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A Nonparametric Repetitive Sampling DEWMA Control Chart Based on Linear Prediction

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ABSTRACT Distribution-free control charts can be useful in statistical process control (SPC) when only limited or no information about the distribution of the data of the process is available. In this paper, a linear prediction related double exponentially weighted moving average (DEWMA) sign control chart using a repetitive sampling scheme (RSNPDEBLP) has been considered for a binomially distributed process variable to improve the efficiency of detecting small drifts in its place of small changes. The proposed RSNPDEBLP control chart is assessed in average run length (ARL) for the various values of sample sizes. The efficiency of the proposed RSNPDEBLP control chart is compared with the existing EWMA and DEWMA sign control charts using single sampling and repetitive sampling schemes in terms of ARLs. When there are small changes in the process after the stabilization period, the proposed control chart is used to control small trends rather than small shifts.

INDEX TERMS Binomial distribution, control chart, DEWMA, EWMA, linear prediction, repetitive sampling, sign statistic.

I. INTRODUCTION

Variation exists in all types of manufacturing process and can be divided into a natural and unnatural variation [1]. The natural variation is inherent and its presence is supposed to be statistically in control(IC) in the process. Moreover, the unnatural variation is not the best and it arises due to some assignable causes of variations like machine error and faulty material etc. Unnatural variations affect the performance of the manufacturing process. Hence, a famous statistician Walter A. Shewhart [2] designed some control charts which are commonly used for such type of variation to identify and eliminate the unnatural variation from the process. The Shewhart control charts are suitable for detecting a large shift in the industrial process and unable to detect a small shift in the process. However, references [3] and [4] introduced cumulative sum (CUSUM) and exponentially weighted moving average (EWMA) control charts which are more efficient than the traditional control charts for quick detection of small shifts. The application of control chart techniques is not only limited to manufacturing industry products, but it has been used in many other disciplines, like health care [5], analytical laboratories [6], [7], nuclear engineering [8], education [9] and many other fields.

Several control charts have been designed with numerous objectives for checking the quality of variables of interest through the control of individual characteristics. Some control charts are the best for detecting the large variations in the mean level of the variable importance, like the traditional $\bar{X}$ control chart. Whereas other control charts have been designed to perceive small modifications, for example, EWMA and double exponentially weighted moving average (DEWMA) control charts. However for the first time, Roberts [3] developed the EWMA control chart and Shamma and Shamma [10] introduced the DEWMA control chart. Since then, these charts have been designed by many other researchers. The extension of the EWMA technique to the DEWMA technique was also presented by Zhang and Chen [11]. But, both DEWMA control chart schemes and their conclusions are the same.

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Although, [12] presented the DEWMA control chart for monitoring a commonaly distributed quality characteristic of interest. Research about EWMA and DEWMA control chart were designed as a reference given, [13] developed the nonparametric robustness of EWMA and DEWMA control charts, Zhang *et al.* [14] also explored the DEWMA control chart scheme for Poisson processes, [15] worked on comparing the characteristics of EWMA and DEWMA control charts. Alkahtani and Schaffer [16] designed a multivariate DEWMA control chart for identifying changes in the mean direction of a multivariate normal distributed quality of interest.

Meanwhile, the above literature reflects that some of these control charts deal with the identifying a change at the mean-level and others deal with the revealing of a difference in variation. However, in experiments, sometimes it is essential to detect small trends or enlarged paths rather than a change in the processes. That is a small linear variation from the actual value of variable interest. Consequently, this ongoing change intends to identify small drifts in the procedure which may occur due to the device friction and many others similar causes. However, such type phenomenon can be observed in different administrative activities and manufacturing process of various products. Thus, till now no control chart is developed to determine the small trends in the process for non-normal data. Nevertheless, [17], [29] have designed the usual control charts by using the linear drift. The effectiveness of repetitive sampling technique of fixing small trends in a process has not been investigated in the existing literature. For the first time [17] studied this literature and predisposed the SPC society to encompass research in this area, so as to increase the information about trend revealing. Reference [27] proposed the use of a smoothing technique to forecast the demand of goods. Meanwhile, [28] showed smoothing techniques which are well known in the business to produce forecasting and are also essential for predicting the demand for services and goods. The [29] context proposed a parametric DEWMA control chart based on Linear prediction for detecting the small drift instead of shifts by using the normal distribution according to the fundamental theorem of exponential smoothing proposed by [30].

As mentioned above, the control charts have been used to check the quality of the product. However, these control charts are designed and presented by different ways and methods in the literature. In SPC, different sampling schemes are used to make the performance of the nonparametric and parametric control charts more efficient. Like as, reference [18] used the variable sampling interval (VSI) for developing the EWMA control chart. Some other sampling schemes such as multiple dependent sampling (MDS) and double sampling (DS) scheme have been used to increase the efficiency of the control charts in detecting the shift in the process [19] worked on control chart using DS scheme. The repetitive group sampling (RGS) is an efficient scheme than the single sampling in sample size plans and in *ARLs* in control chart. In the repetitive sampling, the process to select a sample size is repeated if the experimenter is in-decision at the first sample information. In DS, the decision about the state of the control chart is taken on the basis of combined information of two samples. Therefore, RGS scheme is simple to operate and different from the DS scheme also, the RGS scheme is different from the VSI scheme because the RS scheme adjusts the control limits instead of the sampling interval.

For the first time, [20] and [21] proposed the sampling plans using RGS scheme and proved the efficiency over the single sampling. The control chart using RGS were introduced by [22]–[24]. The Design of hybrid EWMA and a new S^2 control chart have been proposed by [25], [26] proposed hybrid EWMA and variance control charts using the RGS. Reference [36] proposed a control chart using RGS when observations are unclear and indeterminate by using the neutrosophic statistics. Later on, [37] designed an EWMA and DEWMA control chart for the non-normal process using RGS.

Recently, [29] introduced a DEWMA control chart based on linear prediction for small drift in place of shift under the assumption of normality. In the present study, we extend this idea by proposing a new DEWMA control chart by using a RGS scheme under the assumption of non-normality. The proposed control chart is expected to perform better than that of other non-normality based EWMA and DEWMA control charts. The proposed chart shows the efficiency in detecting the changes in the process as compared to the existing control charts. Moreover, the current study is divided into the following sections: A complete description of the proposed chart is given in section 2 that includes the design structure of the proposed control chart, background of nonparametric EWMA and DEWMA control charts including the design structure of existing control charts, and algorithm. In section 3, the results of the proposed chart are described. In section 4, the performance of the proposed chart with existing control charts are made. Real-life implementation of the proposed chart is given in section 5 whereas the conclusion is summarized in section 6.

II. THE DESIGN OF NONPARAMETRIC LINEAR PREDICTION BASED DEWMA CONTROL CHART STRUCTURE

Let Y_i be a random variable generated using the arcsine transformation of binomial distribution which follows a normal distribution, initially $Y_i \sim N(sin^{-1}\sqrt{p_0}, 1/4n)$. Let Z_i shows the DEWMA statistic which is defined as $Z_i' = \lambda Z_i + (1-\lambda)Z_i'$, where Z_i is the EWMA sign statistic which can be calculated as $Z_i = \lambda Y_i + (1-\lambda)Z_{i-1}$. The operational process of the DEWMA is based on upper and lower control limits. The EWMA and DEWMA control charts work efficiently for small shifts, but when the procedure needs a small change with the non-normal data set, the proposed control chart work more efficiently as compared to EWMA and DEWMA control charts.

A. BACKGROUND OF NONPARAMETRIC EWMA AND DEWMA SIGN STATISTIC STRUCTURES

This section of paper provides the background of the EWMA and DEWMA sign statistic is explained in [22], [32], [33]. Let suppose that the quality characteristic X has a T target value and $Y = X - T$ be the deviation of the process from the target value. But, process proportion is $p = P(Y > 0)$. The process is declared IC when $p = 0.5$ and OOC when $p \neq 0.5$. Several random sample sizes n, $X_1, X_2, X_3, \ldots.., X_n$ is nominated at each subgroup from the procedure for examining. Define as;

$$I_j = \begin{cases} 1, & \text{if } Y_j > 0 \text{ for j} = 1, 2, \ldots, \text{n} \\ 0, & \text{otherwise,} \end{cases}$$

Let M be the total number of values for $Y_j > 0$. That is defined as:

$$M = \sum_{j=1}^{n} I_j \tag{1}$$

Let, M follows the binomial distribution with parameters n and $p = 0.5$ for the IC process. If M_i is the i^{th} sequentially recorded value of such M, then the EWMA control chart is explained by Montgomery [34] and for above-mentioned variable EWMA sign statistic S_i is given as follows:

$$S_i = \lambda M_i + (1 - \lambda)S_{i-1} \tag{2}$$

where $0 < \lambda < 1$ and the mean of S_i is used as the initial values of the EWMA sign statistics, i.e., $S_0 = np_0 = n/2$. The mean can be shown below:

$$E(S_i) = \frac{n}{2} \tag{3}$$

The variance of EWMA statistic S_i can be defined as below:

$$Var(S_i) = \frac{\lambda}{2-\lambda}[1 - (1-\lambda)^{2i})](\frac{n}{4}) \tag{4}$$

