Al-Khwarizmi: Jurnal Pendidikan Matematika dan Ilmu Pengetahuan Alam
Maret-2026, Vol.14, No.1, hal.55-68
ISSN(P): 2337-7666; ISSN(E):2541-6499
https://ejournal.iainpalopo.ac.id/index.php/al-khwarizmi
DOI: http://dx.doi.org/10.24256/jpmipa.v14i1.8182

Analysis of Shifts in Product Quality using The Individual-Moving Range and Cumulative Sum Fast Initial Response Methods

Analisis Pergeseran Kualitas Hasil Produksi dengan Metode Individual-Moving Range dan Cumulative Sum Fast Initial Response

[1]**Ramayani Nur Hadiati,** [2]Sherli Yurinanda, [3]Sarmada
[1,2,3]Program Studi Matematika, Fakultas Sains dan Teknologi, Universitas Jambi
Alamat: Mendalo Darat, Kota Jambi, 36122, Indonesia
Email: yayank.rnh@gmail.com

Article History:
Submitted: 14-10-2025; Received in Revised: 12-02-2026; Accepted: 29-03-2026

Abstract

Quality control plays an important role in maintaining production consistency, especially in manufacturing industries such as PT Wirakarya Sakti in Jambi Province. The company faces instability in daily production in achieving the target of 1,044.82 tons. This study aims to analyze the ability of the Individual-Moving Range (I-MR) and Cumulative Sum Fast Initial Response (CUSUM FIR) methods to detect shifts in production quality based on quantitative daily production data, as well as to determine the method that is more sensitive to process instability. The study employed a Statistical Quality Control (SQC) approach through the construction of I-MR and CUSUM FIR control charts. The results showed that the I-MR control chart detected significant fluctuations, with several points exceeding the control limits, while CUSUM FIR was more sensitive in detecting small shifts and was able to provide earlier signals of out-of-control conditions. Therefore, the CUSUM FIR method is considered more effective as an early detection tool for maintaining production process stability, whereas the I-MR method is more suitable for detecting large-scale shifts.

Keywords*: CUSUM FIR; I-MR; Quality Control; Quality Shift.*

Abstrak

Pengendalian kualitas penting untuk menjaga konsistensi hasil produksi, terutama di industri manufaktur seperti PT Wirakarya Sakti di Provinsi Jambi. Perusahaan menghadapi ketidakstabilan produksi harian dalam mencapai target sebesar 1.044,82 ton. Penelitian ini menganalisis kemampuan metode Individual-Moving Range (I-MR) dan Cumulative Sum Fast Initial Response (CUSUM FIR) dalam mendeteksi pergeseran kualitas hasil produksi berdasarkan data produksi harian, serta menentukan metode yang lebih sensitif terhadap ketidakterkendalian proses. Penelitian menggunakan Statistical Quality Control (SQC) melalui pembentukan peta kendali I-MR dan CUSUM FIR. Hasil analisis menunjukkan peta kendali I-MR mendeteksi adanya fluktuasi signifikan dengan beberapa titik melampaui batas kendali, sedangkan CUSUM FIR lebih sensitif mendeteksi pergeseran kecil dan mampu memberikan sinyal ketidakterkendalian lebih awal. Metode CUSUM FIR lebih efektif digunakan sebagai alat deteksi dini untuk menjaga kestabilan proses produksi, sementara I-MR lebih sesuai untuk mendeteksi pergeseran dalam skala besar.

Kata Kunci*: CUSUM FIR; I-MR; Pengendalian Kualitas; Pergeseran Kualitas.*

Introduction

Quality control is a fundamental aspect in every manufacturing industry that aims to maintain consistency and production standards [1]. Poor quality of production not only affects customer satisfaction levels, but can also lead to significant financial losses and damage the company's reputation [2]. Effective and efficient quality control is essential to ensure that each production meets or even exceeds customer expectations, as well as minimizes the costs associated with irregularities in the production process [3].

PT Wirakarya Sakti and PT Lontar Papyrus Pulp and Paper Industries, both part of the Sinarmas Group, have strategic relationships in the supply chain of the pulp and paper industry in Indonesia. PT Wirakarya Sakti, as the main supplier of wood raw materials for PT Lontar Papyrus Pulp and Paper Industries in Jambi Province, faces challenges in maintaining the stability of its daily production to achieve the target of 1,044.82 tons. Based on an analysis of 245 production data during the period from May to December 2024, it was found that 121 data (49.4%) showed production below the target, while 124 data (50.6%) were above the target.

