The comparison of exponentially weighted moving variance and double moving average-S control charts based on neoteric ranked set sampling

R J M Putri¹, M Mashuri¹ and Irhamah¹
¹Department of Statistics, Faculty of Mathematic, Computing and Data Science, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia

E-mail: rjmp28@gmail.com, m_mashuri@statistika.its.ac.id, irhamah@statistika.its.ac.id

Abstract. In manufacturing industry, quality is very important, because it can determine customers’ satisfaction and distinguish the product from others. The effort that can be made by companies to maintain the products quality is by monitoring and controlling them. One of the statistical methods that can be used for monitoring and controlling quality is control charts. Generally, there are two types of control charts, control chart for mean and control chart for variability. Three models of control charts, recently, have been developed, such as Shewhart, Cumulative Sum (CUSUM), and Exponentially Weighted Moving Average (EWMA). This research will be stated Exponentially Weighted Moving Variance (EWMV) and Double Moving Average-S (DMA-S) for monitoring variability based on Neoteric Ranked Set Sampling (NRSS). EWMV and DMA-S control charts can detect small shifts, and NRSS has better performance than Simple Random Sampling (SRS) and Ranked Set Sampling (RSS). Furthermore, the performance of EWMV based on NRSS and DMA-S based on NRSS control charts will be compared and evaluated by using Average Run Length (ARL) value with Monte Carlo simulation approach to detect any particular shifts. Both of the control chart models will be applied in Combined Cycle Power Plant (CCPP) case. By this evaluation, the result shows that the DMA-S control chart based on NRSS performs better than the EWMV control chart based on NRSS.

1. Introduction

Montgomery [1] defined that quality control is a comparing activity of product quality obtained with some predetermined specifications for further action will be taken if there is a discrepancy. Every company always keeps the quality of their products good, so the customers will always be satisfied. There are a lot of methods that can be used for monitoring and controlling the quality of products. One of them is through statistical method in the form of control charts.

Control chart was firstly introduced by Shewhart in 1924. Shewhart’s control chart has a weakness. It is only to detect a big shifting (>1.5σ) [2]. Furthermore, some researchers develop new breakthroughs of control chart that can be used to detect small shifting (≤1.5σ) in the production process. Those breakthroughs are as follows: Cumulative Sum (CUSUM) by Page [3], Exponentially Weighted Moving Average (EWMA) by Robert [4], Moving Average by Wong et al. [5], and Double Moving Average (DMA) by Khoo and Wong [6]. All of these control charts are used to detect a mean shifting in the production process. In addition, some other researchers also develop control charts to
detect variability shifting. It can be described as follows: R and S control charts by Shewhart [7], Exponentially Weighted Moving Variance (EWMV) by MacGregor and Harris [8], Moving Average-S (MA-S) by Adeoti and Olaomi [9], and Double Moving Average-S (DMA-S) by Adeoti et al. [10]. In this research, we focus on EWMV and DMA-S control charts.

In statistical research, sampling is highly necessary to be done when the data used are massive, so that the research can be more efficient. However, the sample that is taken using some rules or random methods must represent all the characteristics of the whole data. In this research, we use Neoteric Ranked Set Sampling (NRSS) to take the sample from the data that will be processed on EWMV and DMA-S control charts. NRSS was designed and proposed by Zamanzade and Al-Omari in 2016 to estimate mean and variance of a population [11]. Based on the research, NRSS has a much better performance than Simple Random Sampling (SRS) and Ranked Set Sampling (RSS) in the same unit size. In 2018, Nawaz et al. [12] applied NRSS design for Shewhart, CUSUM and EWMA control charts.

EWMV and DMA-S control charts based on NRSS will be compared in this research. The performance of control chart process for detecting variability can be measured by using some methods. One of them is Average Run Length (ARL). ARL is the number of plotted points within the boundaries of control chart when evaluating a certain process. ARL can be approximated using Monte Carlo simulation approach. In addition, we will use substantive data that we referred from [13], which is a problem of Combined Cycle Power Plant (CCPP).

