Research Article

Monitoring of Mean Processes with Mixed Moving Average – Modified Exponentially Weighted Moving Average Control Charts

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Abstract
In Statistical Process Control, a control chart is the most effective equipment for monitoring and improving processes. Classic control charts were created in the past and were effective at detecting both small and large changes. However, the mixed control chart has been presented to improve the performance of the traditional control chart. This research introduces a new mixed control chart, MA-MEWMA, which combines the moving average (MA) and the modified exponentially weighted moving average (MEWMA) charts to detect the tiny changes in the procedures both of symmetric and asymmetric distributions. The average run length (ARL) can also be used to measure progress in the MA-MEWMA chart with Shewhart, MA, and MEWMA charts that employ Monte Carlo simulation. The experiments demonstrated that the proposed chart had a greater impact compared to all other control charts with the parameter level ±0.05, ±0.10, ±0.25, ±0.50, ±0.75, ±1.00, ±1.50 through discovering a change in the average of the method in the control where $ARL_0 = 370$. On the other hand, when the parameter level was set to 2.00, ±3.00, ±4.00, the MA control chart performed admirably. An excellent example is data set on viscosity from a batch chemical process. Environmental information data were provided to explain how the suggested chart and MA-MEWMA charts are implemented, demonstrating that the MA-MEWMA chart was more successful than other charts in detecting changes.

Keywords: Mixed control chart, Moving Average - Modified Exponentially Weighted Moving Average control chart, Average Run Length, Monte Carlo simulation

1 Introduction

Statistical Process Control (SPC) provides the technical foundation for quality control and improvement. One of the essential techniques of SPC is the control chart. Classic control charts were created in the past and were effective at detecting both small and large changes within a process parameter. Shewhart [1] was the first to employ the control charting strategy, which is inefficient in detecting minor to moderate shifts because it is based on current data. On the other hand, the exponentially weighted moving average (EWMA) [2], cumulative sum (CUSUM) [3] and modified exponentially weighted moving average (MEWMA) charts used both past and current data, creating them more responsive to minor and moderate shifts. Patel and Divecha [4] developed the MEWMA control chart. Khan *et al.* [5] investigated the MEWMA in greater depth and presented a generalized form of the MEWMA, discovering that the MEWMA chart detects shifts more instantly than the EWMA chart. In addition, Khoo [6] created the moving average (MA) control chart, which is based on the simple average and can detect small shifts close to the EWMA. However, effective monitoring is a necessary component of the upgrading procedure. The average run length (ARL) is a comprehensive measurement for assessing the effectiveness of the proposed control chart.

The mixed control chart has been presented to improve the performance of the traditional control chart. For example, Wong *et al.* [7] created the combined MA–Shewhart scheme to also be easily applied in the financial system. As a result, the MA chart is gently less considerate than the CUSUM and EWMA charts through sensing intentionally, however, the holistic quality is in the same manner. The distributions through in run lengths on the MA chart and the respective EWMA chart are nearly identical. To investigate the process mean changes with both normal and non-normal distributions, Taboran *et al.* [8] presented MA-EWMA charts, whereas Sukparungsee *et al.* [9] indicated EWMA-MA charts. In terms of identifying targets by looking at the average run length and standard deviation of run length, the proposed chart exceeded the Shewhart, MA, and EWMA charts. For monitoring the process mean, Ali and Haq [10] created a mixed generally weighted moving average – cumulative sum (GWMA-CUSUM) control chart. When it comes to detecting minor shifts, the GWMA-CUSUM chart appears to be better than the CUSUM, EWMA, GWMA, and EWMA-CUSUM charts. Similarly, to Lu [11], the proposed GWMA-CUSUM and CUSUM-GWMA charts have a higher sensitivity to identify small process changes and effective constructions than the mixed EWMA-CUSUM and mixed CUSUM-EWMA charts, respectively. A Tukey MA-EWMA control chart [12] and a Tukey MA-DEWMA control chart [13] were described by Taboran *et al.* for monitoring the average process in the symmetric and non-symmetric distribution, respectively. According to the research, the performance of the proposed chart can reliably detect better than other charts in terms of ARL and MRL. Saengsura *et al.* [14] introduced the mixed MA-CUSUM control chart and the results reveal that when ARL, SDRL, and MRL were utilized, the presented chart was more convenient than the Shewhart, CUSUM, MA, and CUSUM-MA charts.