The most common statistical approach or technique used in quality control is Statistical Quality Control (SQC)[4]. The use of a control chart allows companies to more effectively identify irregularities that occur, both caused by internal and external factors, and make corrections before the problem develops to be larger [5]. Early detection of these quality shifts is essential to reduce variation in production yields, maintain quality consistency, and improve the efficiency of the production process [6].

---

[1] Parwadi Moengin et al., "Perancangan Sistem Pendukung Keputusan Untuk Pengendalian Kualitas Pada Departemen Blow PT. D," *Jurnal Teknik Industri* (Jakarta) 7, no. 3 (2017), https://doi.org/10.25105/jti.v7i3.3141.

[2] Wahdaniah Wahdaniah et al., "Dampak Hutan Tanaman Industri Terhadap Perubahan Tutupan Lahan Hutan Dan Kondisi Sosial Ekonomi Masyarakat," *Gorontalo Journal of Forestry Research* (Gorontalo) 5 (October 2022): 101–9, https://doi.org/10.32662/gjfr.v5i2.2151.

[3] Amelia Serli Novia Sari and Sunarso, "Optimalisasi Quality Control Menggunakan Metode Statistical Quality Control Untuk Mengurangi Jumlah Kerusakan Produk Kain (Studi Kasus Pada PT Regar Sport Industri Indonesia Di Wonogiri)," *PENG: Jurnal Ekonomi Dan Manajemen* (Banda Aceh) 2, no. 1 (2025): 830–44, https://doi.org/10.62710/jpe01373.

[4] Sulthan Arkana Dzakirah, "Analisis Pengendalian Kualitas Pada Produk Plywood Dengan Menggunakan Metode Statistical Quality Control (SQC) Dan Fault Mode and Effect Analysis (FMEA)," *JUSTI (Jurnal Sistem Dan Teknik Industri)* (Gresik) 4, no. 4 (2023): 443–51, https://doi.org/10.30587/justicb.v4i4.7998.

[5] Bhisham C. Gupta, *Statistical Quality Control: Using Minitab, R, JMP, and Python*, 1st ed. (Wiley, 2021), https://doi.org/10.1002/9781119671718.

[6] Aulia Resti et al., "Grafik Pengendali Mixed Exponentially Weighted Moving Average – Cumulative Sum (MEC) Dalam Analisis Pengawasan Proses Produksi (Studi Kasus: Wingko Babat Cap 'Moel')," *Jurnal Gaussian* 10, no. 1 (2021): 114–24, https://doi.org/10.14710/j.gauss.10.1.114-124.

In the application of control charts for multiple sample data such as the case of daily production at PT Wirakarya Sakti, the Shewhart Individual-Moving Range (I-MR) method is the right choice. This method uses a moving average-based statistical approach to determine the upper and lower control boundaries [7].

The Individual-Moving Range (I-MR) method applies statistical mathematical concepts through the calculation of Moving Range (MR) which is defined as $MR_i = |x_i - x_{i-1}|$, measure variability between two consecutive observations [8]. Although this method is effective in identifying large shifts, I-MR has limitations in detecting small shifts because it only considers individual values without paying attention to cumulative patterns over time. Small shifts that are not detected early on can develop into larger quality issues and affect production consistency [9].

As a development of the conventional method, Cumulative Sum (CUSUM) offers a more complex mathematical approach by utilizing historical data through cumulative calculations C_i^+ and C_i^- [10]. A further development of conventional CUSUM is CUSUM with Fast Initial Response (FIR) which is a modification to increase the sensitivity of CUSUM at the beginning of process monitoring. The mathematical advantage of CUSUM FIR is strengthened by the concept of head start value of H/2 for $i = 0$. The FIR allows CUSUM to provide an early signal against the shifts that occur in the early phases of control.

The application of the I-MR and CUSUM FIR methods is proposed as a comprehensive analytical solution for PT Wirakarya Sakti. These two methods complement each other in function, where the I-MR method will be used to monitor significant variations in the daily production process, while the CUSUM FIR will help detect small shifts that may not be identified by conventional methods. Although these two methods are complementary, this study will still conduct comparisons to determine the most effective method in the context of quality control of wood production.