2. Material and Methodology

2.1. Control Charts Design

There are two control charts for detecting variability shifting that focus in this research, such as Exponentially Weighted Moving Variance (EWMV) and Double Moving Average-S control charts.

2.1.1 Exponentially Weighted Moving Variance (EWMV)

According to [8], EWMV control chart is used for monitoring the variability of the sustainable process. The statistical form of EWMV is defined in Equation (1) by [8].

\[ V_i^2 = \lambda (Y_i - Z_i)^2 + (1 - \lambda) V_{i-1}^2 \]  

where \( i = 1, 2, ..., n \) and \( 0 < \lambda \leq 1 \) is a smoothing constant. The initial value is \( V_0^2 = \sigma^2 \). Variance value from first data is usually used as initial value on EWMV control chart. Therefore \( V_0^2 = s^2 \). The value of \( Z_i \) can be obtained by calculating the statistic form of EWMA in Equation (2) by [1].

\[ Z_i = \lambda \bar{Y}_i + (1 - \lambda) Z_{i-1} \]  

where

\[ \bar{Y}_i = \frac{\sum_{j=i}^{m} Y_j}{m} \]

where

- \( i \) : sub-group \( (i = 1, 2, ..., n) \)
- \( \bar{Y}_i \) : mean of \( i \)-th sub-group
- \( m \) : the number of units of sample in \( i \)-th sub-group
- \( \lambda \) : smoothing constant \( (0 < \lambda \leq 1) \)

The control limit of EWMV control chart by [8] is formulated in Equation (3).

\[ \text{UCL} = V_0^2 + L\sigma \sqrt{\frac{\lambda}{2 - \lambda} \left[ 1 - (1 - \lambda)^2 \right]} \]  

(3)
CL = \( V_0^2 = s^2 \)

LCL = \( V_0^2 - L\sigma \sqrt{\frac{\lambda}{2-\lambda} \left[1 - (1 - \lambda)^{\frac{1}{2}} \right]} \)

where

- \( i \): sub-group \((i = 1, 2, \ldots, n)\)
- \( V_0^2 \): initial value
- \( L \): width of control limit
- \( \lambda \): smoothing constant \((0 < \lambda \leq 1)\)

After a few periods, the control limit of control chart will steady state, so the value is as follows in Equation (4) and (5) by [8].

UCL = \( V_0^2 + L\sigma \sqrt{\frac{\lambda}{2-\lambda}} \)  \hspace{1cm} (4)

LCL = \( V_0^2 - L\sigma \sqrt{\frac{\lambda}{2-\lambda}} \)  \hspace{1cm} (5)

2.1.2 Double Moving Average-S (DMA-S)

The design of DMA-S control chart is based on moving average (MA) calculations from the sub-group standard deviation, twice. DMA-S control chart on span \( w \) in \( i \)-th sub-group for \( i \geq w \) is defined as follows in Equation (6) according to [10].

\[
DMA_{i} = MA_{w} + MA_{w+1} + \ldots + MA_{w+i-1} \hspace{1cm} (6)
\]

\( MA_{i} \) on span \( w \) in \( i \)-th sub-group is calculated using Equation (7) by [9].

\[
MA_{i} = \frac{S_{i} + S_{i+1} + \ldots + S_{i+w-1}}{w} \hspace{1cm} (7)
\]

where

\[
S_{i} = \sqrt{\frac{1}{m-1} \sum_{j=1}^{m} (Y_{ij} - \bar{Y})^2} \hspace{1cm} (8)
\]

where

- \( i \): sub-group \((i = 1, 2, \ldots, n)\)
- \( S_{i} \): standard deviation of \( i \)-th sub-group
- \( \bar{Y} \): mean of \( i \)-th sub-group
- \( Y_{ij} \): unit of \( j \)-th sample in \( i \)-th sub-group