The goal of this paper became to suggest a mixed control chart, identified as the MA-MEWMA chart, that manages to combine the MA and MEWMA charts to discover the mean change of the procedure under normal and non-normal distributions. The ARL was indeed investigated using exhaustive Monte Carlo simulations, which is the proposed chart's efficiency criterion when tried to compare to the Shewhart, MA, and MEWMA charts.

2 Design of Proposed Control Chart

In this segment, we will develop a massive control chart to detect requirements changes. The parametric control charts are based on the assumptions of normality, dependence, and variance homogeneity. This study employed MA and MEWMA.

2.1 *Moving Average (MA) control chart*

The MA chart implements a random selection from a normal distribution with mean μ and variation σ^2 for each duration (w) of the moving average at time t. The MA statistic with mean and variance are shown in Equations (1)–(3) as follows:

$$MA_t = \begin{cases} \dfrac{X_t + X_{t-1} + X_{t-2} + \ldots}{t}, & t < w \\ \dfrac{X_t + X_{t-1} + \ldots + X_{t-w+1}}{w}, & t \geq w. \end{cases} \quad (1)$$

$$E(X_t) = E(MA_t) = \mu \quad (2)$$

$$V(MA_t) = \begin{cases} \dfrac{\sigma^2}{t}, & t < w \\ \dfrac{\sigma^2}{w}, & t \geq w. \end{cases} \quad (3)$$

The MA chart's control limits are almost as shown in Equation (4):

$$UCL / LCL = \begin{cases} \mu \pm \dfrac{C_1 \sigma}{\sqrt{t}}, t < w \\ \mu \pm \dfrac{C_1 \sigma}{\sqrt{w}}, t \geq w \end{cases} \quad (4)$$

where μ is the average of the processes under consideration, C_1 is a control constant of the MA control chart's acceptable limit and σ represents the component's standard deviation.

2.2 *Modified Exponentially Weighted Moving Average (MEWMA) control chart*

The MEWMA control chart was designed to be highly useful in locating both small and large changes, as presented by Khan *et al.* [5]. The MEWMA statistic that observation X_t for t = 1, 2,... from normal distribution is defined in Equation (5) as follows:

$$M_t = \lambda X_t + (1-\lambda)M_{t-1} + k(X_t - X_{t-1}), t = 1,2,..., \quad (5)$$

where λ is a weighting parameter that ranges from 0 to 1, and k is an additional parameter with a value that is not zero. The average and the asymptotic variance of M_t when $t \to \infty$ are defined in Equations (6) and (7):

$$E(M_t) = \mu \quad (6)$$

$$V(M_t) = \sigma^2 \left[\frac{\left(\lambda + 2\lambda k + 2k^2\right)}{2 - \lambda} \right]. \quad (7)$$

The control limits of the MEWMA chart are about as follows in Equation (8) below,

$$UCL / LCL = \mu \pm C_2 \sigma \sqrt{\frac{(\lambda + 2\lambda k + 2k^2)}{(2-\lambda)}} \quad (8)$$

where C_2 is a control constant of the MEWMA control chart's acceptable limit. μ and σ^2 represent the component's mean and variance.

2.3 *Mixed MA-MEWMA control chart*

The mixed MA-MEWMA control chart was created by combining MA and MEWMA. The statistic ought to be used to provide context for the MA chart [Equation (1)]. The MA-MEWMA control design statistic is described this way in Equation (9):

$$MA - MEWMA_t = \begin{cases} \dfrac{M_t + M_{t-1} + M_{t-2} + ...}{t}, & t < w \\ \dfrac{M_t + M_{t-1} + ... + M_{t-w+1}}{w}, & t \geq w. \end{cases} \quad (9)$$

The MA-MEWMA chart's control limit seems to be the expectation for the data that will be from the MEWMA chart's worth. As seen in Equations (3) and (7), The convergence upper and lower control limits of the MA-MEWMA chart are about as follows in Equation (10):

$$UCL / LCL = \begin{cases} \mu_M \pm C_3 \sqrt{(\dfrac{\sigma_M^2}{t})(\dfrac{\lambda + 2\lambda k + 2k^2}{2-\lambda})}, t < w \\ \mu_M \pm C_3 \sqrt{(\dfrac{\sigma_M^2}{w})(\dfrac{\lambda + 2\lambda k + 2k^2}{2-\lambda})}, t \geq w \end{cases} \quad (10)$$

where C_3 is a control constant of the MA-MEWMA control chart's acceptable limit. μ_M and σ_M^2 are the average and variance of the MEWMA statistics, respectively.