Similarly, the study conducted by Fernandez et al. (2024) aimed to analyze and control throughput performance in palm oil mills (PKS) using the

---

[7] Nurmasyita Nasruddin et al., "Peta Kendali Demerit Untuk Data Autokorelasi (Moving Centerline Demerit Dan Moving Range)," *Statistika: Journal of Theoretical Statistics and Its Applications* 24, no. 2 (2024): 123–34, https://doi.org/10.29313/statistika.v24i2.3145.

[8] Douglas C. Montgomery, *Introduction to Statistical Quality Control* (John Wiley & Sons, 2020).

[9] Nur Sahroni and Rizki Achmad Darajatun, "Efektivitas Proses Produksi Melalui Pengendalian Kualitas Pada Part End Plate Dengan Metode Lean Six Sigma Di PT. GCE," *Industrika : Jurnal Ilmiah Teknik Industri* (Lampung) 8, no. 2 (2024): 343–51, https://doi.org/10.37090/indstrk.v8i2.1259.

[10] Dhea Trinandya Wijayanti et al., "Perbandingan Kinerja Peta Kendali Cumulative Sum Dan Peta Kendali Exponentially Weighted Moving Average," *BIMASTER : Buletin Ilmiah Matematika, Statistika Dan Terapannya* (Pontianak) 9, no. 4 (2020): 549–58, https://doi.org/10.26418/bbimst.v9i4.43367.

I-MR control chart method. The study applied a SQC approach based on 75 throughput production data observations. The results showed that most of the data were within the control limits, indicating that the production process was generally stable. However, several out-of-control points were identified and subsequently corrected through process revisions. These findings demonstrate that the I-MR control chart is effective in monitoring process stability and identifying production deviations that require corrective action [11].

Research by Novoa and Varela (2020) applies CUSUM in thoracic surgery quality monitoring, CUSUM is used as a tool in Statistical Quality Control (SQC) to detect small changes in the quality of surgical outcomes in real-time. The results of the study show that this method is superior to the Shewhart chart in risk analysis in the health sector [12].

Although the research of Fernandez et al. (2024) and Novoa and Varela (2020) demonstrates the successful application of the I-MR and CUSUM methods separately, there is still a gap in the literature regarding the combined use of these two methods in the context of the pulp and paper industry. In addition, no previous studies have analyzed the effectiveness of the CUSUM FIR implementation in the context of timber production for the pulp industry. This study aims to fill this gap by analyzing the effectiveness of the combined use of I-MR and CUSUM FIR methods in the specific context of the pulp and paper industry. This gap is important because production processes in the pulp and paper industry require stable quality control systems and rapid detection of process shifts to prevent production inefficiencies, maintain product consistency, and reduce the risk of quality deviations. The combination of these methods is expected to improve early detection capability and support more effective production monitoring.

To address this gap, this study analyzes the application of the Individual-Moving Range (I-MR) method in detecting shifts in production quality at PT Wirakarya Sakti and evaluates the effectiveness of the Cumulative Sum Fast Initial Response (CUSUM FIR) method in identifying small process changes that are often undetected by conventional control charts. The I-MR method was selected because it is effective in monitoring individual production data and detecting large process variations, whereas the CUSUM FIR method is more sensitive in detecting small and gradual shifts. This study seeks to

---

[11] Benny Rio Fernandez et al., "Throughput Pabrik Kelapa Sawit: Analisis Menggunakan Individual Moving Range (I-MR) Chart," *Jurnal Agroindustri, Agribisnis, dan Agroteknologi* 3, no. 2 (2024): 29–33, https://akses.ptki.ac.id/jurnal/index.php/agrotristek/article/view/182.

[12] Nuria M. Novoa and Gonzalo Varela, "Monitoring Surgical Quality: The Cumulative Sum (CUSUM) Approach," *Mediastinum* 4, no. 0 (2020), https://doi.org/10.21037/med.2019.10.01.

examine the effectiveness of the I-MR and CUSUM FIR methods in detecting production quality shifts and to determine which method is more sensitive in identifying process instability in daily production data. It is expected that the CUSUM FIR method will provide earlier detection of process instability, while the I-MR method will be more effective in identifying significant production deviations. The novelty of this study lies in the comparative analysis of I-MR and CUSUM FIR methods in the context of the pulp and paper industry, which remains limited in previous studies. The findings are expected to support more effective industrial quality control strategies and improve early detection of production quality shifts.