For large values of i, $(1-(1-\lambda)^{2i})$ is equal to 1 and asymptotic variance becomes:

$$Var_{asym}(S_i) = (\frac{\lambda}{2-\lambda})(\frac{n}{4}) \tag{5}$$

But the EWMA sign control chart is not worked the best for getting the fixed required value of IC average run length like $ARL_0 = 370, 500$ etc., when $p_0 = 0.5$. This is happened due to binomial distribution because it is discrete distribution and asymmetrical for a small sample size. So, the possible solution for getting the stabile values of ARL_0 is to use the Arcsine transformation described by [35]. Let $Y_i = sin^{-1}\sqrt{(M_i/n)}$ be the arcsine transformation and (Y_i) has an approximately normally distributed with mean and variance i.e., $Y_i \sim N(sin^{-1}\sqrt{p_0}, 1/4n)$. For IC process the mean of arcsine transformation Y_i is $sin^{-1}\sqrt{0}.5$. The control chart using the EWMA sign statistic based on Y_i is defined as:

$$Z_i = \lambda Y_i + (1-\lambda)Z_{i-1} \tag{6}$$

where $Z_0 = sin^{-1}\sqrt{p_0}$ and $\lambda \in (0, 1]$ be a smoothing constant. Consequently, the mean and variance of transformed EWMA sign control chart are $E(Z_i) = sin^{-1}\sqrt{p_0}$ and $Var(Z_i) = \lambda/((2-\lambda)4n)$ for the large value of i the term $1-(1-\lambda)^{2i})$ approaches to unity. The control limits of EWMA sign and arcsine control chart for the single sampling can be written as:

$$UCL/LCL = \frac{n}{2} \pm k\sqrt{\frac{\lambda n}{(2-\lambda)4}}$$

$$UCL/LCL = \sin^{-1}(\sqrt{(0.5)}) \pm k\sqrt{\frac{\lambda n}{(2-\lambda)4n}}$$

1) EXISTING NONPARAMETRIC EWMA SIGN CONTROL CHART USING REPETITIVE SAMPLING

More details of the EWMA sign statistic control chart which is based on a repetitive sampling scheme (RSNPSE) explained in [22]. According to [22], the control limits for existing EWMA control chart for repetitive sampling can be written as:

$$UCL_1/LCL_1 = \frac{n}{2} \pm k_1\sqrt{\frac{\lambda n}{(2-\lambda)4}}$$

$$CL = \frac{n}{2}$$

$$UCL_2/LCL_2 = \frac{n}{2} \pm k_2\sqrt{\frac{\lambda n}{(2-\lambda)4}}$$

where k_1 and k_2 $(k_1 \geq k_2 > 0)$ are the coefficient of the control limits, which is the distance from the centre line to both control limits. So the nonparametric EWMA sign control chart using repetitive sampling (RSNPSE) is declared as out-of-control if $Z_i \geq UCL_1$ or $Z_i \leq LCL_1$.

2) EXISTING NONPARAMETRIC ARCSINE MODIFIED EWMA SIGN STATISTIC CONTROL CHART

The modified EWMA sign control chart under the arcsine transformation (NPASME) developed by [33]. They designed the NPASME by adding an extra coordinated term in traditional EWMA sign statistic. The formulation of the NPASME control chart statistic is written as:

$$M_i' = \lambda Y_i + (1-\lambda)M_{i-1}' + L(Y_i - Y_{i-1})$$

where $Y_i = sin^{-1}\sqrt{(M_i/n)}$ that can calculate by following the procedure of section (II.A) and $L = -\lambda/2$. The mean and variance of M_i' are $\sin^{-1}(\sqrt{(0.5)})$ and $\lambda + 2\lambda L + 2L^2/((2-\lambda)4n)$. The initial value of the M_i' control chart is set equal to the mean of Y_i. Thus, the control limits of NPASME are defined as:

$$UCL/LCL = \sin^{-1}(\sqrt{(0.5)}) \pm k\sqrt{\frac{\lambda + 2\lambda L + 2\,L^2}{(2-\lambda)4n}}$$

The process is declared in-control if $LCL \leq M_i' \leq UCL$. Otherwise, the process is deemed to be out-of-control. For more detail of modified EWMA sign control chart, reader may refer to [33]

B. EXISTING NONPARAMETRIC DOUBLE ARCSINE EWMA SIGN CONTROL CHART (NPASDE)

First time Shamma and Shamma [10] developed a DEWMA control chart statistics which is defined as:

$$Z_i' = \lambda Z_i + (1-\lambda)Z_{i-1}' \tag{7}$$

where Z_i is an EWMA control statistics which can calculate by using the Eq. 6. The mean of DEWMA control statistics can be shown as:

$$E(Z\prime_i) = \sin^{-1}\sqrt{p_0} \tag{8}$$

The variance of the DEWMA control statistic for the large value i (asymptotic variance) can be written as: Detail can be seen in Appendix A. A.

$$Var_{asym}(Z\prime_i) = \frac{\lambda(2-2\lambda+\lambda^2)}{(2-\lambda)^3(4n)} \tag{9}$$

The asymptotic arcsine sign DEWMA control chart limits for single sampling

$$UCL/LCL = \sin^{-1}\sqrt{p_0} \pm k\sqrt{\frac{\lambda(2-2\lambda+\lambda^2)}{(2-\lambda)^3(4n)}}$$

More detail for the calculation of DEWMA control chart can be obtained in [10], [15].

C. PROPOSED NONPARAMETRIC LINEAR PREDICTION BASED DEWMA SIGN CONTROL CHART USING REPETITIVE SAMPLING

In this section, we present the design and operational procedure of the proposed control chart. The proposed nonparametric linear prediction based DEWMA control chart using repetitive sampling (RSNPDEBLP) is designed using the fundamental theorem explained by reference [30]. A linear prediction can be forecast by a DEWMA with the linear relationship by using the below equation:

$$F_{(i+t)} = a_i + b_i t \tag{10}$$

where F_{i+t} is the forecast in the t period ($t = 1$) and the detail of intercept and slop (a_i and b_i) below

$$a_i = 2Z_i - Z\prime_i$$
$$b_i = \frac{\lambda}{1-\lambda}(Z_i - Z\prime_i)$$

We will present the design of three control charts using the statistic F_t assuming that the process is in-control state: the first one is the intercept a_i control chart which is similar to arcsin EWMA Sign control chart [32]. This control chart tests the null hypothesis that mean is equal to mean ($sin^{-1}\sqrt{p_0}$) at time t; the second control chart is for slop b_i that is used to test the null hypothesis $b_i = 0$ at time t against the alternative hypothesis $b_i \neq 0$; and the third one is a linear prediction based proposed control chart F_t that used to test the IC process. This control chart used to test the null hypothesis $F_t = \mu_0 = sin^{-1}\sqrt{p_0}$ at time t.

1) A NONPARAMETRIC RSDEWMA CONTROL CHART FOR INTERCEPT (a_i)

The expected value and variance of intercept of linear prediction a_i as below: detail see in Appendix A, A.1.

$$E(a_i) = \sin^{-1}\sqrt{p_0} \tag{11}$$

The asymptotic variance for the intercept a_i for the large value of i proposed by [38] written as: see the detail in Appendix A. A.1

$$Var_{asym}(a_i) = \frac{\lambda(1+4(1-\lambda)+5(1-\lambda)^2)}{(1+(1-\lambda))^2(4n)} \tag{12}$$

Hence, the repetitive sampling control limits for the intercept a_i control chart became:

$$UCL_1/LCL_1 = \sin^{-1}\sqrt{p_0} \pm k_1\sqrt{\frac{\lambda(1+4(1-\lambda)+5(1-\lambda)^2)}{(1+(1-\lambda))^2(4n)}} \tag{13}$$

$$CL = sin^{-1}\sqrt{p_0}$$

$$UCL_2/LCL_2 = \sin^{-1}\sqrt{p_0} \pm k_2\sqrt{\frac{\lambda(1+4(1-\lambda)+5(1-\lambda)^2)}{(1+(1-\lambda))^2(4n)}} \tag{14}$$

2) A NONPARAMETRIC RSDEWMA CONTROL CHART FOR SLOPE (b_i)

The mean and variance of slop b_i by using the expected value of Z_i and Z_i' are given by;

$$E(b_i) = 0 \tag{15}$$

The asymptotic variance of slop b_i showed Brown [38] and detail are explained in Appendix A. A.4.:

$$Var_{asym}(b_i) = \frac{2\lambda^3}{(1+(1-\lambda))^3(4n)} \tag{16}$$

Then, the limits for the b_i chart using repetitive sampling become:

$$UCL_1/LCL_1 = \pm k_1\sqrt{\frac{2\lambda^3}{(1+(1-\lambda))^3(4n)}} \tag{17}$$

$$CL = 0$$

$$UCL_2/LCL_2 = \pm k_2\sqrt{\frac{2\lambda^3}{(1+(1-\lambda))^3(4n)}} \tag{18}$$