The variance of MA-MEWMA is shown in Equation (11):

$$V(MA - MEWMA_t) = \begin{cases} (\dfrac{\sigma_M^2}{t})(\dfrac{\lambda + 2\lambda k + 2k^2}{2-\lambda}), t < w \\ (\dfrac{\sigma_M^2}{w})(\dfrac{\lambda + 2\lambda k + 2k^2}{2-\lambda}), t \geq w. \end{cases} \quad (11)$$

The proposed chart alarms if any point of the MA-MEWMA statistic in Equation (9) declines outsides the control limits described by Equation (10).

3 Performance Measurement

The average run length (ARL) is often used to examine the performance of the control charts. The average data points displayed until the out of signal was shown can be defined as the ARL [15]. When the situation has been stabilized, the ARL_0 should be large enough to avoid alerts, and when the situation is out of control, the ARL_1 ought to be tiny enough to discover all procedure shifts quickly. The lowest ARL_1 is discovered by the control chart with the best capability. The ARL is defined as follows in Equation (12):

$$ARL = \frac{\sum_{t=1}^{N} RL_t}{N} \quad (12)$$

where RL_t refers to the number of samples required before the method becomes unmanageable for the initial time, N is the amount of trials that are repeated and t is the amount of data simulations.

The ARL properties of all control charts were assessed using Monte Carlo simulation in the step follows:

1) Take the random sample of size n, which is set to 10,000 from any certain distribution.

2) Compute the proposed charting statistic.

3) Consider "C" at a specified value of ARL_0 is set to 370.

4) Calculate the control limit and run the values statistic in step 2.

5) Iterate steps 1–4 with 200,000 repetitions (N) to calculate the ARL.

4 Result and Discussion of Simulations

The efficiency of the proposed chart was measured by ARL when the procedure was out of control. We compared the performance of all charts with symmetric distributions such as Normal(0,1) and Laplace(0,1), as well as unsymmetric distributions such as Exponential(1) and Gamma(4,1) with specific shifts of [–4, 4].

From Table 1 and Figure 1, the outcomes of a system with normal observations, which mean zero and variance equal 1. We used $w = 5$, $\lambda = 0.25$, $k = –0.125$ and coefficient of control limit $C_3 = 5.086$ We discovered that the ARL_1 of MA-MEWMA control chart emerged as the most capable of detecting changes at all change levels except the change at ±1.50, ±2.00, ±3.00, ±4.00 where the MA control chart outperformed than other charts.

From Table 2 and Figure 2, the observation from Laplace distribution with parameters alpha and beta were equal to zero and one, respectively. The result showed that when $w = 5$, $\lambda = 0.25$, $k = –0.125$ and coefficient of control limit $C_3 = 3.826$ the ARL_1 of MA-MEWMA chart was lower than the Shewhart, MA and MEWMA control charts at change levels ±0.05, ±0.10, ±0.25, ±0.50, ±0.75, ±1.00 and ±1.50. When the change parameter threshold was set to ±2.00, ±3.00, ±4.00, the MA control chart was possibly the most effective at detecting changes.

Based on Table 3 and Figure 3, the data from Exponential distribution with set parameter lambda equal 1, $w = 5$, $\lambda = 0.25$, $k = –0.125$ and coefficient of control limit $C_3 = 4.272$. We conclude that the ARL_1 from proposed chart performs slightly better than the other charts. On the other side, for the shift parameter at levels 2.00, 3.00 and 4.00, the MA chart performs slightly better than them.

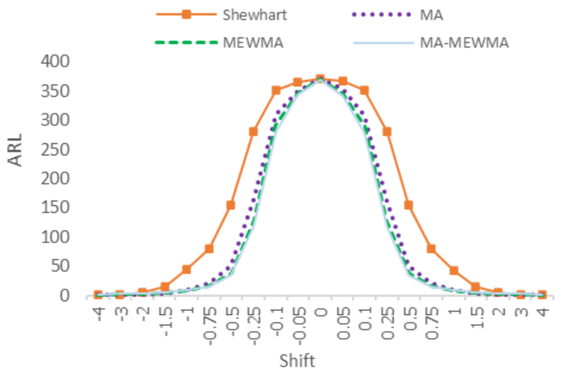

Figure 1: Shewhart, MA, MEWMA, and MA-MEWMA ARL curves for the Normal distribution.