Method

This study uses daily production data during the period from May to December 2024 at PT Wirakarya Sakti, Camp District II. This data is obtained from internal documents of PT Wirakarya Sakti, which records production results for the purpose of monitoring and evaluating productivity. The research variables used in this study can be seen in Table 1.

Table 1. Research Variables

Variable Name	Variable Definition	Data Scale	Unit
production output (x_i)	The amount of output produced by PT Wirakarya Sakti in a period, which is measured based on daily production in tons.	Ratio	Tons

This study applied the I-MR and CUSUM FIR methods to detect variations in the production process and compare the sensitivity of both methods. The analysis was conducted using Python software. Although SQC generally distinguishes Phase I and Phase II analysis, this study used the entire production dataset for both parameter estimation and process analysis because the primary objective was to compare the sensitivity of the I-MR and CUSUM FIR methods in detecting production shifts.

The I-MR control chart, also referred to as the XmR chart in some literature, was selected because it is considered robust for time-series data and does not require strict distributional assumptions such as normality. This method determines control limits empirically using the average moving range of the observed data, as explained by Anthony Poots and Thomas Woodcock, who stated that the XmR chart does not rely on strict distribution assumptions and uses the moving range of the observed data to establish empirical control limits [13].

[13] Alan J. Poots and Thomas Woodcock, "Statistical Process Control for Data Without Inherent Order," *BMC Medical Informatics and Decision Making* 12 (August 2012): 86, https://doi.org/10.1186/1472-6947-12-86.

The stages of analysis are as follows:

1. Application of I-MR Control Chart
   Steps taken:
   a. Calculate moving range.
   b. Determine the average production yield and average moving range.
   c. Setting Center Line (CL), Upper Control Limit (UCL) and Lower Control Limit (LCL) for I-Chart and MR-Chart.
   d. Compile a graph of the I-MR control chart.
   e. Analyze the results of the control chart
2. Implementation of CUSUM FIR Control Chart
   Steps taken:
   a. Determine the production target value (μ_0) based on daily targets and historical averages.
   b. Calculate standard deviations and set shift sizes.
   c. Determining the out-of-control value (μ_1), reference value (K), and decision interval (H). The parameters $K$and Hwere determined based on standard SQC guidelines to optimize sensitivity in detecting small process shifts. The value of $h = 4$ was used because this study focuses on detecting small shifts in the production process.
   d. Calculating CUSUM FIR Statistics.
   e. Compile and analyze the CUSUM FIR control chart.
3. Sensitivity Analysis
   a. Compare the initial detection time between the two methods.
   b. Assess the number of points that are outside the control limit.

Results and Discussion

This study analyzed daily production data from May to December 2024 obtained from PT Wirakarya Sakti, Camp District II. A total of 245 production observations were used in the analysis based on the production output variable presented in Table 1. The data were analyzed using the Individual-Moving Range (I-MR) and Cumulative Sum Fast Initial Response (CUSUM FIR) control charts to evaluate process stability and compare the sensitivity of both methods in detecting production shifts.

Overall, the results indicate that the I-MR control chart was effective in identifying significant production variations, while the CUSUM FIR method demonstrated higher sensitivity in detecting small and gradual process shifts. In addition to identifying out-of-control points, several production patterns such as fluctuations, temporary shifts, and unstable production movements were also observed during the monitoring period.

1. *Application of I-MR Control Chart*

a. Calculate moving range.

MR or moving range is calculated using the formula:

$$MR_i = |x_i - x_{i-1}|$$

The results of the moving range calculation are presented in Table 2.