The statistic form of DMA-S for \( i < w \) is calculated as average of all MA standard deviations and written as follows according to [10].

\[
DMA_{i} = MA_{1} + MA_{2} + \ldots + MA_{i} \hspace{1cm} (8)
\]

where

\[
MA_{i} = \frac{S_{1} + S_{2} + \ldots + S_{i}}{i} \hspace{1cm} (9)
\]

The control limit of DMA-S control chart is formulated in Equation (9) and (10) by [10].

\[
\frac{UCL}{LCL} = c_{4}\sigma \pm 3\sqrt{\frac{\sigma^2 \left(1-c_{4}^2\right)}{w^2}} \hspace{1cm} i \geq w \hspace{1cm} (9)
\]
\[
UCL_{LCL} = c_4 \sigma \pm 3 \sqrt{\frac{\sigma^2 (1-c_4^2)}{i^2}} \sum_{k=1}^{i} \frac{1}{k} \quad i < w \tag{10}
\]

However, in many cases, the value of variability \(\sigma\) of the process is unknown, so that must be estimated first and assumed in-control. Montgomery [1] gives unbiased estimator to estimate the standard deviation \(\sigma\) for S control chart and MA-S, \(\hat{\sigma} = \frac{\bar{S}}{c_4}\), where \(\bar{S}\) is mean of sub-group standard deviation that is assumed in-control. Therefore, upper and lower control limit \(3\sigma\) of DMA-S control chart when \(\sigma\) is unknown, is become [10]

\[
UCL_{LCL} = \bar{S} \pm 3 \left( \frac{\bar{S}}{wc_4} \right) \sqrt{1-c_4^2} \quad i \geq w \tag{11}
\]

\[
UCL_{LCL} = \bar{S} \pm 3 \left( \frac{\bar{S}}{ic_4} \right) \sqrt{1-c_4^2} \sum_{k=1}^{i} \frac{1}{k} \quad i < w \tag{12}
\]

2.2. Sampling Method and Performance Evaluation of Control Charts

Sampling method that used in this research is Neoteric Ranked Set Sampling (NRSS) and performance evaluation of control charts by using Average Run Length (ARL) value.

2.2.1 Neoteric Ranked Set Sampling (NRSS) Method

The whole selected units are sorted into a single sub-group for NRSS design. The NRSS design was introduced by Zamanzade and Al-Omari [11]. The procedure of NRSS will be described as follows.

1. Choosing the sample using simple random method with \(n^2\) unit size from the targeted population.
2. Sorting ascending all the selected units based on personal judgement. If \(n\) is odd, then the \(\left[ \frac{n+1}{2} + (i-1)n \right]\)-th unit order is taken as NRSS sample for \(i = 1, 2, ..., n\). If \(n\) is even, then choose the \(\left[ p + (i-1)n \right]\)-th unit order, where \(p = \frac{n}{2}\) for \(i\) even and \(p = \frac{n+2}{2}\) for \(i\) odd, \(i = 1, 2, ..., n\). The simple form of these notation are \(Y_{\frac{n+1}{2}}, Y_{\frac{3n+1}{2}}, Y_{\frac{5n+1}{2}}, \ldots, Y_{\frac{2n^2-n+1}{2}}\) for \(i\) odd and \(Y_{\frac{n+2}{2}}, Y_{\frac{3n+2}{2}}, Y_{\frac{5n+2}{2}}, \ldots, Y_{\frac{2n^2-n}{2}}\) for \(i\) even.
3. Repeating step 1 and 2 until \(m\) times to prove that the size of NRSS sample is \(K = mn\)

The estimator which is specified in Equation (13) - (14) is an unbiased estimator of population mean when its underlying distribution is symmetric and more efficient than the SRS and RSS estimators [12].

