney demerit control chart.



(a) (b)

Fig. 5. AHP-Based Laney Demerit Control Chart in Phase I
(a) out of control, (b) in control

Based on Figure 5. (a), the results of the analysis using the AHP-based Laney demerit control chart in phase I with $\sigma_Z = 9.0780$ and $CL = 0.0432$, there are 22 out of control data. This indicates that the production process in phase I is not statistically controlled. Therefore, it is necessary to deal with the out of control data by removing the observations that are located farthest from the control limits.

Figure 5. (b) is the result of the AHP-based Laney demerit control chart in phase I after 36 iterations to remove out of control data and using $\sigma_Z = 6.4362$. This result indicates that the plastic spoon production process in phase I has been statistically controlled and can proceed to phase II using a $CL = 0.0341$.

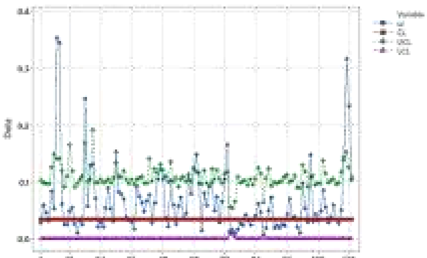


Fig. 6. AHP-Based Laney Demerit Control Chart in Phase II

Based on Figure 6, the analysis of AHP-based Laney demerit control chart in phase II with using $\sigma_Z = 12.1011$ and $CL = 0.0341$. The analysis results show that there are 18 data that are outside the control limits. From this analysis, it can be concluded that the plastic spoon production process in phase II has not been statistically controlled, indicating a change in the process between phase I and phase II.

Process capability analysis is used to determine whether the production of plastic spoons in 2022 is in accordance with specifications or not. A process is considered to have capability if the process is statistically controlled and the resulting product is within the specification limits set by the company. Based on the result obtained, the $\hat{P}_{pk}^{\%}$

value obtained is 0.610, which means that the value is less than one. With this result, it can be concluded that the plastic spoon production process in 2022 was not capable.

5 Conclusion and Suggestion

The results of monitoring the plastic spoon production process in 2022 using demerit control chart, and AHP-based demerit control chart found too many out of control observation points. This means that the use of both control charts is too sensitive. Therefore, it is necessary to conduct further analysis using Laney demerit control chart, and AHP-based Laney demerit control chart. The monitoring results using Laney demerit control chart, and AHP-based Laney demerit control chart obtained that the plastic spoon production process in phase I has been statistically controlled after handling the out of control observation points. In phase II, it was found that for Laney demerit there were 19 observation points that were out of control, and AHP-based Laney demerit there were 18 observation points that were out of control. The results of the process capability analysis show that the plastic spoon production process in 2022 was not capable. This can be seen from the $\hat{P}_{pk}^{\%}$ value that is smaller than one, which is 0.610.

A suggestion for future researchers is to consider applying the fuzzy approach as a development of the Analytical Hierarchy Process (AHP) method in overcoming subjectivity in the assessment of defect seriousness. Moreover, the research can include performance evaluation for Laney demerit control chart and AHP-based Laney demerit control chart.

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