Table 2. Moving Range Calculation Results

i	MR_i	i	MR_i	i	MR_i	i	MR_i	i	MR_i	i	MR_i
1	224,76	42	687,83	83	466,6	124	153,83	165	318,49	206	340,01
2	292,7	43	58,97	84	87,22	125	304,45	166	380,35	207	7,58
3	288,82	44	450,02	85	78,52	126	31,08	167	115,77	208	39,17
4	705,58	45	395,11	86	219,31	127	452,36	168	240,94	209	60,33
5	114,59	46	771,88	87	29,71	128	19,12	169	238,62	210	442,59
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
37	401,17	78	14,83	119	236,9	160	25,93	201	25,49	242	469,03
38	387,21	79	78,12	120	278,17	161	291,28	202	132,2	243	51,72
39	174,94	80	158,98	121	136,25	162	400,58	203	129,96	244	119,96
40	32,87	81	151,04	122	1,86	163	422,5	204	153,69		
41	66,1	82	156,22	123	355,83	164	47,11	205	96,58		

Source: Processed data

b. Determine the average production yield and average moving range.

1) The average individual value is 1078.13 tons.

2) The average moving range value of 229.57 tons.

These values indicate that daily production experienced considerable fluctuations between consecutive observations, reflecting variations in the production process during the observation period.

c. Defining the Line of Control

These control lines include CL, UCL, and LCL which are calculated using the standard formula in the SQC.

1) I-Chart Control Line

$$CL_I = \bar{x} = 1078{,}13$$

$$UCL_I = \bar{x} + 3\frac{\overline{MR}}{d_2} = 1078{,}13 + 3\frac{229{,}57}{1{,}128} = 1078{,}13 + 610{,}56 = 1688{,}69$$

$$LCL_I = \bar{x} - 3\frac{\overline{MR}}{d_2} = 1078{,}13 - 3\frac{229{,}57}{1{,}128}$$

$$= 1078{,}13 - 610{,}56$$
$$= 467{,}57$$

2) MR-Chart Control Line

$$CL_{MR} = \overline{MR}$$
$$= 229{,}57$$
$$UCL_{MR} = D_4 \cdot \overline{MR}$$
$$= 3{,}267 \cdot 229{,}57$$
$$= 750{,}01$$
$$LCL_{MR} = D_3 \cdot \overline{MR}$$
$$= 0 \cdot 229{,}57$$
$$= 0$$

d. I-MR Control Chart Results

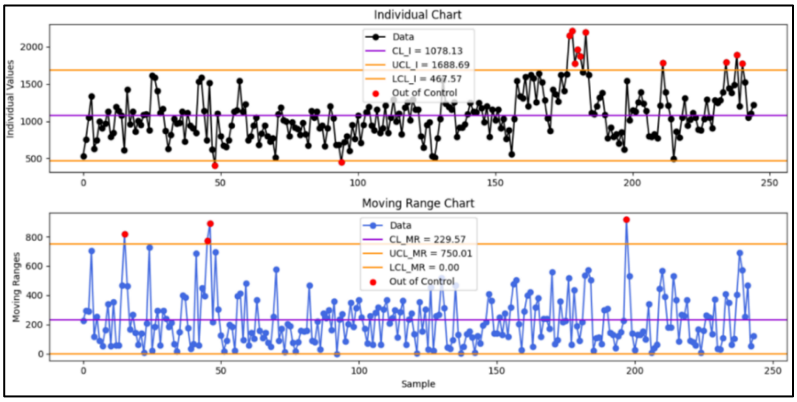

Figure 1. I-MR Control Chart

Figure 1 presents the I-MR control chart of daily production at PT Wirakarya Sakti Camp District II. In the Individual Chart, the center line represents the average daily production of 1078.13 tons, while the upper and lower control limits are 1688.69 tons and 467.57 tons, respectively. Meanwhile, the Moving Range Chart illustrates the variation between consecutive production observations, with an average moving range of 229.57 tons, an upper control limit of 750.01 tons, and a lower control limit of 0.00 tons.

The I-MR control chart indicates that the production process experienced several fluctuations during the observation period. Several observations were located near or beyond the control limits, indicating the presence of process instability and significant production variation. In addition to the out-of-control points, the chart also shows temporary upward and downward movements in production values, suggesting short-term shifts in the production process. Consecutive observations above and below the center line further indicate unstable production patterns and variations in daily operational performance.

The Moving Range Chart also shows that several observations had relatively large moving range values compared to other periods, indicating sudden changes between consecutive production observations. These fluctuations suggest that the production process did not operate under fully stable conditions throughout the observation period. However, several periods also showed relatively stable movements around the center line, indicating that the process stability varied across different observation periods.

