Quality control of cardboard using MEWMA and MEWMV control chart (case study in PT. Y Kediri Indonesia)

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Abstract. Cardboard is one type of paper that has a grammatic value above 200 g/m². Controlling the quality of competing products is important to improve product competitiveness. The purpose of this study was to analyze cardboard quality and provide improvements at PT. Y Kediri East Java. The research methods used were MEWMA (Multivariate Exponentially Weighted Moving Average) and MEWMV (Multivariate Exponentially Weighted Moving Variance). The data used were nine variables of quality of cardboard, that were grammage, thickness, pull resistance, PS surface smoothness, BS surface smoothness, print surface smoothness, oil print, PS color, and BS color, with a time span between 2016 and 2018. Data were taken for ICB 230, ICB 210, WHI 230 and ICB 250 type of cardboard. From the MEW MV control chart, the types of ICB 230, ICB 210, WHI 230 and ICB 250 successively have out-of-control points of 19, 10, 6, and 5, while in the MEWMA control, types of ICB 230, ICB 230, ICB 210, WHI 230, and ICB 250 respectively have out of control points of 13, 9, 9, and 6. The main causes of product defects were repeated machine configurations and uneven spraying of pulp, and dew dripping over the production machine. In addition, other causes were adhesives and coating materials which were too thick/runny, and materials which were not suitable for production enter the process. Some suggestions for improvement that can be done are placing filters at the entrance of the coating material, and adjusting the temperature of the production machine's environment.

1. Introduction
Both paper and cardboard have two basic ingredients of wood fiber [1]. Long fibers (spruce and pine) are used for paper with high strength, stiffness, and structure with a fiber length of 3 - 4 millimeters. Short fibers (eucalyptus and acacia) are used for paper with low density and high surface smoothness, with a fiber length of between 1 - 1.5 millimeters. Indonesia is one of the high paper exporting countries in the world. PT. Y is one company in Indonesia that produces cardboard. The main problem faced by the company is regarding the cardboard production process which the number of defects reach 3.22 percent on average. According to Abuhav [2], the minimum limit for the number of products that do not pass the test is 5% of the total production. If it is below this value, there is no need for a major evaluation. However, it only needs detailed improvements so that the product damage can be reduced as small as possible. Several processes require strict checking because they are directly related to paper quality, that are forming (printing), drying and calendering processes. In the application of process control, it is
necessary to observe several quality characteristics that are correlated simultaneously. One of the tools
to observe is the Multivariate Exponentially Weighted Moving Average (MEWMA). In the design of
the MEWMA procedure, it is assumed that it is desirable to detect any shifts of the mean as early as
possible and that the \( \lambda \) value is observed [3]. The MEWMV (Multivariate Exponentially Weighted
Moving Variance) control chart is a map used to detect small to moderate shifts of the variance of the
data. The MEWMV control chart is implemented to detect changes in variance assuming that there is
no shift in the mean of the data [4]. Therefore, this control chart is used simultaneously with the
MEWMA control chart. According to Montogomery and Runger [5], in making control charts based on
a certain time span, it is more likely that there is a shift in the mean and variance of the data. In order to
maximize process improvement, the average value is used as the basis for the evaluation of each data
set for each specific time unit and the variance is used for the evaluation of the overall process. The
purpose of this study was to identify the quality of cardboard and provide suggestions for improvement
at PT. Y Kediri Indonesia.

2. Materials and Methods
The data used was secondary data with a time span between 2016 and 2018. Sampling was carried out
every month in the last three years from four types of cartons that have the highest production capacity
at PT. Y. Data was taken from the monthly production average for each type of carton. The nine variables
are grammage, thickness, pullout resistance, PS surface smoothness, BS surface smoothness, print
surface smoothness, oil print, PS color, and BS color. Data every month was not repeated because it was
average data. Those quality variables were taken to analyze because of quality priorities in the company.

The data sample for each type of 230 ICB (Ivory Coated Board) cardboard, ICB (Ivory Coated Board)
210, WHI (White) 230, and ICB (Ivory Coated Board) 250 were 36, 33, 31 and 20 samples respectively.
The amount of data varies, because the types of ICB 230, ICB 210, WHI 230, and ICB 250 are not
always produced every month. The data was processed using MEWMA and MEWMV control charts,
then the results are analyzed for improvement using Pareto and fishbone diagram (cause-effect diagram).