3) THE PROPOSED RSNPDEBLP CONTROL CHART FOR F_t

The expected value of linear prediction F_t is given by: detail can be seen in Appendix B. B1.

$$E(F_{i+t}) = sin^{-1}\sqrt{p_0} \tag{19}$$

The asymptotic Variance of F_t is given by: detail see in Appendix B. B.2.

$$Var_{asym}(F_t) = \frac{1}{4n}\Big(\frac{\lambda(1+4(1-\lambda)+5(1-\lambda)^2)}{(1+(1-\lambda))^2} + \frac{2\lambda^3}{(1+(1-\lambda))^3} + \frac{\lambda^2(1+3(1-\lambda))}{(1+(1-\lambda))^3}\Big) \tag{20}$$

The asymptotic control limits of nonparametric linear prediction based DEWMA sign control chart designed for repetitive sampling are written as:

$$UCL_1/LCL_1 = \sin^{-1}\sqrt{p_0} \pm k_1\sqrt{(Var_{asym}(F_t))} \quad (21)$$
$$CL = \sin^{-1}\sqrt{p_0}$$
$$UCL_2/LCL_2 = \sin^{-1}\sqrt{p_0} \pm k_2\sqrt{(Var_{asym}(F_t))} \quad (22)$$

where k_1 and k_2 ($k_1 > k_2$) are the control coefficient, which directly affect the width of the control limits. The values of control chart coefficient k_1 and k_2 depends on the values of n, λ and ARL_0 for the RSNPASDEBLP control chart which gives the minimum values of ARL_1. The procedure is asserted to be IC if any $LCL_2 \leq F_t \geq UCL_2$. If $UCL_2 \leq F_t < UCL_1$ or $LCL_1 < F_t \leq LCL_2$ then repeat the process.

D. DESIGN OF A RSNPDEBLP CONTROL CHART F_t

The designed control chart RSNPDEBLP are calculated by using the different values of k_1, k_2, n, p_0 and smooth parameter λ. It is possible to select all the factors values for a certain number to give the mean presentation of IC ARL in the null hypothesis. For example, an $ARL_0 = 370$ is the equivalent of average run length of Shewhart control chart under the null hypothesis H_0 for 3σ as its control limits. The RSNPDEBLP can be designed to obtain the $ARL_0 = 370, 500$ by using the different values of k_1, k_2, n and λ. The ARL is a common scale that used to rate the proficiency of the control chart. Therefore, for calculating the ARL_0 values and the first point to be out of control the following Algorithm is used.

III. RESULTS AND DISCUSSION

Tables 1 and 2 represent the $ARLs$ and $SDRL$ for different values of control constants, n, λ when $r_0 = 370, 500$. The $ARLs$ are very sensitive to chosen the pair of control limits coefficients, so that's why must be selected carefully. During the simulation, it is noted that several combinations of control limits coefficients (k_1 and k_2) exist which give the specified values of ARL_0. But, we just use the combination of control limits coefficients which give the minimum values of ARL_1 for a specific design shift under the restriction of $ARL_0 = 370, 500$ and $k_1 > k_2$. The values of control constants k_1 and k_2 calculated for the proposed chart are shown in Table 1 and 2 for various values of λ and n. While, the selected values of control constants, smoothing parameters λ, and sample size n have shown that the planned control chart provided small ARLs for all p_1. Moreover, the RSNPDEBLP control chart gives smaller OOC ARL values when λ is smaller (e.g. 0.05, 0.10, 0.20, 0.25, 0.40). From both tables, the following trends of OOC ARL values have been noted:

- When $p_0 = 0.5$, the ARL is close to specified r_0.
- For specified values of p_1, the values of OOC ARL_1 increase as the λ increase and ARL_1 values reduce as the sample size n increase. But ARL_1 values reduce speedily as the shift p_1 and λ values increase.
- For other specified values, the ARL_1 values also decrease as the value of r_0 increase. For example, when $r_0 = 370$, $\lambda = 0.05$, $n = 5$ and $p_1 = 0.70$ the value of $ARL_1 = 4.06$, while the value of $ARL_1 = 3.47$ when $r_0 = 500$.
- The new control chart is more efficient to detect small shifts in the process, increases as the value of λ decreases. For example, when $\lambda = 0.20$, $n = 5$, $p_1 = 0.55$, $ARL_1 = 243.19$ and when $\lambda = 0.05$, $n = 5$, $p_1 = 0.55$, $ARL_1 = 112.72$.
- The ARL and SDRL values decreases when the level of p_1 increases, considering the fixed values of λ and n.
- We also note that a large shift in the process is identified more quickly when λ is large and small shift is identified more quickly when λ is small. For instance, when $r_0 = 370$, $\lambda = 0.05$, $n = 5$, and $p_1 = 0.55$, the value of OOC ARL is 112.72, and the value of OOC ARL is 243.19 when $\lambda = 0.20$, but when $p_1 = 0.90$ with the same values of all

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Algorithm R Program for IC and OOC Procedure of RSNPDEBLP Control Chart by Using Monte Carlo Simulation

(1) Computation of the NPASDE statistics Z_i' and F_t.
(1.1) Fix the values of sample size (n), smoothing constant λ, and the value of IC ARL, say r_0.
(1.2) Calculating a random number M_i and Y_i from the Binomial Distribution having n and $p_0 = 0.5$.
(1.3) Calculate the Z_i for i^{th} subgroup.
(1.4) Compute the NPASDE Z_i' for i^{th} subgroup.
(1.5) Calculate the a_i, b_i and F_t for i^{th} subgroup.
(2) Compute the control limits (LCL_1, LCL_2, UCL_1 and UCL_2) using randomly selected values of k_1 and k_2.
(2.1) Based on 100,000 repetitions, get various combinations of λ, n, and limit coefficients k_1 and k_2 for which $ARL_0 = 370, 500$.
(2.2) Select a pair of limit coefficients from step 2.1 for which OOC ARL_1 is minimum for a specific shift (p_1).
(2.3) Declare the process as OOC if $F_t > UCL_1$ or $F_t < LCL_1$. The procedure is asserted to be IC if any $LCL_2 \leq F_t \geq UCL_2$. If $UCL_2 \leq F_t < UCL_1$ or $LCL_1 < F_t \leq LCL_2$, go to Step 1 and repeat the process.
(2.4) If the procedure is IC, repeat the Steps 1 to 2.3. If the process is asserted OOC, then record the subgroup's number as the IC ARL. If IC ARL is equal to the fix ARL_0 value, then move to Step 3 with recorded values of coefficients k_1 and k_2. Otherwise, modify the values of coefficients and repeat Step 2.
(3) Evaluating the OOC ARL.
(3.1) Generate a random number M_i, and Y_i for the i^{th} subgroup from the binomial distribution with parameters n and $p = p_1 \neq 0.5$ considering a shift.
(3.2) Compute the Z_i, Z_i' and F_t for the i^{th} subgroup.
(3.3) Repeat the Steps 3.1 and 3.2 until the process is declared as OOC. Count the number of subgroups as an OOC run length.

TABLE 1. The *ARL* and *SDRL* values of the proposed chart for Different Values of *n* and λ when $r_0 = 370$.