Table 1: ARL values for the normal distribution of Shewhart, MA, MEWMA, and MA-MEWMA

Shift	w = 5, λ = 0.25, k = –0.125			
	Shewhart	MA	MEWMA	MA-MEWMA
	$C = 2.999$	$C_1 = 2.882$	$C_2 = 2.199$	$C_3 = 5.086$
–4.00	1.19	**1.00**	1.07	2.07 ± 0.00
–3.00	2.00	**1.10**	1.49	2.70 ± 0.00
–2.00	6.29	**1.99**	2.69	4.02 ± 0.00
–1.50	14.93	**3.75**	4.28	5.39 ± 0.00
–1.00	43.78	10.09	9.10	**9.42** ± 0.01
–0.75	80.99	20.60	16.41	**15.66** ± 0.03
–0.50	155.09	51.32	38.44	**34.72** ± 0.07
–0.25	280.86	162.62	129.24	**117.59** ± 0.25
–0.1	351.46	311.10	290.96	**280.52** ± 0.61
–0.05	365.08	350.63	347.39	**343.25** ± 0.76
0	370.98	370.70	370.67	370.26 ± 0.82
0.05	366.76	353.30	346.66	**342.64** ± 0.75
0.1	351.85	309.36	289.90	**279.66** ± 0.61
0.25	280.83	161.35	129.30	**117.89** ± 0.25
0.50	154.89	51.48	38.37	**34.66** ± 0.07
0.75	80.86	20.53	16.38	**15.68** ± 0.03
1.00	43.69	10.05	9.05	**9.41** ± 0.01
1.50	14.91	**3.75**	4.29	5.39 ± 0.00
2.00	6.29	**1.99**	2.69	4.01 ± 0.00
3.00	1.99	**1.10**	1.49	2.70 ± 0.00
4.00	1.19	**1.00**	1.07	2.07 ± 0.00

Note: The amount in bold is the lowest number of ARL and after the sign (±) is the ARL deviation.

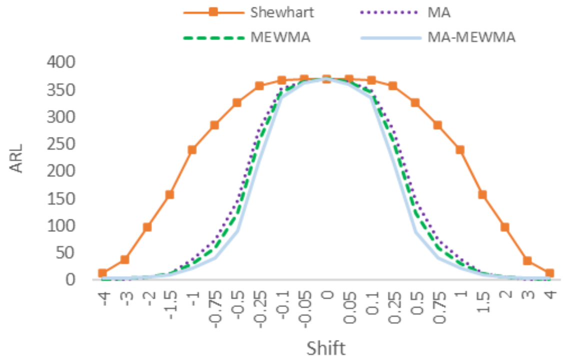

Figure 2: Shewhart, MA, MEWMA, and MA-MEWMA ARL curves for the Laplace distribution.

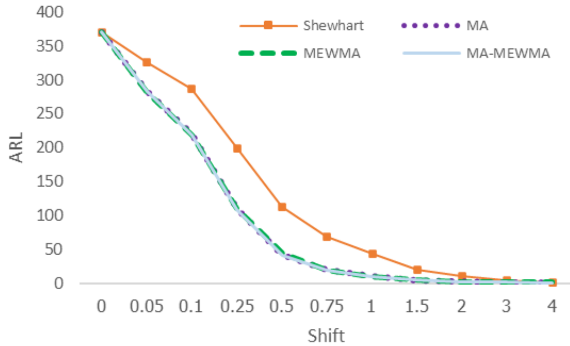

Figure 3: Shewhart, MA, MEWMA, and MA-MEWMAA RL curves for the Exponential distribution.