Overall, the findings suggest that the production process at PT Wirakarya Sakti Camp District II was not fully statistically controlled during the observation period and still experienced process variations that may have been influenced by operational or environmental factors.

2. *Implementation of CUSUM FIR Control Chart*

a. Determining the Target Value

This target value can be either a historical average or a specific value expected in production output. The daily production target at PT Wirakarya Sakti Camp District II is 1044.82 tons, so that $\mu_0 = 1044{,}82\ ton$.

b. Calculate standard deviations and set shift sizes

The standard deviation for this study was 319.37 tons and the size of the shift in the standard deviation unit was $\delta = 1$.

c. Specifies the out-of-control value (μ_1), the reference value (K) and the control limit (H).

1) Out-of-control value (μ_1)

$$\begin{aligned}\mu_1 &= \mu_0 + \delta\sigma \\ &= 1044{,}82 + 1(319{,}37) \\ &= 1364{,}19\end{aligned}$$

2) Reference value (K)

$$\begin{aligned}K &= \frac{\delta}{2}\sigma \\ &= \frac{1}{2}\ 319{,}37 \\ &= 159{,}69\end{aligned}$$

3) Control limit (H)

$$\begin{aligned}H &= h\sigma \\ &= 4\ (319{,}37) \\ &= 1277{,}48\end{aligned}$$

d. Calculating CUSUM FIR Statistics

The CUSUM FIR control chart has two directions, namely a positive CUSUM FIR (C_i^+) and negative CUSUM FIR (C_i^-) to consider autocorrelations that affect processes. The CUSUM FIR residual control diagram is formulated as follows:

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

This calculation uses the FIR feature so that:

$$C_0^+ = C_0^- = \frac{H}{2} = \frac{1277{,}48}{2} = 638{,}74$$

Table 3. Statistical CUSUM FIR Calculation Results

No	Production Results (tons)	CUSUM FIR POSITIVE			CUSUM FIR NEGATIVE		
		$x_i - 1204,51$	C_i^+	N^+	$885,13 - x_i$	C_i^-	N^-
1	532,34	-672,17	0	0	352,79	991,53	1
2	757,1	-447,41	0	0	128,03	1119,56	2
3	1049,8	-154,71	0	0	-164,67	954,89	3
4	1338,62	134,11	134,11	1	-453,49	501,4	4
5	633,04	-571,47	0	0	252,09	753,49	5
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
240	1201,23	-3,28	4592,76	82	-316,1	0	0
241	1772,2	567,69	5160,45	83	-887,07	0	0
242	1520,99	316,48	5476,93	84	-635,86	0	0
243	1051,96	-152,55	5324,38	85	-166,83	0	0
244	1103,68	-100,83	5223,55	86	-218,55	0	0
245	1223,64	19,13	5242,68	87	-338,51	0	0

Source: Processed data

e. Results of CUSUM FIR Control Chart

The following are the results of the CUSUM FIR control chart.

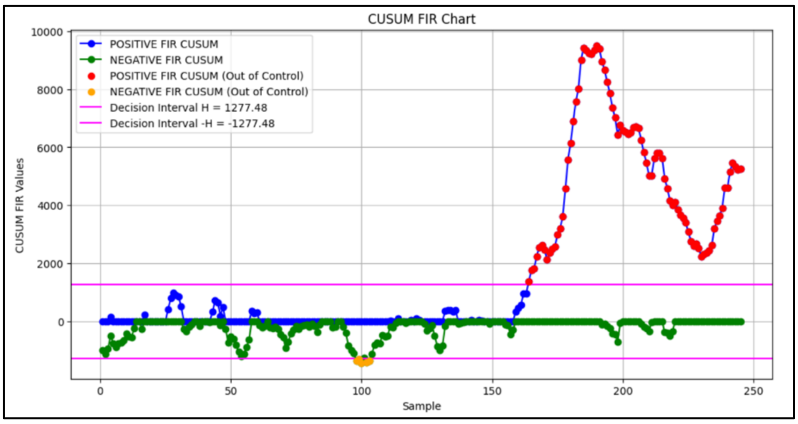

Figure 2. CUSUM FIR Control Chart

In figure 2 it can be seen that at the beginning of the process (about samples 0 to 90), the value is C_i^+ (blue line) and C_i^- (green line) is mostly within the control boundary marked by the magenta horizontal line at $H = \pm 1277.48$. This shows that daily production at PT Wirakarya Sakti Camp District II is still under control during this period.