λ	n		k_1	k_2	p_1								
					0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.90	0.95
0.05	5	ARL	2.62	0.93	370.92	112.72	18.02	8.05	4.06	3.37	2.53	1.64	1.29
		SDRL			362.24	104.94	15.01	5.10	2.84	1.91	1.33	0.83	0.62
	10	ARL	2.21	0.84	370.01	39.21	8.62	4.77	3.07	2.29	2.08	1.74	1.46
		SDRL			422.07	42.85	5.80	2.56	1.32	0.82	0.54	0.44	0.55
	15	ARL	2.18	0.63	370.71	20.59	5.39	2.57	2.04	1.66	1.44	1.03	1.01
		SDRL			426.97	19.47	2.82	1.51	0.85	0.85	0.55	0.17	0.10
	20	ARL	2.09	0.86	370.78	17.04	5.11	3.13	2.49	2.02	1.54	1.05	1.00
		SDRL			407.49	12.67	2.91	1.41	1.08	0.71	0.53	0.22	0.00
	25	ARL	2.06	0.93	370.14	15.74	4.60	2.96	2.28	1.85	1.57	1.13	1.01
		SDRL			421.72	11.92	2.27	1.23	0.73	0.61	0.49	0.34	0.10
0.10	5	ARL	2.83	1.92	370.23	157.02	31.38	12.27	4.36	3.00	2.05	1.50	1.30
		SDRL			353.73	155.50	26.63	11.55	3.00	1.92	1.05	0.64	0.48
	10	ARL	2.46	0.72	371.69	83.47	9.76	3.41	2.38	1.76	1.42	1.11	1.02
		SDRL			329.01	88.71	9.12	2.41	1.45	0.86	0.63	0.31	0.14
	15	ARL	2.26	1.29	370.64	57.67	10.80	4.06	3.15	2.32	2.00	1.43	1.12
		SDRL			381.13	47.22	8.94	2.15	1.36	0.75	0.56	0.51	0.32
	20	ARL	2.18	1.58	370.44	43.53	8.80	4.78	3.03	2.43	1.84	1.39	1.06
		SDRL			394.54	48.44	6.06	2.46	1.02	0.75	0.54	0.51	0.23
	25	ARL	2.18	1.22	370.63	29.83	5.60	2.93	2.11	1.68	1.38	1.06	1.00
		SDRL			379.18	27.48	3.85	1.31	0.77	0.65	0.54	0.23	0.00
0.15	5	ARL	3.14	0.90	371.65	191.59	52.50	13.92	5.00	2.85	2.14	1.41	1.22
		SDRL			394.15	175.11	52.87	14.93	4.13	1.76	1.07	0.55	0.44
	10	ARL	2.64	0.83	371.42	134.32	23.04	3.99	2.11	1.90	1.41	1.08	1.01
		SDRL			389.15	132.92	24.51	2.88	1.00	0.98	0.60	0.27	0.10
	15	ARL	2.47	0.90	370.72	84.73	9.28	3.00	1.85	1.47	1.18	1.00	1.00
		SDRL			352.95	82.76	7.33	2.38	0.93	0.70	0.41	0.00	0.00
	20	ARL	2.39	0.91	370.50	37.49	5.35	1.99	1.58	1.28	1.05	1.01	1.00
		SDRL			376.64	33.42	4.38	1.26	0.75	0.56	0.22	0.10	0.00
	25	ARL	2.49	0.52	371.17	31.10	2.61	1.57	1.13	1.07	1.00	1.00	1.00
		SDRL			335.28	32.10	1.66	0.70	0.36	0.25	0.00	0.00	0.00
0.20	5	ARL	3.26	1.40	370.39	243.19	86.03	31.14	11.01	5.54	2.70	1.62	1.22
		SDRL			399.76	209.12	90.77	34.39	11.41	5.01	1.87	0.70	0.46
	10	ARL	2.96	0.70	370.73	174.25	37.02	7.11	2.17	1.27	1.09	1.02	1.00
		SDRL			337.00	163.94	35.89	6.75	1.62	0.52	0.28	0.14	0.00
	15	ARL	2.75	0.54	371.34	101.30	11.66	2.43	1.41	1.27	1.07	1.00	1.00
		SDRL			330.64	107.56	12.88	1.81	0.71	0.51	0.29	0.00	0.00
	20	ARL	2.52	0.81	371.72	66.59	7.35	2.24	1.43	1.29	1.16	1.02	1.00
		SDRL			385.17	61.62	6.43	1.40	0.62	0.53	0.36	0.14	0.00
	25	ARL	2.49	0.79	370.85	47.45	4.44	1.69	1.22	1.08	1.01	1.00	1.00
		SDRL			382.15	46.24	4.34	0.95	0.50	0.27	0.10	0.00	0.00
0.25	5	ARL	3.42	1.67	370.51	291.31	127.46	40.59	19.06	8.87	4.12	1.60	1.23
		SDRL			384.01	282.85	112.07	46.90	19.63	11.11	3.37	0.89	0.48
	10	ARL	2.82	1.78	370.38	236.27	60.76	22.11	6.94	3.20	2.21	1.37	1.04
		SDRL			406.61	255.36	71.55	21.16	7.62	2.05	1.04	0.52	0.19
	15	ARL	2.73	0.84	370.52	152.40	19.03	4.46	1.59	1.22	1.03	1.00	1.00
		SDRL			348.96	158.16	18.05	4.36	0.91	0.52	0.17	0.00	0.10
	20	ARL	2.64	0.72	370.69	84.65	8.51	2.14	1.31	1.18	1.04	1.00	1.00
		SDRL			362.60	89.45	7.99	1.38	0.61	0.43	0.19	0.00	0.00
	25	ARL	2.60	0.85	370.83	76.76	7.37	1.70	1.34	1.05	1.03	1.00	1.00
		SDRL			357.08	70.99	7.39	1.07	0.55	0.21	0.17	0.00	0.00
0.40	5	ARL	3.65	1.39	371.50	290.27	109.09	56.46	32.20	10.79	5.76	1.55	1.24
		SDRL			368.02	302.91	110.06	75.82	31.88	9.94	5.83	0.78	0.53
	10	ARL	3.74	0.93	369.69	248.01	102.63	33.71	12.48	3.41	1.70	1.00	1.00
		SDRL			396.18	233.04	96.83	31.23	12.01	3.16	1.19	0.00	0.00
	15	ARL	3.12	0.78	369.88	186.91	58.06	13.35	2.99	1.44	1.07	1.00	1.00
		SDRL			364.82	183.46	55.54	15.15	2.68	0.79	0.25	0.00	0.00
	20	ARL	3.03	0.71	371.44	164.78	27.16	5.12	1.72	1.13	1.01	1.00	1.00
		SDRL			365.48	161.68	26.62	4.95	1.35	0.39	0.10	0.00	0.00
	25	ARL	2.92	0.81	370.53	123.37	17.75	3.19	1.24	1.04	1.01	1.00	1.00
		SDRL			344.04	112.24	17.63	3.36	0.62	0.19	0.10	0.00	0.00

parameters the OOC ARL for $\lambda = 0.05$ is 1.64 and the value of OOC ARL is 1.62 when $\lambda = 0.20$ (Ref. Table 1). The same trend we can see in the Table 2, when $r_0 = 500$, $\lambda = 0.05$, $n = 5$, and $p_1 = 0.55$, the OOC ARL value is 231.16 and OOC ARL value is 277.27 when $\lambda = 0.20$, but when $p_1 = 0.90$ with the same other parameters values the OOC ARL is 1.48 for $\lambda = 0.05$ and it is 1.42 when $\lambda = 0.20$.

- From tables 1 and 2, it has been noted that if the value of r_0 is large, the reducing trend of ARL_1 is also increased. Such as, when $r_0 = 370$ and $\lambda = 0.05$, $n = 5$, the value of OOC *ARL* decreased

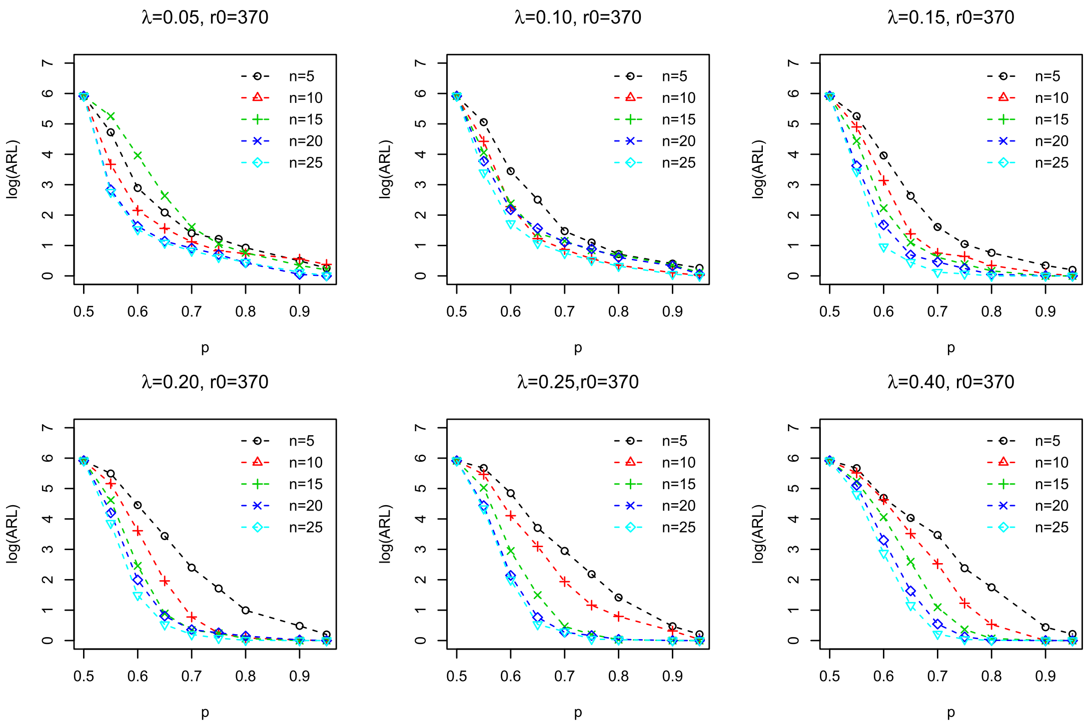

FIGURE 1. ***ARL* comparison of the RSNPDBLP chart for different values of λ and *n* at $ARL_0 = 370$.**

31.30% to ARL_0 value for $p_1 = 0.55$ and 2.18% for $p_1 = 0.65$. With the same sample size n, ARL_0 values, and different value of $\lambda = 0.20$, the value of $ARL1$ decreased 65.64% for $p_1 = 0.55$ and 8.41% for $p_1 = 0.65$. While, when sample size and fixed IC ARL are the same but $\lambda = 0.25$, the value of ARL_1 decreased 78.6% for $p_1 = 0.55$ and 10.9% for $p_1 = 0.65$. On the other hand, when r_0 value is increased, for example, when $r_0 = 500$ and smoothing constant same like as $\lambda = 0.05$ and $n = 5$, the value of ARL_1 decrease 45.2% to IC ARL for $p_1 = 0.55$ and 1.06% for $p_1 = 0.65$, when same r_0, and n but different value of $\lambda = 0.20$ the ARL_1 value decrease 55.41% to ARL_0 for $p_1 = 0.55$ and 6.52% for $p_1 = 0.65$. However, with the same value of ARL_0 and sample size but the different value of $\lambda = 0.25$, the value of OOC ARL decrease 62.72% to IC ARL for $p_1 = 0.55$ and 10.5% for $p_0 = 0.65$.