Table 2: ARL values for Laplace distribution of Shewhart, MA, MEWMA and MA-MEWMA

Shift	w = 5, λ = 0.25, k = –0.125			
	Shewhart	**MA**	**MEWMA**	**MA-MEWMA**
	$C = 2.956$	$C_1 = 2.199$	$C_2 = 1.749$	$C_3 = 3.862$
–4.00	13.56	**1.20**	1.91	3.05 ± 0.00
–3.00	36.76	**1.98**	2.88	4.02 ± 0.00
–2.00	98.22	**5.35**	5.93	6.13 ± 0.01
–1.50	157.01	12.54	11.28	**9.41** ± 0.01
–1.00	240.47	38.53	30.39	**21.31** ± 0.04
–0.75	284.83	74.04	58.44	**39.99** ± 0.08
–0.50	327.61	146.84	122.72	**89.39** ± 0.19
–0.25	357.58	276.69	255.95	**219.27** ± 0.48
–0.1	367.86	351.87	346.17	**335.55** ± 0.74
–0.05	369.47	364.12	363.77	**362.03** ± 0.79
0	370.78	370.75	370.56	370.55 ± 0.82
0.05	369.21	364.68	364.27	**361.58** ± 0.79
0.1	367.23	350.53	346.95	**335.94** ± 0.74
0.25	357.88	275.59	255.68	**218.33** ± 0.48
0.50	326.74	146.61	122.73	**89.22** ± 0.19
0.75	285.98	74.33	58.39	**40.06** ± 0.08
1.00	239.37	38.59	30.42	**21.31** ± 0.04
1.50	156.57	12.57	11.29	**9.41** ± 0.01
2.00	98.26	**5.34**	5.95	6.14 ± 0.01
3.00	36.69	**1.98**	2.88	4.01 ± 0.00
4.00	13.51	**1.19**	1.92	3.05 ± 0.00

Note: The amount in bold is the lowest number of ARL and after the sign (±) is the ARL deviation.

Table 3: ARL values for Exponential distribution of Shewhart, MA, MEWMA and MA-MEWMA

Shift	w = 5, λ = 0.25, k = –0.125			
	Shewhart	**MA**	**MEWMA**	**MA-MEWMA**
	$C = 1.947$	$C_1 = 1.512$	$C_2 = 1.382$	$C_3 = 4.272$
0	370.51	370.35	370.51	370.27 ± 0.82
0.05	325.59	284.03	281.59	**281.54** ± 0.54
0.1	287.53	220.39	219.15	**219.06** ± 0.37
0.25	199.48	109.48	109.95	**108.55** ± 0.15
0.50	113.23	41.71	44.61	**41.51** ± 0.06
0.75	68.31	19.61	19.52	**19.44** ± 0.03
1.00	43.12	10.75	10.65	**9.44** ± 0.02
1.50	19.42	4.52	4.50	**4.50** ± 0.01
2.00	10.08	**2.52**	2.86	2.72 ± 0.00
3.00	3.81	**1.32**	1.92	1.33 ± 0.01
4.00	2.06	**1.06**	1.39	1.07 ± 0.00

Note: The amount in bold is the lowest number of ARL and after the sign (±) is the ARL deviation.

Table 4 and Figure 4 matched the MA-MEWMA chart's performance to that of other charts where the compiled Gamma distribution with parameters alpha and beta equal four and one, respectively. We used $w = 5$, $\lambda = 0.25$, $k = -0.125$ and coefficient of control limit $C_3 = 5.617$. The results indicated that the smallest ARL_1 values from the MA-MEWMA chart for specific shifts at 0.05, 0.10, 0.25, 0.50, 0.75 and 1.00. Whereas, the smallest ARL_1 values from the MA chart for specific shifts at 1.50, 2.00, 3.00 and 4.00.

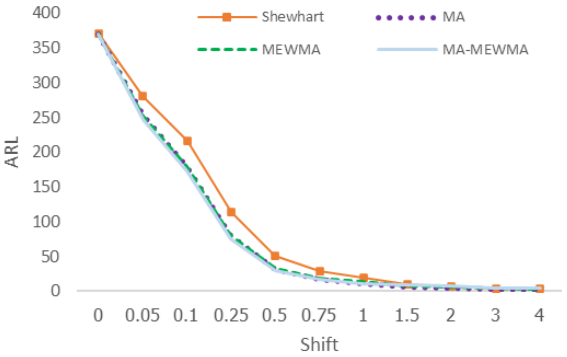

Figure 4: Shewhart, MA, MEWMA, and MA-MEWMA ARL curves for the Gamma distribution.