\[
E(\bar{Y}_{NRSS}) = \frac{1}{mn} \sum_{i=1}^{m} \sum_{r=1}^{n} Y_{\left[p+i-1\mu_i\right]} \tag{13}
\]

\[
Var(\bar{Y}_{NRSS}) = \frac{1}{mn} \sum_{i=1}^{m} \sum_{r=1}^{n} Var(Y_{\left[p+i-1\mu_i\right]}) + \frac{2}{mn} \sum_{i=1}^{m} \sum_{r=1}^{n} Cov(Y_{\left[p+i-1\mu_i\right]}, Y_{\left[p+i+1\mu_i\right]}) \tag{14}
\]
2.2.2 Average run length (ARL)
ARL is an average number of sample points that will be plotted until an out-of-control state is found in the first place. If a process is in-control state, then $ARL_0 = \frac{1}{\alpha}$ is used, where $\alpha$ is a probability of error type I (it is stated out-of-control, when actually it is in-control state). Furthermore, if a process is in out-of-control state, then $ARL_1 = \frac{1}{1-\beta}$ where $\beta$ is a probability of error type II (it is stated in-control, when it actually is in-out-of-control state). There are three procedures that used to obtain ARL distribution of EWMA control chart, such as; integral equation, Markov Chain approach, and Monte Carlo simulation.

Monte Carlo simulation is one of three common procedures of an approaching method that is utilized to calculate ARL value. According to [14], the procedures of Monte Carlo simulation will be described as follows:

1. Determining the shifting for variance.
2. Designing the parameters used in control charts.
3. Establishing a control limit in control charts.
4. Generating the sample randomly using normal standard distribution with $\mu = 0$ and $\sigma = 1$.
5. Calculating the statistical plot of control charts. If the process is in in-control state, it is needed to compare the statistic plot with the control limit in the fifth and the third steps. If the out-of-control state happens, then run length $i \; or \; run \; length$ is counted when $i$-th sub-group firstly exceeds the control limit.
6. Repeating the steps 1 – 5 for $n_{iter}$ times.
7. Calculating the ARL value as an average using formula that is written

$$ ARL = \frac{\sum_{i=1}^{n_{iter}} \text{Run Length}}{n_{iter}} $$

2.3. Procedure
The procedure of this research will be described as follows:

1) Conducting a sampling method by using the NRSS procedures in 2.2.1 and estimating the parameters by using Equation (13) and (14).
2) Calculating the statistic and control limit of EWMV based on NRSS control chart.

$$ V^2_{(i)_{\text{NRSS}}} = \hat{\lambda} \left( \bar{Y}_{(i)_{\text{NRSS}}} - Z_{(i)_{\text{NRSS}}} \right)^2 + (1-\hat{\lambda}) V^2_{(i-1)_{\text{NRSS}}} $$

According to [12], $Z_{(i)_{\text{NRSS}}}$ is defined as follows

$$ Z_{(i)_{\text{NRSS}}} = \hat{\lambda} \bar{Y}_{(i)_{\text{NRSS}}} + (1-\hat{\lambda}) Z_{(i-1)_{\text{NRSS}}} $$

The initial value is $Z_{(0)_{\text{NRSS}}} = \mu_0$ and $V^2_{(0)_{\text{NRSS}}} = \sigma^2_{\text{NRSS}}$, where those parameters are estimated in Equation (13) and (14).

where

$V^2_{(i)_{\text{NRSS}}}$ : EWMV statistic of $i$-th sub-group in NRSS design

$\bar{Y}_{(i)_{\text{NRSS}}}$ : mean of $i$-th sub-group in NRSS design

$Z_{(i)_{\text{NRSS}}}$ : EWMV statistic of $i$-th sub-group in NRSS design

$V^2_{(i-1)_{\text{NRSS}}}$ : EWMV statistic of $(i-1)$-th sub-group in NRSS design

$Z_{(i-1)_{\text{NRSS}}}$ : EWMV statistic of $(i-1)$-th sub-group in NRSS design
\( \lambda \) : smoothing constant \((0 < \lambda \leq 1)\)

