Monitoring Non-Conforming Products Using Multiple Dependent State Sampling Under Indeterminacy-An Application to Juice Industry

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ABSTRACT In this article a new np control chart for the multiple dependent state sampling using the neutrosophic statistics has been introduced for the efficient monitoring of the number of defective items in any production process or the customer services agencies. The coefficients of the control limits of the proposed control chart have been determined using the neutrosophic algorithms. The efficiency of its quick performance has been determined by computing the neutrosophic average run lengths with respect to different false alarm rates under different process settings at different process shift levels. The comparison with the existing counterparts for the quick detecting ability of the proposed chart has also been conducted. The practical application of the proposed chart has been elucidated using a real-world example.

INDEX TERMS Attribute control chart, multiple dependent state sampling, neutrosophic statistics, average run length, indeterminacy.

I. INTRODUCTION

The control chart is historic and broadly utilized the methodology of the statistical process control to control the production of defective items or the monitoring of bad repute of any services providing company [1]. Quality characteristics for any type of goods and services can be broadly classified as an attribute and the variable items. Attribute quality characteristic is adopted for the production process when the produced items are bifurcated on the criteria as the good or defective, life or dead, go or not go, conforming or non-conforming satisfy or not satisfy, etc. Firstly, the attribute quality characteristic is practically easy to use and secondly, a smaller sample size provides sufficient information to reach the decision [2]. Chan et al. [3] developed a monitoring scheme for nonconforming items using the cumulative counts by calculating optimal probabilities of false alarm. Epprecht, et al. [4] developed an adaptive attribute chart for one, two, or three parameters to choose an effective model. Rudisill, et al. [5] investigated the attribute charts using the Poisson distribution for observing the smaller number of nonconforming items. Chiu and Kuo [6] proposed an attribute chart for multivariate Poisson distribution. Niaki and Abbasi [7] developed the multi-attribute control chart when these attributes are correlated. Lee, et al. [8] investigated the np chart using the large subgroup size with executed statistical constraints.

The aforementioned chart is well-presented using the multiple dependent state sampling (MDS) instead of the conventional single sampling scheme Hsu, et al. [9]. Due to its broad spectrum of the production process, it has attracted the attention of several researchers during the last few years. Conventional sampling schemes are applied only to observe the current status of the product whether it is defective or non-defective but the MDS sampling scheme keeps the history of the product to declare the process about its production of defective or non-defective items. Zhou, et al. [10] suggested that MDS sampling improves the performance of the np chart because the Shewhart type charts have the tendency of lacking the responsiveness towards small changes in the production process. Reference [11] claimed that the efficiency of the MDS sampling plan is manifold as compared to a single sampling scheme as the lot sentencing.
is based upon not only the current lot information but also considers the information of the already submitted lots. Several SPC researchers explored the MDS sampling and declared it an efficient scheme including Wu and Wang [11], Aslam, et al. [12], [13]–[20].

It is not very uncommon for the researchers to face the uncertain data in real-life situations. Smarandache [21] float the concept of neutrosophic statistics, which is the generalization of the traditional statistics, to analyze the uncertain, unclear, vague, and incomplete data. Smarandache [22] enhanced the fuzzy logic due to its limitations and suggested a neutrosophic set to deal with the doubted situations. Khan, et al. [23] designed the dispersion chart using the standard deviation for the neutrosophic statistics. Aslam, et al. [24] presented the post hoc tested for the neutrosophic statistics. Albassam, et al. [25] designed a technique to study the village population of the USA under the neutrosophic statistics. Zhang, et al. [26] expressed the general symmetry of singular neutrosophic extended group under the neutrosophic logic. Aslam, et al. [27] developed a chart for the neutrosophic statistics under the gamma distribution. Aslam, et al. [28] developed a new attribute Shewhart chart under the neutrosophic interval method. Abdel-Basset et al. [29] developed criteria for project selection using a hybrid neutrosophic environment. Rich material is available for further reading on neutrosophic statistics for instance [30]–[46]. Motivated by the neutrosophic statistics the current article is aimed to develop an attribute np chart using the MDS sampling scheme.