Table 4: ARL values for Gamma distribution of Shewhart, MA, MEWMA and MA-MEWMA

Shift	w = 5, λ = 0.25, k = –0.125			
	Shewhart	**MA**	**MEWMA**	**MA-MEWMA**
	$C = 4.915$	$C_1 = 3.338$	$C_2 = 2.691$	$C_3 = 5.617$
0	370.39	370.64	370.53	370.35 ± 0.83
0.05	280.55	253.22	252.04	**246.95** ± 0.63
0.1	217.00	179.68	178.76	**172.60** ± 0.49
0.25	113.95	79.73	80.25	**75.43** ± 0.24
0.50	51.59	31.41	33.38	**30.42** ± 0.09
0.75	29.43	16.93	19.34	**16.46** ± 0.04
1.00	19.23	10.97	13.29	**10.88** ± 0.02
1.50	10.64	**6.05**	8.09	9.07 ± 0.01
2.00	7.18	**4.14**	5.85	7.01 ± 0.00
3.00	4.38	**2.58**	3.84	5.04 ± 0.00
4.00	3.27	**1.97**	2.92	4.06 ± 0.00

Note: The amount in bold is the lowest number of ARL and after the sign (±) is the ARL deviation.

5 Demonstrative Case

We will illustrate using the proposed chart, as well as the Shewhart, MA, and MEWMA charts, with viscosity data from a batch chemical process by Montgomery [16]. The normal distribution is guided by the eighty observations. The outcomes seen in Figure 5 indicate that at the 2nd sample, the MA-MEWMA control chart could still detect the first outside from the control signal.

Regarding that, the MEWMA chart revealed a shift also on the fifth, the MA chart detected a change on the 33rd and the Shewhart control chart failed to check a change in the viscosity data.

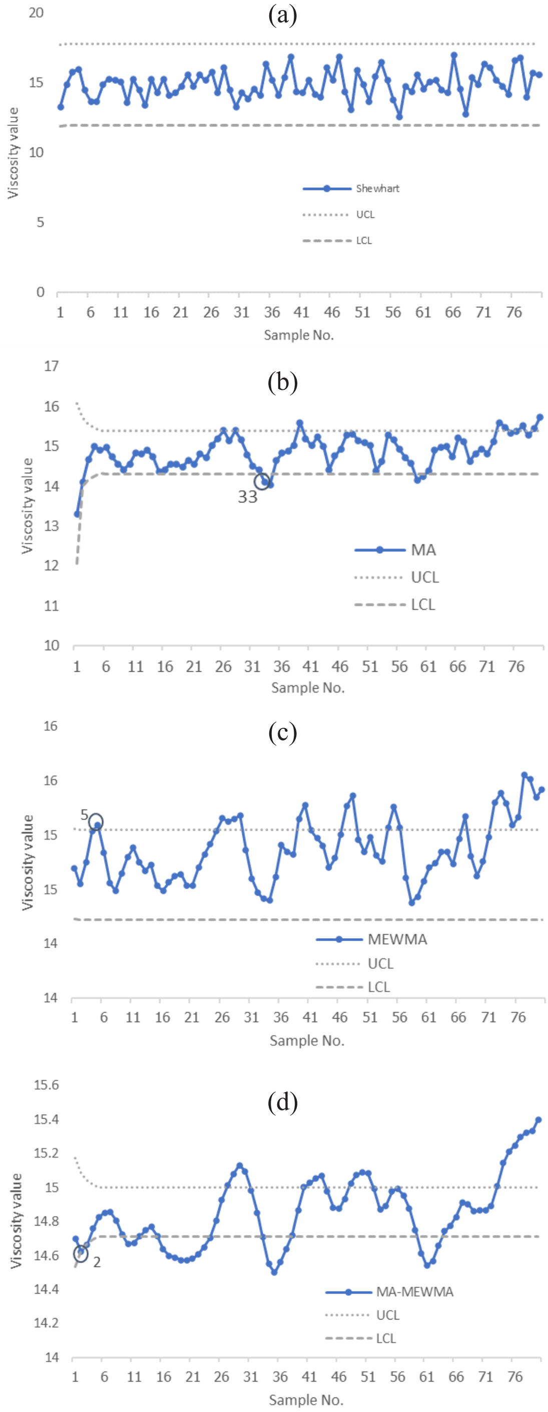

Figure 5: The ability of the Shewhart chart (a), MA chart (b), MEWMA chart (c), and MA-MEWMA chart (d) to detect a change in viscosity data.