The control limit of EWMV control chart based on NRSS design is defined as follows in

\[
\text{UCL} = V_{0,\text{NRSS}}^2 + L \sqrt{\sigma_{V_{0,\text{NRSS}}}^2}
\]

\[
\text{CL} = V_{0,\text{NRSS}}^2
\]

\[
\text{LCL} = V_{0,\text{NRSS}}^2 - L \sqrt{\sigma_{V_{0,\text{NRSS}}}^2}
\]

with \( \sigma_{V_{0,\text{NRSS}}}^2 = \sigma_{r_{\text{NRSS}}}^2 \left( \frac{\lambda}{2 - \lambda} \right) \left[ 1 - (1 - \lambda)^{2i} \right] \). Control limit that used when steady state is defined as follows.

\[
\text{UCL} = V_{0,\text{NRSS}}^2 + L \sigma_{r_{\text{NRSS}}} \sqrt{\frac{\lambda}{2 - \lambda}}
\]

\[
\text{LCL} = V_{0,\text{NRSS}}^2 - L \sigma_{r_{\text{NRSS}}} \sqrt{\frac{\lambda}{2 - \lambda}}
\]

3) Calculating the statistic DMA-S based on NRSS by using Equation (6) and (8). Parameters that used in this control chart are \( w = 2, 3, 4, 5 \). And also calculating the control limit by using Equation (11) and (12).

4) Plotting both of proposed control charts.

5) Evaluating the proposed control charts by using ARL value with Monte Carlo simulation procedures.

3. Results

3.1. Real Data Application

The data used in this research based on previous research by [12] are Combined Cycle Power Plant (CCPP) with 9568 observation points that have been collected for 6 years (2006-2011). We obtained these data from Tufekci’s research in 2014 [13], but we only use vacuum as the variable. From the data, the samples are taken using NRSS method of 25 sub-groups with 5 units in each. In the Table 1, it is denoted the statistic values and the control limit of EWMV and DMA-S control chart based on NRSS.

| Sub-group | \( V_i^2 \) | UCL  | LCL  | DMA  | UCL  | LCL  |
|-----------|--------------|------|------|------|------|------|
| 1         | 10.03805     | 0.26620 | -0.24363 | 0.67206 | 1.15294 | 0.45275 |
| 2         | 2.06557      | 0.27125 | -0.24869 | 0.57146 | 1.06542 | 0.54027 |
| 3         | 0.41894      | 0.27145 | -0.24889 | 0.49271 | 1.01680 | 0.58890 |
| 4         | 0.10195      | 0.27145 | -0.24888 | 0.44614 | 0.98520 | 0.62051 |
| 5         | 0.03556      | 0.27145 | -0.24889 | 0.41256 | 0.87287 | 0.73282 |
| 6         | 0.02216      | 0.27145 | -0.24889 | 0.31528 | 0.87287 | 0.73282 |
| 7         | 0.03362      | 0.27145 | -0.24889 | 0.27254 | 0.87287 | 0.73282 |
| 8         | 0.05858      | 0.27145 | -0.24889 | 0.27798 | 0.87287 | 0.73282 |
| 9         | 0.05076      | 0.27145 | -0.24889 | 0.29960 | 0.87287 | 0.73282 |
| 10        | 0.06803      | 0.27145 | -0.24889 | 0.36726 | 0.87287 | 0.73282 |
| 11        | 0.19838      | 0.27145 | -0.24889 | 0.49677 | 0.87287 | 0.73282 |
| 12        | 0.32510      | 0.27145 | -0.24889 | 0.60315 | 0.87287 | 0.73282 |
| 13        | 0.54758      | 0.27145 | -0.24889 | 0.77056 | 0.87287 | 0.73282 |
| 14        | 0.65446      | 0.27145 | -0.24889 | 0.99543 | 0.87287 | 0.73282 |
| 15        | 0.46048      | 0.27145 | -0.24889 | 1.16671 | 0.87287 | 0.73282 |
| 16        | 0.24137      | 0.27145 | -0.24889 | 1.30597 | 0.87287 | 0.73282 |
| 17        | 0.26259      | 0.27145 | -0.24889 | 1.46350 | 0.87287 | 0.73282 |
These statistic values and control limits are obtained with parameters setting as follows: EWMV-NRSS uses $\lambda = 0.8$ and $L = 3.00$, while DMA-S-NRSS uses $w = 5$. From Table 1, it is known that DMA-S-NRSS control chart detects more signal of out-of-control state compared with EWMV-NRSS control chart. It obviously can be seen that the DMA-S control chart based on NRSS has more statistic values that exceed the control limit. The comparison of the two control charts in Fig. 1 and Fig. 2 will be explained below.