Consequently, as slope p_1 values arises in the process proportion at pre-specified values of $r_0 = 370, 500$, the ARL_1 values performance shows the decreasing trend. It is also noted that when sample size increases the ARL_1s values decreases rapidly, specially for smaller shifts. For example, in table 1 when $r_0 = 370$, $\lambda = 0.05$ and slope (p_1) is 0.60 observed that $ARL_1 = (18.02, 8.62, 5.39, 5.11, 4.60)$ values have shown a decreasing trend when $n = (5, 10, 15, 20, 25)$ values are increasing. Similarly, when $\lambda = 0.25$ but sample size and slope values are the same the values of ARL_1 were (127.46,60.76,19.03, 8.51,7.37). It also shows the decreasing trend in OOC ARL when n are increased. In Table 2, the $ARLs$ values of the proposed control chart are calculated, when $r_0 = 500$, $\lambda = 0.05, 0.10, 0.20, 0.25, 0.40$ and $n = 5, 10, 15, 20, 25$. This also shows the decreasing trend in OOC ARL at different λ and sample size values. A comparison between the ARL values of the planned control chart is revealed in Figures 1 and 2 for identified values of $r_0 = 370, 500$. From these graphs, it is identified that $ARLs$ values for the proposed control chart RSNPDEBLP are relatively smaller at every value of the shifted parameter p_1.

IV. COMPARISON OF PROPOSED CONTROL CHART RSNPDEBLP ARLs WITH DIFFERENT EXISTING CONTROL CHARTS

In this section, the efficiency of the RSNPDEBLP control chart with the existing control charts NPSE and NPASE proposed by [32], newly designed control chart NPASDE, NPASME presented by [33], and RSNPSE control chart introduced by [22] are discussed. The efficiency of the new control chart is calculated in positions of ARL with the existing control charts. For example, when $n = 20$, $\lambda = 0.05$ and $p_1 = 0.60$ the value of proposed chart ARL_1 is 5.11, while the ARL_1 value of NPSE is 12.43, NPASE is 12.24, NPASDE is 18.52, NPASME is 12.41 and RSNPSE is 10.44.

A. RSNPDEBLP CONTROL CHART VERSUS NPSE AND NPASE CONTROL CHART

This section describes the explanation of the advantages of newly developed RSNPDEBLP control chart as competed to

TABLE 2. The *ARL* and *SDRL* values of the proposed chart for Different Values of *n* and λ when $r_0 = 500$.

λ	n		k_1	k_2	p_1								
					0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.90	0.95
0.05	5	ARL	3.20	0.71	500.56	231.16	22.05	5.234	3.47	2.62	2..25	1.48	1.26
		SDRL			482.10	224.91	25.11	3.64	2.22	1.55	1.08	0.64	0.44
	10	ARL	2.86	0.82	500.76	143.65	9.37	4.10	2.69	2.05	1.88	1.31	1.09
		SDRL			589.17	160.37	8.03	2.26	1.32	0.95	0.82	0.51	0.29
	15	ARL	2.81	1.39	500.73	147.03	10.53	5.52	3.91	3.06	2.57	1.83	1.50
		SDRL			712.36	170.94	5.99	2.48	1.25	0.97	0.67	0.51	0.50
	20	ARL	2.78	1.44	500.54	87.54	9.10	5.05	3.66	2.88	2.38	1.94	1.73
		SDRL			773.53	89.94	4.33	1.85	1.32	0.73	0.50	0.34	0.44
	25	ARL	2.76	1.26	500.31	43.62	6.42	3.77	2.90	2.37	2.03	1.46	1.10
		SDRL			786.02	44.83	3.02	1.27	0.94	0.70	0.45	0.50	0.30
0.10	5	ARL	3.11	0.82	500.78	234.92	33.38	9.48	4.11	2.57	1.98	1.48	1.18
		SDRL			465.40	231.57	31.04	8.31	3.04	1.23	1.13	0.61	0.38
	10	ARL	2.92	0.61	502.92	212.65	13.86	3.41	2.10	1.63	1.23	1.05	1.02
		SDRL			430.10	203.08	15.11	2.36	1.26	0.77	0.46	0.22	0.14
	15	ARL	2.82	0.71	499.52	175.10	6.65	2.34	1.70	1.29	1.20	1.00	1.00
		SDRL			519.64	195.67	5.26	1.28	0.92	0.47	0.43	0.00	0.00
	20	ARL	2.84	0.84	500.07	121.95	4.71	2.30	1.91	1.49	1.23	1.02	1.00
		SDRL			624.93	115.35	2.78	1.29	0.84	0.61	0.42	0.14	0.00
	25	ARL	2.72	0.65	499.87	40.70	3.29	1.72	1.33	1.18	1.09	1.00	1.00
0.15	5	ARL	3.23	0.97	501.22	242.51	62.51	16.37	6.15	3.17	2.15	1.51	1.20
		SDRL			499.49	238.38	59.19	16.32	5.21	2.45	1.18	0.63	0.40
	10	ARL	2.82	0.90	500.88	178.32	31.37	5.59	2.54	1.83	1.47	1.11	1.00
		SDRL			450.62	178.48	31.43	4.52	1.62	0.91	0.72	0.31	0.00
	15	ARL	2.69	0.69	499.69	91.78	11.47	2.65	1.66	1.36	1.20	1.02	1.00
		SDRL			472.97	112.16	11.35	1.57	0.76	0.55	0.45	0.14	0.00
	20	ARL	2.59	0.73	501.51	72.57	5.78	1.96	1.49	1.33	1.12	1.01	1.00
		SDRL			455.98	70.18	4.98	0.99	0.61	0.58	0.35	0.10	0.00
	25	ARL	2.52	0.67	500.19	41.85	3.61	1.57	1.18	1.07	1.00	1.00	1.00
		SDRL			436.55	40.11	2.46	0.80	0.41	0.25	0.00	0.00	0.00
0.20	5	ARL	3.51	0.83	500.27	277.27	84.54	32.64	7.84	3.29	2.08	1.42	1.21
		SDRL			478.72	238.44	82.05	36.35	8.13	2.63	1.25	0.55	0.41
	10	ARL	3.10	0.80	500.45	246.58	45.41	9.96	2.48	1.83	1.40	1.07	1.01
		SDRL			448.08	253.23	40.84	9.43	1.76	0.96	0.58	0.25	0.10
	15	ARL	2.70	0.92	500.43	165.00	17.87	3.83	1.89	1.32	1.14	1.00	1.00
		SDRL			460.88	167.05	23.08	2.80	0.87	0.56	0.41	0.00	0.00
	20	ARL	2.52	1.45	500.04	102.16	14.68	4.24	2.20	1.89	1.37	1.10	1.00
		SDRL			518.38	94.64	12.86	2.73	1.07	0.72	0.58	0.30	0.00
	25	ARL	2.50	1.26	501.63	78.77	8.21	2.54	1.53	1.27	1.11	1.00	1.00
		SDRL			496.17	74.02	7.85	1.37	0.73	0.48	0.31	0.00	0.00
0.25	5	ARL	3.52	1.55	500.93	312.96	126.64	52.72	22.86	7.86	4.29	1.66	1.28
		SDRL			490.66	292.17	128.00	56.89	29.14	7.87	3.87	0.94	0.55
	10	ARL	3.26	0.79	501.57	271.29	64.86	17.67	4.28	1.57	1.12	1.02	1.00
		SDRL			461.51	255.74	60.03	17.06	3.87	1.07	0.38	0.14	0.00
	15	ARL	2.90	0.79	501.63	190.52	29.12	4.07	1.66	1.18	1.08	1.00	1.00
		SDRL			474.17	191.12	26.60	3.71	0.96	0.38	0.27	0.00	0.00
	20	ARL	2.87	0.68	503.67	136.64	13.13	2.65	1.36	1.15	1.03	1.00	1.00
		SDRL			442.55	144.95	14.63	2.46	0.62	0.35	0.17	0.00	0.00
	25	ARL	2.91	0.72	503.17	135.84	9.24	1.85	1.30	1.04	1.02	1.00	1.00
		SDRL			483.19	148.80	8.79	1.02	0.55	0.19	0.14	0.00	0.00
0.40	5	ARL	3.86	2.01	500.10	332.53	172.27	109.77	63.36	32.79	10.96	3.03	1.97
		SDRL			457.19	343.26	181.62	111.66	74.56	37.59	14.14	4.32	5.18
	10	ARL	3.66	1.37	500.78	300.71	148.65	34.38	19.02	6.08	2.88	1.12	1.01
		SDRL			552.43	280.86	131.98	31.84	17.36	7.17	3.13	0.35	0.10
	15	ARL	3.16	0.99	501.95	266.79	74.64	18.65	3.60	1.42	1.08	1.00	1.00
		SDRL			496.37	2.82.58	65.78	17.45	4.15	0.82	0.34	0.00	0.00
	20	ARL	3.06	0.98	500.96	197.50	43.69	7.18	2.19	1.22	1.06	1.00	1.00
		SDRL			481.73	194.84	47.74	6.69	2.09	0.56	0.24	0.00	0.00
	25	ARL	3.03	0.91	501.09	171.11	24.47	4.55	1.54	1.05	1.01	1.00	1.00
		SDRL			435.17	1.62.59	24.55	4.92	0.79	0.22	0.10	0.00	0.00