3. Results and Discussion

3.1. Quality control chart of cardboard
Cardboard has a grammage above 200 g/m2. Carton specifications are generally adjusted according to
demand, which affects the fiber treatment and cardboard manufacturing process. Some cardboard design
techniques are designed to meet the desired level of specifications. They need high-density overcoat
printing, with the middle and bottom layers being lower. This can increase the stiffness of cardboard
with a low level of fiber-binding capacity [6]. In this study, the quality of cardboard was measured using
MEWMA and MEWMV control charts on four types of cardboard.

3.1.1. Ivory coated board (ICB) 230 type
The data collected for carton type ICB 230 is 36 observations. The weights used on the MEWMV control
chart are \( \omega \) (omega) and \( \lambda \) (lambda) with a limit between 0.1 to 0.9. To determine the best weighting on
the MEWMV control chart, there were 3 stages. The steps in question are the smallest difference
between the largest tr (Vn) value and the UCL (upper control limit) value, and the smallest difference
between the UCL and the LCL (lower control limit) and choosing the least out-of-control point [7].
Referring to the 3 stages of determining the best weighting of the MEWMV control chart, the optimal
weighting used in the MEWMV control chart type ICB 230 is to use a weight of \( \omega = 0.1 \) and \( \lambda = 0.4 \). In
making MEWMA control charts for all types of paper, a weighting \( \lambda \) (lambda) was used with a range
between 0.1 and 0.9. Making the MEWMA control chart uses an ARL value of 370. According to
Nehzad and Niaki [8], the ARL value of 370 is the 3 sigma standard value used in the SPC (Statistical
Process Control) analysis. ARL value of 370 was also used as a detector whether the output is stable or
not from the SPC (Statistical Process Control) in the study. The principle of determining the best weight
of the MEWMA control chart for all types of paper was the same as determining the best weighting of
MEWMV, by looking at the smallest difference between the UCL value and the highest plot point. Therefore, the best weighting of the MEWMA control chart for the ICB 230 type uses a weighting of \( \lambda = 0.9 \). The MEWMV control chart with a weighting of \( \omega = 0.1 \) and \( \lambda = 0.4 \) and MEWMA with a weighting of \( \lambda = 0.9 \) for the ICB 230 type is shown in Figure 1.

![Figure 1. MEWMV and MEWMA control chart for ICB 230](image)

(a) MEWMV control chart using \( \omega = 0.1 \) and \( \lambda = 0.4 \); (b) MEWMA control chart using \( \lambda = 0.9 \).

The UCL value of the MEWMV control chart tends to be constant at 2.0897 and the LCL value tends to be constant at 0.5958. When using the best weight, the MEWMV control chart shows 19 out-of-control points. The chart shows a quadratic trend because there are some local optimum values in some observations. This concludes that ICB 230 type cardboard production based on process variability was not statistically standard. This was indicated because the production department which requires high temperature is not optimal in the drying process in the production of cardboard, causing 9 variables of the quality of cardboard to experience physical and chemical defects. The UCL value of the MEWMA control chart was 25.25 and the LCL value was 0. When using the best weighting weight, the MEWMA control chart shows that 13 points experience out-of-control which were shown by the red dot. They are labeled as out-of-control points because of the multivariate mean values of each observation beyond the UCL value. It can be seen on the MEWMA control chart that there were 2 or 3 out-of-control points in sequential observation, for example, 1st and 2nd point, 4th and 5th point, 11th and 12th point, 21th and 22nd point, and the last were 29th, 30th and 31st point of observation. From the existence of these 13 out-of-control points can be concluded that the production of cardboard type ICB 230 based on the mean value of the process was not statistically controlled.