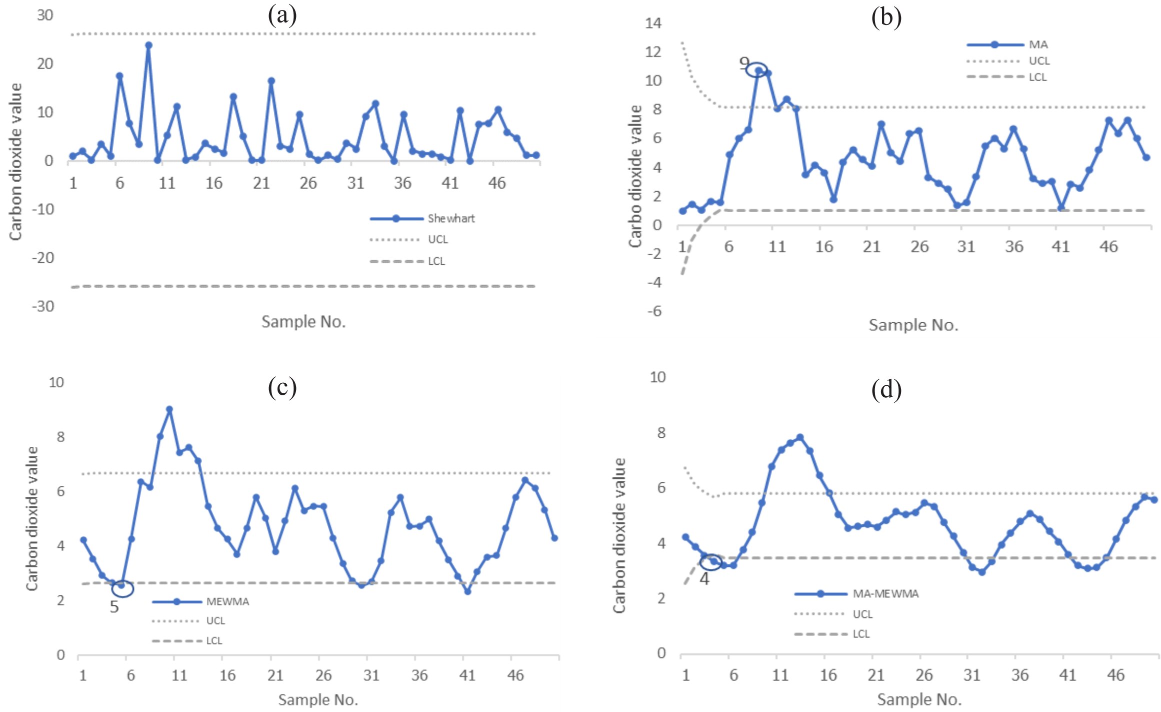

Figure 6: The ability of the Shewhart chart (a), MA chart (b), MEWMA chart (c), and MA-MEWMA chart (d) to detect a change in the carbon dioxide data.

The second data set was used to store environmental information. It is carbon dioxide data from 50 countries collected by OECD in 2000 [17] following the exponential distribution and used to construct the Shewhart, MA, MEWMA, and MA-MEWMA charts are displayed in Figure 6. The results demonstrated that the MA-MEWMA control chart can detect a first out of control signal as early as the fourth sample. The MEWMA chart then identified a change on the fifth, the MA chart on the ninth, and the Shewhart control chart failed to detect a change in carbon dioxide value.

6 Conclusions

This paper introduces a new control chart focused on the MA combined with MEWMA statistics to identify shifts mostly in the mean of procedure under symmetric and non-symmetric distribution functions. The proposed chart's achievement was analyzed and compared to appropriate control charts using widely used average run length obtained from Monte Carlo simulation. The proposed control chart significantly improves the detecting ability of the tiny to moderately shifted process when compared to the Shewhart, MA, and MEWMA charts, whereas the MA control chart enhances the sensing capacity of the largely shifted procedure. The effects of applying the correct chart to the two sets of data confirmed that it was successful in detecting changes in both data sets. This indicates that using the proposed control chart to minimize the defect rate in procedures is beneficial and might be applied to other fields such as manufacturing processes, health care, business, etc. In future research, the scope of the current study may also be extended to mix with nonparametric distributions to design an efficient monitoring process.

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Author Contributions

S.S.: conceptualization, investigation, funding acquisition, project administration, reviewing and editing; K.T.: investigation, methodology, data analysis, data curation, writing an original draft; Y.A.: research design, conceptualization, investigation, All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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