| Sub-group | $V_i^2$ | $UCL$   | $LCL$   | DMA   | $UCL$   | $LCL$   |
|-----------|---------|---------|---------|-------|---------|---------|
| 18        | 0.24265 | 0.27145 | -0.24889 | 1.49064 | 0.87287 | 0.73282 |
| 19        | 0.22099 | 0.27145 | -0.24889 | 1.41021 | 0.87287 | 0.73282 |
| 20        | 0.18914 | 0.27145 | -0.24889 | 1.33484 | 0.87287 | 0.73282 |
| 21        | 0.11527 | 0.27145 | -0.24889 | 1.23199 | 0.87287 | 0.73282 |
| 22        | 0.08286 | 0.27145 | -0.24889 | 1.07601 | 0.87287 | 0.73282 |
| 23        | 0.09905 | 0.27145 | -0.24889 | 0.94792 | 0.87287 | 0.73282 |
| 24        | 0.19729 | 0.27145 | -0.24889 | 0.82768 | 0.87287 | 0.73282 |
| 25        | 0.35597 | 0.27145 | -0.24889 | 0.71853 | 0.87287 | 0.73282 |

Based on Fig. 1 and Fig. 2, we can see that DMA-S-NRSS control chart has only four points in in-control state, which are 1st, 2nd, 13th and 24th sub-groups, and the leftovers (21 points) are in out-of-control state, while EWMV-NRSS control chart has 8 points in out-of-control state, which are sub-grouped in order 1, 2, 3, 12, 13, 14, 15 and 25. Therefore, from this simulation, we know that NRSS based-DMA-S control chart has a better performance for detecting variability shifting than NRSS based-EWMV control chart.

### 3.2. Evaluation and Comparison

The performance of control chart can be evaluated by using OC ARL value. Table 2 shows the values of OC ARL for NRSS based-EWMV control chart. The values of OC ARL for NRSS based-DMA-S control chart are shown in Table 3. The selection of number for $L$ and $w$ is based on previous research and $\lambda = 0.6$ and $\lambda = 0.8$ because the result of ARL value close to 1. In out-of-control condition, ARL value can be expected by small value. When the ARL value close to 1, can be concluded that $\lambda$ is forming optimal ARL value.

| $\theta$ | $L = 2.49$ | $L = 2.49$ | $L = 2.701$ | $L = 2.701$ | $L = 3.00$ | $L = 3.00$ |
|----------|------------|------------|-------------|-------------|------------|------------|
| $\lambda$ | 0.6 | 0.8 | 0.6 | 0.8 | 0.6 | 0.8 |

![Plot EWMV-NRSS](image1)

**Figure 1. EWMV-NRSS Control Chart**

![Plot DMA-S-NRSS](image2)