3.1.2. Ivory coated board (ICB) 210 type

The data collected for cardboard type ICB 210 is 30 observations. The variables taken sequentially were grammage, thickness, pullout resistance, print side surface smoothness (PS), backside surface smoothness (BS), print surface smoothness, oil print, print side color (PS), and backside color (BS). Referring to the 3 stages of determining the best weighting of the MEWMV control chart, the optimal weighting used in the MEWMV control chart type ICB 210 is to use a weight of \( \omega = 0.3 \) and \( \lambda = 0.4 \). The best weighting of the MEWMA control chart type ICB 210 uses a weighting \( \lambda = 0.9 \). The MEWMV control chart with a weighting of \( \omega = 0.3 \) and \( \lambda = 0.4 \) and MEWMA with a weighting of \( \lambda = 0.9 \) for the ICB 210 type is shown in Figure 2.
Figure 2. MEWMV and MEWMA for ICB 210 (a) MEWMV control chart using $\omega = 0.3$ dan $\lambda = 0.4$; (b) MEWMA control chart using $\lambda = 0.9$.

The UCL value tends to be constant at 3.1118 and the LCL value tends to be constant at -0.4118. When using the best weight, the MEWMV control chart shows 10 out-of-control points. From this chart, it shows that start from 5th to 30th observation were under control (inside UCL and LCL). This shows that the production of cardboard type ICB 210 based on process variability was not statistically standard. It was indicated that in the same type, the smaller the weight ($\omega$), the smaller the number of out-of-control points. The grammage value is influenced by the amount of pulp, sizing press material, and coating material used. The UCL value was 25.25 and the LCL value was 0. When using the best weighting, the MEWMA control chart shows 9 out-of-control points which were in the first five observations, in the two middle observations (21st and 22nd point), and the almost two last points of observation. The existence of these 9 out-of-control points can be concluded, the production of ICB 210 cardboard based on the average value of the process was not statistically controlled.

3.1.3. White (WHI) 230 type

The data collected for the carton type WHI 230 is 31 observations. The variables taken sequentially were grammar, thickness, pullout resistance, print side surface smoothness (PS), backside surface smoothness (BS), print surface smoothness, oil print, print side color (PS), and backside color (BS). Referring to the 3 stages of determining the best weighting of the MEWMV control chart, the optimal weighting used in the MEWMV type of WHI 230 control chart is to use weightings $\omega = 0.1$ and $\lambda = 0.4$. The best weighting MEWMA control chart type WHI 230 uses a $\lambda = 0.9$. The MEWMV control chart with a weighting of $\omega = 0.1$ and $\lambda = 0.4$ and MEWMA with a weighting of $\lambda = 0.9$ for the WHI 230 is shown in Figure 3.

The UCL value tends to be constant at 2.0893 and the LCL value tends to be constant at 0.5863. When using the best weight, the MEWMV control chart shows 6 out-of-control points which were in the last five observation. This shows that the production of cardboard Type WHI 230 based on process variability was not statistically standard. It was indicated that there was a need for changes or the use of other coating materials in order to improve the physical and chemical properties of the cardboard or finished cardboard fibers. The UCL value was 25.25 and the LCL value is 0. When using the best weighting, the MEWMA control chart shows 9 out-of-control points. The existence of 9 out-of-control points can be concluded, the production of cardboard type WHI 230 based on the average value of the process was not statistically controlled.
3.1.4. Ivory coated board (ICB) 250

The data collected for the ICB 250 cardboard is 20 observations. The variables taken sequentially were grammar, thickness, pullout resistance, print side surface smoothness (PS), backside surface smoothness (BS), print surface smoothness, oil print, print side color (PS), and backside color (BS). The weights used on the MEWMV control chart are \(\omega\) (omega) and \(\lambda\) (lambda) with a range between 0.1 and 0.9. Referring to the 3 stages of determining the best weighting of the MEWMV control chart, the optimal weighting used in the MEWMV control chart type ICB 250 is to use a weight of \(\omega = 0.4\) and \(\lambda = 0.4\). In making the MEWMA control map, the \(\lambda\) (lambda) weighting is used with a range between 0.1 to 0.9. The making of the MEWMA control chart uses the ARL value of 370. The best weighting of the MEWMA control chart for the ICB 250 type uses a weighting \(\lambda = 0.9\). The MEWMV control chart with a weighting of \(\omega = 0.4\) and \(\lambda = 0.4\) and MEWMA with a weighting of \(\lambda = 0.9\) for the ICB 250 is shown in Figure 4.