In this paper, we will explain an efficient monitoring scheme for attribute data using the neutrosophic interval method to determine the control chart coefficients and to calculate the neutrosophic average run lengths under different process settings. The rest of the paper is organized as the design of the suggested chart is explained in the second section. In section three the advantages of the proposed methodology have been discussed. The comparison of the proposed chart with the existing np attribute neutrosophic chart has been given in section four. A simulated example has been included and discussed in section five.

II. DESIGN AND METHODOLOGY OF THE PROPOSED CHART

In this section, the methodology of the np chart using the MDS sampling under the neutrosophic statistics is elaborated. Let the neutrosophic probability \( p_N \in [p_L, p_U] \) be the neutrosophic proportion of non-conforming items which fail to meet the specified standard criteria. Further, suppose that the neutrosophic sample size be denoted by \( n_N \in [n_L, n_U] \). We are dealing with the data consisting of uncertainty or fuzziness so the parameters of the attribute control chart can be determined using the neutrosophic statistics. Here we suppose that the neutrosophic probability that \( p_N \in [p_L, p_U] \) is the same for all \( n_N \in [n_L, n_U] \) and further, suppose that the non-conforming numbers are denoted by \( X_N \in [X_L, X_U] \). According to [47] the above-mentioned conditions support to use the well-known binomial probability distribution based upon the neutrosophic statistics which can be defined as

\[
P_N\left(x_N; n_N, p_N\right) = \binom{n_N}{x_N} p_N^{x_N} (1 - p_N)^{n_N - x_N},
\]

\( x_N = 0, 1, \ldots, n_N \) (1)
Therefore, in this article, the following steps have been adopted to develop the \textit{np} chart using neutrosophic statistics denoted by \textit{Nnp} chart:

\textbf{Step-I} Select a random sample of size \(n_N \in [n_L, n_U]\) from any production process at each subgroup then count the defective items \(D_N \in [D_L, D_U]\).

\textbf{Step-II} If \(LCL_{2}\) \(\leq D_N \leq UCL_{2}\) then declare the process as in-control, otherwise, the process is straightforwardly declared as out-of-control if \(n_N\) subgroups are out-of-control.

In this way, we can state that the proposed chart is the generalization of the traditional Shewhart \textit{np} chart. The two control limits \(LCL_{1N} \in [LCL_{1L}, LCL_{1U}]\) is the lower control limit and \(UCL_{1N} \in [UCL_{1L}, UCL_{1U}]\) is known as the upper control limit and can be defined as

\[
LCL_{1N} = n_{PN0} + k_{1N}\sqrt{n_{PN0}(1 - p_{N0})};
\]

\[
UCL_{1N} = \max(0, n_{PN0} - k_{1N}\sqrt{n_{PN0}(1 - p_{N0})});
\]

where \(p_{N0}\) is termed as the probability of the in-control process based upon the neutrosophic statistics and the term \(k_{1N} \in [k_{1L}, k_{1U}]\) and \(k_{2N} \in [k_{2L}, k_{2U}]\) are neutrosophic control limits coefficients. Then the probability-based upon the neutrosophic statistics under the in-control process at \(p_N = p_{N0}\) is calculated as

\[
P_{N0|pN0} = P(LCL_{2N} \leq D_N \leq UCL_{2N})
\]

\[
+ P(UCL_{1N} \leq D_N \leq UCL_{1L})
\]

\[
\times P(LCL_{2N} \leq D_N \leq UCL_{2N})^{m_N}
\]

The probability of the in-control is given in Eq. (6) can be rewritten as

\[
P_{N0|pN0} = \sum_{d_N=|UCL_{2N}|}^{\min(\text{d}_{N}, \text{d}_{P})} \left( \frac{n_{d_N}}{d_N} \right) p_{N0}^{d_N} (1 - p_{N0})^{n - d_N}
\]

\[
+ \sum_{d_N=|LCL_{1N}|}^{\min(\text{d}_{N}, \text{d}_{P})} \left( \frac{n_{d_N}}{d_N} \right) p_{N0}^{d_N} (1 - p_{N0})^{n - d_N}
\]

\[
+ \sum_{d_N=|UCL_{2N}|+1}^{\min(\text{d}_{N}, \text{d}_{P})} \left( \frac{n_{d_N}}{d_N} \right) p_{N0}^{d_N} (1 - p_{N0})^{n - d_N}
\]