However, several observations after this period exceeded the control limit H, indicating the presence of process shifts and production instability. The points that crossed the upper or lower decision interval suggest that the cumulative deviation from the target production had become significant. These signals indicate that the production process experienced changes that may have been caused by operational disturbances, production inefficiencies, or variations in field conditions.

In addition, the gradual movement of the CUSUM lines toward the control limits demonstrates the ability of the CUSUM FIR method to detect small and continuous shifts earlier than conventional control charts. This finding confirms that the CUSUM FIR chart is more sensitive in identifying subtle changes in the production process.

3. Sensitivity Analysis

a. Compare the initial detection time between the two methods.
   The CUSUM FIR chart shown in Figure 2 shows high sensitivity to the shift in daily production at PT Wirakarya Sakti Camp District II. This can be seen from the early detection of uncontrollable signals since the 98th and 164th periods. CUSUM is able to detect small changes quickly and consistently. In contrast, the new I-MR chart presented in Figure 1 detects uncontrollability in the 47th (I-Chart) and 16th (MR-Chart) periods, as well as being more responsive to large shifts. This shows that I-MR has a slower time to signal than CUSUM.
b. Assess the number of points that are outside the control limit.
   CUSUM FIR excels at identifying pattern changes systematically, as seen in Figure 2. This method not only marks points beyond the boundaries of control, but also indicates the direction of the shift and the last point before the process of getting out of control, helping management trace the source of change. In contrast, the I-MR chart shown in Figure 1 is able to detect some points outside the boundary, but does not indicate the direction of shift, thus limiting the analysis. In addition, the lower limit of the MR-Chart reaching zero indicates limitations in measuring negative variation.

Conclusion

Based on the results of the research and analysis of the production process at PT Wirakarya Sakti, it can be concluded that the application of the Individual-Moving Range (I-MR) and Cumulative Sum Fast Initial Response (CUSUM FIR) methods successfully identified shifts in production quality with different detection characteristics. The I-MR method showed significant production fluctuations with an average I-Chart value of 1078.13 $tons$ and an average MR-Chart value of 229.57 $tons$. The control limits obtained were $467.57 - 1688.69$ $tons$ for the I-Chart and $0 - 750.01$ $tons$ for the MR-Chart. Meanwhile, the implementation of the CUSUM FIR method using the company production target of 1044.82 $tons$ indicated out-of-control signals beginning in the 98th and 164th observation periods, suggesting the occurrence of production shifts during the monitoring process.

Overall, the CUSUM FIR method proved to be more sensitive in detecting small and gradual process shifts, as well as providing earlier directional information regarding process instability. In contrast, the I-MR method was more effective in identifying significant production variations, although with a relatively slower response. These findings indicate that the combined use of I-MR and CUSUM FIR methods can provide a more comprehensive monitoring system for industrial production quality control.

The contribution of this study lies in the comparative implementation of I-MR and CUSUM FIR methods in the context of the pulp and paper industry, particularly in timber production monitoring, which remains limited in previous studies. Practically, the findings of this study can support companies in improving process monitoring effectiveness, reducing the risk of production instability, and enhancing consistency in raw material supply quality.

However, this study is limited to production data from one company and one observation period, which may affect the generalizability of the findings. In addition, the analysis focused only on production output variables without considering other operational factors that may influence process stability.

Future research is recommended to involve longer observation periods, additional production variables, and the integration of other Statistical Quality Control (SQC) methods or machine learning approaches to improve the accuracy and effectiveness of production quality monitoring systems.

Bibliography

Dzakirah, Sulthan Arkana. "Analisis Pengendalian Kualitas Pada Produk Plywood Dengan Menggunakan Metode Statistical Quality Control (SQC) Dan Fault Mode and Effect Analysis (FMEA)." *JUSTI (Jurnal Sistem Dan Teknik Industri)* (Gresik) 4, no. 4 (2023): 443–51. https://doi.org/10.30587/justicb.v4i4.7998.