![Figure 4. MEWMV and MEWMA control chart for ICB 250 (a) MEWMV control chart using \(\omega = 0.4\) dan \(\lambda = 0.4\); (b) MEWMA control chart using \(\lambda = 0.9\).](image)

The UCL value tends to be constant at 3.5767 and the LCL value tends to be constant at -0.8767. When using the best weight, the MEWMV control chart shows 5 out-of-control points which were in the two first observations and the middle of observation. This shows that the ICB 250 type cardboard production based on process variability was not statistically standard. The existence of 5 points out of control can indicate that the coating material was not applied properly to the two cartons. The UCL value of the control chart was 25.25 and the LCL value was 0. When using the best weighting weight,
the MEWMA control chart shows 6 points out of control. The nature of the plot lines on the MEWMA control chart shows fluctuation. The existence of 6 out of control points can be concluded, the production of ICB 250 cardboard based on the average value of the process was not controlled statistically.

3.2. Improvement analysis
Two diagrams will be used for improvement analysis, the Pareto diagram and the fishbone diagram.

3.2.1. Pareto diagram
Before the cause-effect diagram (Fishbone diagram), a Pareto diagram was drawn. This Pareto diagram is used to determine the tendency for out-of-control points to appear based on each of the variables. The Pareto diagram image can be seen in Figure 5.

![Pareto Diagram](image)

According to Agra and Hasan [9], doing an in-depth analysis of 80 percent of the total events in one object will help 20 percent of the total other events. This principle can be used on several topics, including product pricing, consumer profitability, inventory control, activity-based costing, and quality control. This was then supported by research by Devani and Wahyuni [10], the paper production under study contained 4 types of defects, namely wavy, rewinder wrinkle, dented roll, and less diameter. Based on this literature, making a cause and effect diagram can be concentrated on the thickness variables, BS surface smoothness, PS surface smoothness, and oil printing. It is expected that 19.6% of disabilities based on other variables can improve. Because it is based on the production process, the variable surface smoothness of PS and BS, as well as oil printing, affects the variables related to the coating process. Among them are the variable print surface smoothness, and the PS and BS colors. Then the thickness variable affects the forming and sizing press process. The variables that are affected in this process are grammar and pullout resistance.

3.3. Improvement efforts using fishbone diagram
Cause and effect diagrams are made based on out-of-control data information on the MEWMA, MEWMA control chart, and based on question and answer activities to parties related to quality control in the company. The cause and effect diagram can be seen in Figure 6.
Based on an observational study, the fatigue of workers on certain work shifts can cause defects in cardboard production. Night shift workers tire more quickly because the heart pumps blood faster, which can make them more easily sleepy and less alert [11]. Information about the dangers of employees being sleepy and workers less aware of their duties (e.g. work accidents, uncontrolled pulp quantity). On production machines, there needs to be a dry air circulation regulation, this is to reduce moisture from the paper. It aims to reduce 5-10 percent of defective cardboard that appears every new production. The existence of a heater or blower on top of the production machine (leading out of the company) can be placed, aiming to reduce cold air entering through the roof or removing hot air emerging from the production machine (blower).

The defect of the adhesive was too thick/runny, the coating material was too thick or runny, as well as other materials that are not aware of the production process. According to [12], the content of the coating material with carbonization engineering of $91.73 \pm 2.89$ can increase the uniformity of the coating material and give good results to several important parameters on cardboard. The filter is placed at the inlet of the coating material, which aims to reduce the chances of materials that are not supposed to be used in the coating process, for example, ropes, wire, packaging paper, and others. It needs regular checking at least once within one hour after routine checking of the coating material to ensure the consistency of the coating material is right before it is applied to the surface of the cardboard.

4. Conclusions
Analysis of the causes of product defects is very important to be carried out by the quality control division in the company to find out how many product defects have occurred. Quality control analysis also useful to detect the causes of defects and correct the causes of product defects. If the company has made good efforts to improve, the proportion of product defects is expected to be minimized in the next production process.

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