**Figure 2. DMA-S-NRSS Control Chart**

- **Table 2. The values of OC ARL for EWMV-NRSS control chart based on IC ARL = 215**

| $\theta$ | $L = 2.49$ | $L = 2.49$ | $L = 2.701$ | $L = 2.701$ | $L = 3.00$ | $L = 3.00$ |
|----------|------------|------------|-------------|-------------|------------|------------|
| $\lambda$ | 0.6 | 0.8 | 0.6 | 0.8 | 0.6 | 0.8 |
From Table 2, we can see that EWMV-NRSS control chart is in a different control limit length, which is $L = 2.49, 2.701, 3.00$, and smoothing constant $\lambda = 0.6, 0.8$. Generally, the smaller the value of $\lambda$, the smaller the value of OC ARL would be. This means that the EWMV-NRSS control chart is more sensitive in detecting the shifting with a different combination of $L$ values in all shifting levels. Taken example, when $\lambda = 0.6$ and $L = 2.49$, OC ARL value is smaller than the value of OC ARL when $\lambda = 0.8$ and $L = 2.49$.

Based on the results as shown in Table 2 and Table 3, it is noticeable that the value of OC ARL of DMA-S-NRSS control chart is smaller than the value of OC ARL of EWMV-NRSS control chart in all shifting levels. Therefore, based on these OC ARL values, we know that NRSS based-DMA-S control chart has a better performance for detecting variability shifting than NRSS based on the EWMV control chart.

4. Conclusion
Based on the results of the simulation for exponentially weighted moving variance (EWMV) and double moving average-s (DMA-S) control charts based on neoteric ranked set sampling (NRSS), we can conclude that DMA-S control chart is more sensitive for detecting any variability shifting of a process in all levels and the value of out-of-control average run length (OC ARL) of DMA-S control chart is smaller than the value of OC ARL of EWMV control chart based on NRSS design. For the next, this research can be developed by comparing EWMV or DMA-S control chart based on different sampling method or choose another control chart for monitoring variability.

References
[1] Montgomery D 2009 Introduction to Statistical Quality Control 6th ed New York John Wiley & Sons Inc
[2] Shewhart W A 1924 Some Applications of Statistical Methods to the Analysis of Physical and Engineering Data Bell Syst Tech J 3(1) 43-87
[3] Page E S 1954 Continuous Inspection Schemes Biometrika 41(1/2) 100
[4] Roberts S W 1959 Control Chart Tests Based on Geometric Moving Averages Dent Tech 1(3) 239-250
[5] Wong H B, Gan F F and Chang T C 2004 Designs of Moving Average Control Chart. *Journal of Statistical Computation and Simulation* **74**(1) 47-62

[6] Khoo M B C and Wong V H 2008 A Double Moving Average Control Chart *Communications in Statistics-Simulation and Computation* **37**(8) 1696-1708

[7] Shewhart W A 1931 Economic Control of Quality of Manufactured Product New York D Van Nostrand Company

[8] MacGregor J F and Harris T J 1993 The Exponentially Weighted Moving Variance *Journal of Quality Technology* **25** 106-118

[9] Adeoti O A and Olaomi J A 2016 A Moving Average S Control Chart for Monitoring Process Variability *Quality Engineering* **28**(2) 212-219

[10] Adeoti O A, Akomolafe A A and Adebola F B 2019 Monitoring Process Variability Using Double Moving Average Control Chart. *Journal of Industrial Engineering and Management Systems* **18**(2) 210-221.

[11] Zamanzade E and Al-Omari A I 2016 New Ranked Set Sampling for Estimating the Population Mean and Variance. *Hacettepe J Math Stat* **45** 1891-1905

[12] Nawaz T, Raza M A and Han D 2018 A New Approach to Design Efficient Univariate Control Charts to Monitor the Process Mean *Qual Reliab Engig Int* 1-20

[13] Tufekci P 2014 Prediction of Full Load Electrical Power Output of a Base Load Operated Combined Cycle Power Plant Using Machine Learning Methods *Electr Power Energy Syst* **60** 126-140

[14] Dyer J N 2016 Monte Carlo Simulation Design for Evaluating Normal-Based Control Chart Properties *Journal of Modern Applied Statistical Methods* **15**(2)