the NPSE and NPASE control charts. The calculated average run length values for the usual control chart when $r_0 = 370$, $\lambda = 0.05, 0.10, 0.25$ and $n = 10, 15, 20$ are given in Table 3. The computed values of *ARL* have shown that for the new control chart OOC ARL values are smaller at all values of p_1 as competed to existing control charts. For Example, when $p1 = 0.60$, $\lambda = 0.05$ and $n = 10$ the value of ARL_1 for the proposed control chart is 8.62, while the existing control charts ARL_1 are 19.08 and 19.09. This presented the efficiency of the new control chart because it detects a reduced trend in the procedure as equated to the NPSE and NPASE control charts [32]. Same as, we can see that when λ value is same but $n = 20$ increase, the proposed chart OOC ARL is 5.11 and the existing charts' OOC ARL values are

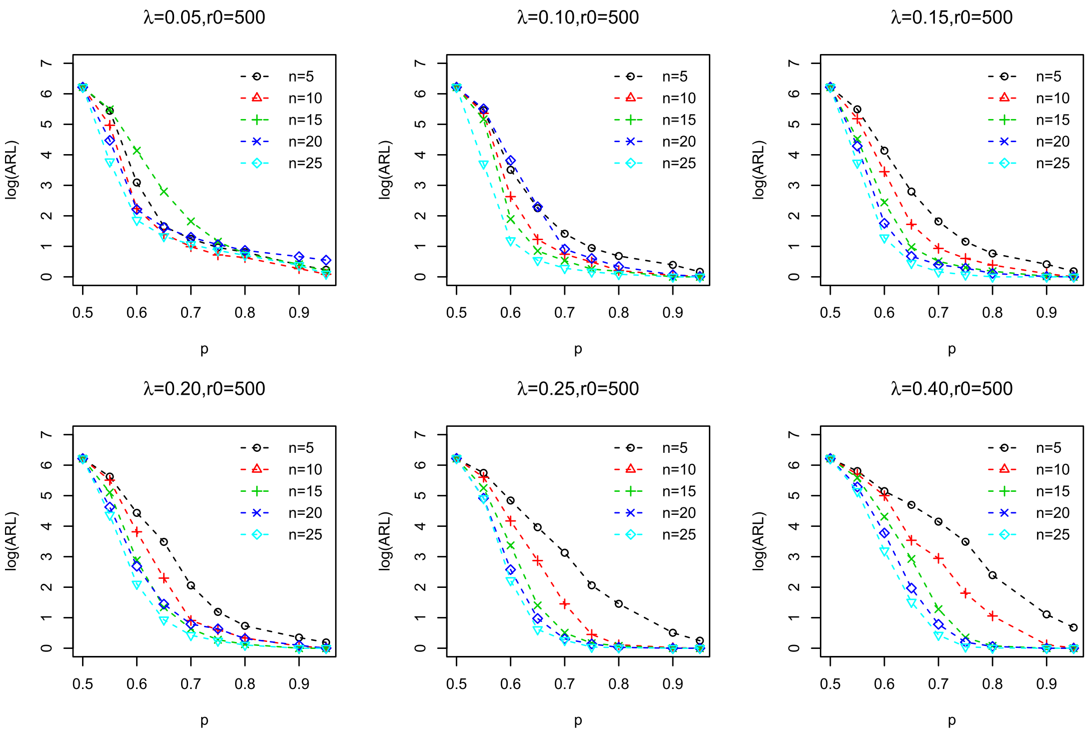

FIGURE 2. *ARL* **comparison of the RSNPDBLP chart for different values of λ and *n* at $ARL_0 = 500$.**

TABLE 3. **Comparison Between proposed RSNPDEBLP and Existing NPSE, NPASE, NPASME, NPASDE control charts for Different Values of Slope (p_1), λ and *n* when $ARL_0 = 370$.**

Control Chart (Coefficient)	p_1								
	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.90	0.95
	$\lambda = 0.05, n = 10$								
NPSE(k=2.50)	382.41	51.59	19.08	11.45	8.10	6.34	5.21	3.91	3.44
NPASE(k=2.67)	371.23	52.05	19.09	11.28	7.93	5.99	4.78	3.26	2.71
NPASDE(k=2.00)	372.07	52.34	24.99	17.58	14.18	12.11	10.58	8.31	7.44
NPASME($k = 2.595$)	370.62	52.36	19.22	11.47	8.17	6.29	5.12	3.67	3.20
RSNPSE($k_1 = 2.69, k_2 = 0.87$)	373.46	33.08	14.65	9.75	6.78	5.54	4.45	3.67	3.02
RSNPASDEBLP($k_1 = 2.21, k_2 = 0.84$)	370.01	39.21	8.62	4.77	3.07	2.29	2.08	1.74	1.46
	$\lambda = 0.05, n = 20$								
NPSE(k=2.51)	385.68	31.42	12.43	7.69	5.62	4.43	3.69	2.93	2.61
NPASE(k=2.56)	374.53	31.11	12.24	7.46	5.40	4.19	3.43	2.44	2.08
NPASDE(k=1.93)	374.63	34.46	18.52	13.67	11.41	9.88	8.74	6.93	6.16
NPASME(k=2.495)	370.87	31.17	12.41	7.73	5.71	4.57	3.83	2.88	2.50
RSNPSE($k_1 = 2.84, k_2 = 0.56$)	370.16	22.80	10.44	6.22	5.72	4.37	3.17	2.00	2.00
RSNPASDEBLP($k_1 = 2.09, k_2 = 0.86$)	370.78	17.04	5.11	3.13	2.49	2.02	1.54	1.05	1.00
	$\lambda = 0.10, n = 15$								
NPSE(k=2.70)	374.06	43.46	13.99	7.91	5.54	4.27	3.49	2.59	2.18
NPASE(k=2.82)	378.47	43.97	14.02	7.87	5.41	4.14	3.32	2.34	2.05
NPASDE(k=2.30)	373.09	39.75	15.85	10.93	8.68	7.35	6.37	4.99	4.37
NPASME(k=2.722)	370.37	45.85	13.99	8.02	5.64	4.39	3.61	2.75	2.35
RSNPSE($k_1 = 2.19, k_2 = 0.71$)	370.46	44.12	11.55	6.75	4.96	3.60	3.35	2.05	2.00
RSNPASDEBLP($k_1 = 2.33, k_2 = 0.94$)	370.92	43.62	3.45	2.07	1.14	1.21	1.18	1.01	1.00
	$\lambda = 0.25, n = 20$								
NPSE(k=2.89)	377.58	50.54	12.38	6.12	3.92	2.92	2.36	1.89	1.64
NPASE(k=3.00)	375.87	52.55	12.80	6.10	3.91	2.89	2.31	1.61	1.25
NPASDE(k=2.73)	378.21	99.31	11.46	6.58	4.85	3.96	3.39	2.70	2.26
NPASME(k=2.914)	371.36	110.45	21.28	10.19	6.08	3.12	2.56	2.03	2.00
RSNPSE($k_1 = 2.37, k_2 = 0.83$)	374.91	100.17	27.65	13.31	5.18	3.76	2.39	2.04	2.00
RSNPASDEBLP($k_1 = 2.64, k_2 = 0.72$)	370.69	84.65	8.51	2.04	1.31	1.18	1.04	1.00	1.00

12.43 and 12.24. Which are larger than the proposed chart OOC ARL values. Another comparison of the proposed and the existing chart can be seen in table 3 with different values of λ and *n* that show the efficiency of the new chart too.