Fernandez, Benny Rio, Irwan Rachmiadji, and Rycce Sylviana Pratikha. "Throughput Pabrik Kelapa Sawit: Analisis Menggunakan Individual Moving Range (I-MR) Chart." *Jurnal Agroindustri, Agribisnis, dan Agroteknologi* 3, no. 2 (2024): 29–33. https://akses.ptki.ac.id/jurnal/index.php/agrotristek/article/view/182.

Gupta, Bhisham C. *Statistical Quality Control: Using Minitab, R, JMP, and Python*. 1st ed. Wiley, 2021. https://doi.org/10.1002/9781119671718.

Moengin, Parwadi, Rina Fitriana, and Buana Ramadhan. "Perancangan Sistem Pendukung Keputusan Untuk Pengendalian Kualitas Pada Departemen Blow PT. D." *Jurnal Teknik Industri* (Jakarta) 7, no. 3 (2017). https://doi.org/10.25105/jti.v7i3.3141.

Montgomery, Douglas C. *Introduction to Statistical Quality Control*. John Wiley & Sons, 2020.

Nasruddin, Nurmasyita, Erna Tri Herdiani, and Nasrah Sirajang. "Peta Kendali Demerit Untuk Data Autokorelasi (Moving Centerline Demerit Dan Moving Range)." *Statistika: Journal of Theoretical Statistics and Its Applications* 24, no. 2 (2024): 123–34. https://doi.org/10.29313/statistika.v24i2.3145.

Novoa, Nuria M., and Gonzalo Varela. "Monitoring Surgical Quality: The Cumulative Sum (CUSUM) Approach." *Mediastinum* 4, no. 0 (2020). https://doi.org/10.21037/med.2019.10.01.

Poots, Alan J., and Thomas Woodcock. "Statistical Process Control for Data Without Inherent Order." *BMC Medical Informatics and Decision Making* 12 (August 2012): 86. https://doi.org/10.1186/1472-6947-12-86.

Poots, Alan J., and Thomas Woodcock. "Statistical Process Control for Data without Inherent Order." *BMC Medical Informatics and Decision Making* 12, no. 86 (2012): 2–7.

Resti, Aulia, Tatik Widiharih, and Rukun Santoso. "Grafik Pengendali Mixed Exponentially Weighted Moving Average – Cumulative Sum (MEC) Dalam Analisis Pengawasan Proses Produksi (Studi Kasus: Wingko Babat Cap 'Moel')." *Jurnal Gaussian* 10, no. 1 (2021): 114–24. https://doi.org/10.14710/j.gauss.10.1.114-124.

Sahroni, Nur, and Rizki Achmad Darajatun. "Efektivitas Proses Produksi Melalui Pengendalian Kualitas Pada Part End Plate Dengan Metode Lean Six Sigma Di PT. GCE." *Industrika : Jurnal Ilmiah Teknik Industri* (Lampung) 8, no. 2 (2024): 343–51. https://doi.org/10.37090/indstrk.v8i2.1259.

Sari, Amelia Serli Novia, and Sunarso. "Optimalisasi Quality Control Menggunakan Metode Statistical Quality Control Untuk Mengurangi Jumlah Kerusakan Produk Kain (Studi Kasus Pada PT Regar Sport

Industri Indonesia Di Wonogiri).” *PENG: Jurnal Ekonomi Dan Manajemen* (Banda Aceh) 2, no. 1 (2025): 830–44. https://doi.org/10.62710/jpe01373.

Wahdaniah, Wahdaniah, Sukirman Rahim, and Irwan Bempah. “Dampak Hutan Tanaman Industri Terhadap Perubahan Tutupan Lahan Hutan Dan Kondisi Sosial Ekonomi Masyarakat.” *Gorontalo Journal of Forestry Research* (Gorontalo) 5 (October 2022): 101–9. https://doi.org/10.32662/gjfr.v5i2.2151.

Wijayanti, Dhea Trinandya, Helmi Helmi, and Nurfitri Imro’ahh. “Perbandingan Kinerja Peta Kendali Cumulative Sum Dan Peta Kendali Exponentially Weighted Moving Average.” *BIMASTER : Buletin Ilmiah Matematika, Statistika Dan Terapannya* (Pontianak) 9, no. 4 (2020): 549–58. https://doi.org/10.26418/bbimst.v9i4.43367.