B. RSNPDEBLP CONTROL CHART VERSUS NPASDE CONTROL CHARTS

This section shows the comparison between the implementation of the RSNPDEBLP control chart over the existing nonparametric DEWMA control chart (NPASDE). For different values of λ and n the proposed control chart has smallest values at every values of p_1 in contrast of NPASDE control chart. The ARL values of NPASDE and RSNPDEBLP control chart for the specified value of $r_0 = 370$ are given in Table 3, that shows the OOC ARL_1 values of the RSNPDEBLP are lesser at all value of the shift. For example, when $\lambda = 0.05$, $n = 10$, and $p_1 = 0.60$, the ARL_1 value for the newly developed control chart is 8.62, while 24.99 for the NPASDE control chart. Other than that, we can also see the efficiency of the proposed chart when λ and n are increased. For example, when $\lambda = 0.10$ and $n = 15$, the proposed chart ARL_1 is 6.45 and the existing chart's ARL_1 is 15.85 (see in table 3).

C. RSNPDEBLP CONTROL CHART VERSUS RSNPSE CONTROL CHART

This part deals with the lead of the RSNPDEBLP control chart as competed to the RSNPSE control chart which is designed by [22]. In Table 3, the determined *ARLs* for new control chart shows the fast decreasing trend in contrast to Reference [22] control chart at different values of λ, n, and shift. For example, when $\lambda = 0.05$, $p_1 = 0.65$ and $n = 10$, the $ARL_1 = 4.77$ for proposed control chart and $ARL_1 = 0.75$ for the existing control chart. Also, the efficiency of the proposed control chart increases for large shift values for example when $\lambda = 0.25$ and $n = 20$, the $ARL_1 = 2.04$ and existing chart's $ARL_1 = 3.13$.

D. RSNPDEBLP CONTROL CHART VERSUS NPASME CONTROL CHART

A review of newly designed control chart with a nonparametric Modified EWMA sign control chart designed by [33] are described in this section. The comparison has shown that, the proposed control chart gives smaller value of OOC ARL_1 and existing control chart gives a larger value of OOC ARL_1. For example, when $\lambda = 0.05$, $p_1 = 0.6$ and $n = 10$, the new control chart ARL_1 value is 8.62, while $ARL_1 = 19.22$ for the existing control chart. Furthermore, when sample size is increasing from 10 to 20 with same λ value but the ARL_1 decreasing at every values of p_1, given in Table 3. Alongside this, in Table 3, when λ and n are increasing at that time the decreasing trend is also justified in the values of all control charts ARL_1. However, the ARL_1 values of the newly designed control chart decrease rapidly as competed to usual control charts. The detailed comparison of proposed control chart with different existing control charts have been revealed that the proposed control chart shows the greater efficiency to detect a smaller shift in the process. For large values of λ, n and shift the RSNPSE control chart perform efficiently as compared to proposed chart but for small shift and large values of other parameters proposed chart perform efficiently.

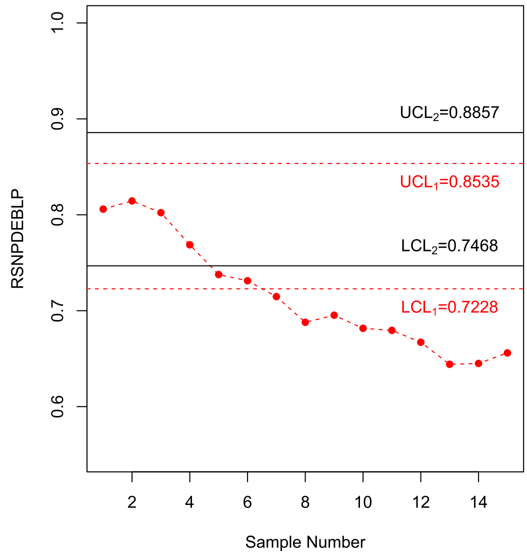

FIGURE 3. Proposed Control chart with $n = 10$, $\lambda = 0.05$, $k_1 = 2.21$, $k_2 = 0.84$.

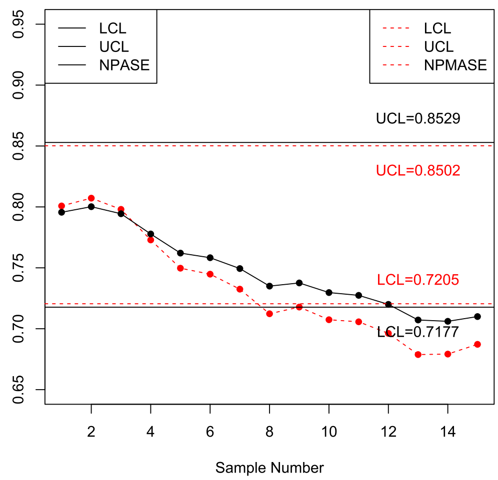

FIGURE 4. NPMASE [33] and NPASE [32] Control chart with $n = 10$, $\lambda = 0.05$, $k = 2.595$, $k = 2.67$.

It means that a new control chart presented best as competed to different already planned control charts.

V. REAL LIFE IMPLEMENTATION OF PROPOSED CHART

This section describes the proposed control chart application in everyday life. The data set has been adopted from the [1] "fill volume of soft drink beverage bottles. The volume measure by placing a gauge over the crown and comparing the height of the liquid in the neck of the bottle against a coded scale." The data is defined in Table 4. In this data set, 15 sample size are collected and each sample size has 10 observations. The focus value is supposed to be zero. The $\lambda = 0.05$ is used for calculating the proposed and existing EWMA, DEWMA sign statistics. The values of control limits coefficients k, k_1 and k_2 are taken from the Table 3. The control chart is developed for the new scheme and existing schemes (NPASE [32], NPASME [33], and RSNPASE [22]).

TABLE 4. The proposed RSNPDEBLP control chart and existing control chart for the data set from the [1].

Sample	M_i	Y_i	NPASE	NPASDE	a_i	b_i	F_t	NPASME	NPSE
1	7	0.9911	0.7956	0.7859	0.8054	0.0005	0.8059	0.8008	5.1000
2	6	0.8860	0.8002	0.7866	0.8137	0.0007	0.8144	0.8072	5.1450
3	4	0.6847	0.7944	0.7870	0.8012	0.0004	0.8022	0.7980	5.0877
4	2	0.4636	0.7778	0.7865	0.7692	-0.0004	0.7687	0.7729	4.9333
5	2	0.4636	0.7621	0.7853	0.7390	-0.0012	0.7377	0.7497	4.7866
6	4	0.6847	0.7583	0.7839	0.7326	-0.0013	0.7312	0.7448	4.7473
7	3	0.5796	0.7494	0.7822	0.7164	-0.0017	0.7147	0.7325	4.6599
8	2	0.4636	0.7350	0.7799	0.6902	-0.0023	0.6879	0.7123	4.5269
9	5	0.7853	0.7376	0.7777	0.6974	-0.0021	0.6953	0.7178	4.5506
10	3	0.5796	0.7297	0.7753	0.6840	-0.0024	0.6816	0.7074	4.4731
11	4	0.6847	0.7274	0.7729	0.6819	-0.0023	0.6795	0.7057	4.4494
12	3	0.5796	0.7200	0.7703	0.6697	-0.0026	0.6671	0.6962	4.3769
13	2	0.4636	0.7072	0.7671	0.6473	-0.0031	0.6441	0.6788	4.2581
14	4	0.6847	0.7061	0.7641	0.6481	-0.0030	0.6450	0.6792	4.2452
15	5	0.7853	0.7100	0.7614	0.6587	-0.0027	0.6560	0.6872	4.2829

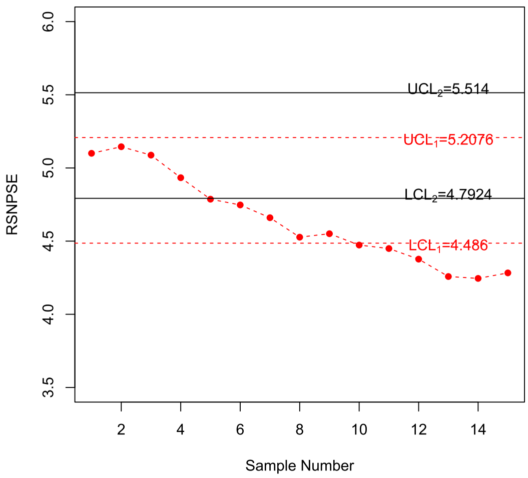

FIGURE 5. RSNPSE [22] Control chart with $n = 10$, $\lambda = 0.05$, $k_1 = 2.84$, $k_2 = 0.56$.

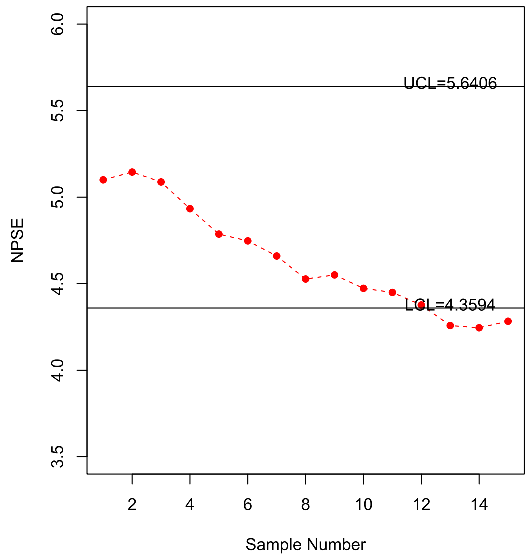

FIGURE 6. NPSE [32] Control chart with $n = 10$, $\lambda = 0.05$, $k = 2.67$.

Moreover, the control limits of the new control chart are estimated as $LCL_1 = 0.7228$, $LCL_2 = 0.7486$, $UCL_1 = 0.9083$ and $UCL_2 = 0.8321$. The RSNPDEWBLP is plotted against their calculated control limits in Figure 3. Beside that the new designed control chart trigger the OOC value in sample 6. The NPASE [32] and NPASME [33] control chart is plotted in figure 4 that showed the OOC signal NPASE in sample 12 and NPASME in sample 8. From Figure 3 and 4, it is observed the RSNPDEBLP control chart triggers the OOC signal 6 time earlier as compared to existing control chart NPASE [32] control chart. However, in Figure 4 the existing control chart NPASME [33] detects the OOC signal 4 times efficiently as compared to NPASE [22] control chart in Figure 4. But new control chart detecting the OOC value 3 times earlier as compared to existing control chart NPASME [33] shown in Figure 4. A repetitive sampling scheme control chart is plotted in Figure 5, that proposed by [22]. This control chart showed the OOC signal in sample 9, while it also less efficient as compared to NPASME [33] and proposed control chart too. Therefore, from Figures 3-6, it can be seen that the proposed RSNPDEBLP control chart performs best than the three existing control charts in accommodating the quick indication of a shift in the process. Thus the appropriate explanation of the new control chart will lead to a fall in the frequency of defective goods. It has been noted that the control chart NPASME proposed by [33] is detecting the OOC signal more efficiently than the proposed charts in [22] and [32]. As like this RSNPSE control chart [22] detects OOC signal faster as compared to the NPASE control chart offered [32]. After this explanation, we can say that the proposed control chart perform more efficiently as compared to all existing control charts.

VI. CONCLUSION

The OOC average run length ARL_1 values under linear drift for different p_1 values were used for checking the efficiency of the proposed control chart with some existing control charts. The RSNPDEBLP control chart has smallest OOC *ARL* value which is considered as the best control chart. The major purpose of the control chart was to identify an OOC value as rapidly as achievable for getting the non-defective pieces in the production process or avoid the non-defective items' production during the manufacturing process. So, the control chart having lower values of the OOC ARL is observed as the efficient control chart for checking the procedure. Table 3 perform the assessment of existing control charts (NPSE, NPASE [32], NPASDE, NPASME [33], RSNPSE [22], and new RSNPDEBLP) control chart for several values of n and λ. The proposed control chart is best for detecting the OOC signals in the process for small to moderate linear trend as competed to the existing EWMA and DEWMA control charts (see table 3). This procedure was repeated several times using the different values of n, and λ for the slop p_1. For example, when $\lambda = 0.05$ and $n = 10, 20$, it can be observed in Table 3 the OOC ARL_1 values of the RSNPDEBLP control chart are smaller than the ARL_1 of the other control charts only when magnitude shift ($\delta = |p_0 - p_1|$) has large deviations in the process proportion. Moreover, ARL_1 value of RSNPDEBLP control chart is smaller than the ARL_1 values of the existing control charts while $p_1 < 0.40$ or magnitude shift $\delta > 0.10$. Conclusively, it is noted that for different values of λ, n in Table 1 to 4, the OOC ARL values of RSNPDEBLP control chart are less than the ARL_1 values of other control chart for slope values. Hence, the proposed control chart is more efficient than the existing control charts in identifying the process shift.

APPENDIXES

APPENDIX A

A. The variance of DEWMA statistics Control is:

$$Var(Z\prime_i) = \frac{\lambda^4}{4n((1-(1-\lambda)^2)^3)}(1+(1-\lambda)^2-(1-\lambda)^{2i}$$
$$((i+1)^2-(2i^2+2i-1)(1-\lambda)^2+i^2(1-\lambda^4))) \quad (23)$$

A.1. Mean a_i can be verified by using equations (3) and (7).

$$\begin{aligned}E(a_i) &= E(2Z_i - Z_i')\\ &= 2E(Z_i) - E(Z_i')\\ &= 2sin^{-1}\sqrt{p_0} - sin^{-1}\sqrt{p_0}\\ &= sin^{-1}\sqrt{p_0}\end{aligned}$$

A.2. The asymptotic variance of a_i can be derived by using the (5) and (9).

$$\begin{aligned}Var_{asym}(a_i) &= V(2Z_i - Z_i')\\ &= 4V(Z_i) - V(Z_i') + 4\,Cov(Z_i, Z_i')\\ &= 4V(Z_i) - V(Z_i') + 4(0)\\ &= 4(\frac{\lambda}{(2-\lambda)4n}) - (\frac{\lambda(2-2\lambda+\lambda^2}{(2-\lambda)^3}\frac{1}{4n})\\ &= \frac{4}{4n}(\frac{\lambda}{(2-\lambda)}) - (\frac{\lambda(2-2\lambda+\lambda^2}{(2-\lambda)^3}\frac{1}{4n})\\ &= \frac{\lambda(1+4(1-\lambda)+5(1-\lambda)^2)}{(1+(1-\lambda))^2(4n)}\end{aligned}$$

A.3.

$$\begin{aligned}E(b_i) &= E(\frac{\lambda}{1-\lambda}Z_i - Z_i'))\\ &= \frac{\lambda}{1-\lambda}(EZ_i) - E(Z_i'))\\ &= \frac{\lambda}{1-\lambda}(sin^{-1}\sqrt{p_0} - (sin^{-1}\sqrt{p_0}))\\ &= 0\end{aligned}$$

A.4. The variance of slop b_i is defined as:

$$\begin{aligned}Var(b_i) &= Var(\frac{\lambda}{1-\lambda}(Z_i - Z_i'))\\ &= (\frac{\lambda}{1-\lambda})^2\,Var(Z_i - Z_i')\\ &= (\frac{\lambda}{1-\lambda})^2(\frac{\lambda}{(2-\lambda)4n} - \frac{\lambda(2-2\lambda+\lambda^2}{(2-\lambda)^3}\frac{1}{4n})\\ &= \frac{2\lambda^3}{(1+(1-\lambda))^3(4n)}\end{aligned}$$

APPENDIX B

B.1. The expected value of linear prediction f_t can be calculated by using the A1. and A.3.

$$\begin{aligned}E(F_{i+t}) &= E(a_i + b_i t)\\ &= E(a_i) + tE(b_i)\\ &= sin^{-1}\sqrt{p_0} + 0\\ &= sin^{-1}\sqrt{p_0}\end{aligned}$$

B.2. The Variance of F_t is

$$\begin{aligned}Var(F_{i+t}) &= Var(a_i + b_i t)\\ &= Var(a_i) + Var(b_i t) + 2\,Cov(a_i, b_i t)\end{aligned}$$

The covariance process in the above equation was investigate by using the simulation to verify the possible relationship between a_i and b_i. Simulation for the covariance relationship between the a_i and b_i were performed for different values of λ which is a smooth parameter in this process. The $Cov(a_i, b_i)$ simulated values very close to zero and it can be supped negligible. Moreover, the asymptotic $Cov(a_i, b_i)$ for $t = 1$ introduced by [27] and it can be written as:

$$Cov(a_i, b_i) = \frac{\lambda^2(1+3(1-\lambda))}{(1+(1-\lambda))^3(4n)}$$

By using the Appendix A.2 and A.4 in above equation and calculate the asymptotic variance of the linear trend production F_t as below:

$$\begin{aligned}Var_{asym}(F_t) &= A.2 + A.4 + Cov(a_i, b_i t)\\ &= \frac{\lambda(1+4(1-\lambda)+5(1-\lambda)^2)}{(1+(1-\lambda))^2(4n)}\\ &\quad + \frac{2\lambda^3}{(1+(1-\lambda))^3(4n)} + \frac{\lambda^2(1+3(1-\lambda))}{(1+(1-\lambda))^3(4n)}\\ &= \frac{1}{4n}(\frac{\lambda(1+4(1-\lambda)+5(1-\lambda)^2)}{(1+(1-\lambda))^2}\\ &\quad + \frac{2\lambda^3}{(1+(1-\lambda))^3} + \frac{\lambda^2(1+3(1-\lambda))}{(1+(1-\lambda))^3})\end{aligned}$$

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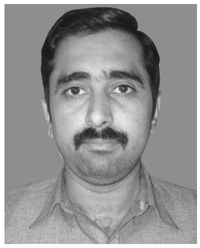

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