\[
\times \sum_{d_N=|LCL_{1N}|+1}^{\min(\text{d}_{N}, \text{d}_{P})} \left( \frac{n_{d_N}}{d_N} \right) p_{N0}^{d_N} (1 - p_{N0})^{n - d_N}
\]
The average run length (ARL) is used to evaluate the performance of the developed control chart which may be defined as the average number of samples before the process is declared as out-of-control. In this article, the ARL calculated for the neutrosophic statistics are denoted as NARL. Thus, the NARL is computed as

\[
NARL_{N0} = \frac{1}{1 - P_{N1}^{P_{N0}}} ; \\
NARL_{N0} \in [NARL_{N0L}, NARL_{N0U}] \tag{8}
\]

The shift is considered as the natural inherent phenomena which may provoke any time in the running process. Therefore, let we suppose that the fraction of the defectives may exist in the process in which this fraction is shifted from \( p_{N0} = p_{N0L} \in [p_{L0}, p_{U0}] \) to \( p_{N1} = p_{N1L} \in [p_{L1}, p_{U1}] \). Then, the neutrosophic probability of the shifted the process when it is termed as in-control is written as

\[
P_{N1|N0} = P(\text{LCL2N} \leq D_{N} \leq \text{UCL2N}) \\
+ [P(\text{LCL1N} \leq D_{N} \leq \text{LCL2N}) \\
+ P(\text{LCL2N} \leq D_{N} \leq \text{UCL1N})]^{m_{N}} \tag{9}
\]

where \( p_{N1} = p_{N0} + c_{N0}; p_{N0L} \in [p_{L0}, p_{U0}] \).

The probability \( P_{N1|N0} \) can be written as

\[
P_{N1|N0} = \sum_{d_{N}=\text{LCL2N}+1}^{\text{UCL2N}} \left( \frac{n}{d_{N}} \right) \binom{d_{N}}{n_{N1}} (1 - p_{N1})^{n-n_{N1}} \\
+ \sum_{d_{N}=\text{LCL1N}+1}^{\text{LCL2N}} \left( \frac{n}{d_{N}} \right) \binom{d_{N}}{n_{N1}} (1 - p_{N1})^{n-n_{N1}} \\
+ \sum_{d_{N}=\text{UCL1N}}^{\text{LCL2N}} \left( \frac{n}{d_{N}} \right) \binom{d_{N}}{n_{N1}} (1 - p_{N1})^{n-n_{N1}} \binom{d_{N}}{d_{N}} \tag{10}
\]

Then, the NARL denoted by \( NARL_{N1} \) for the shifted process it is calculated as

\[
NARL_{N1} = \frac{1}{1 - P_{N1|N0}^{P_{N0}} ;} \\
NARL_{N1} \in [NARL_{N1L}, NARL_{N1U}] \tag{11}
\]

An R-code program was written using the above-mentioned methodology under different parametric settings. The control chart coefficients \( k_{1N} \in [k_{1L}, k_{1U}] \) and \( k_{2N} \in [k_{2L}, k_{2U}] \) have been determined and mentioned in Tables 1-3 under different specified parameters. For example in Table 1 the control chart coefficient \( k_{1N} \) is estimated as \([4.377,5.773], [3.779,4.647]\)
TABLE 5. The simulated data for the proposed chart.

| Sr# | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|-----|------|------|------|------|------|------|------|------|------|------|
| DN  | [25,23] | [14,20] | [22,27] | [14,20] | [22,24] | [26,15] | [19,22] | [20,19] | [15,19] | [15,13] |
| Sr# | 11   | 12   | 13   | 14   | 15   | 16   | 17   | 18   | 19   | 20   |
| DN  | [16,20] | [18,28] | [17,27] | [20,21] | [14,24] | [23,23] | [20,26] | [15,18] | [17,24] | [15,20] |
| Sr# | 21   | 22   | 23   | 24   | 25   | 26   | 27   | 28   | 29   | 30   |
| DN  | [19,27] | [21,30] | [18,35] | [27,29] | [22,26] | [25,21] | [15,28] | [23,29] | [16,25] | [20,37] |
| Sr# | 31   | 32   | 33   | 34   | 35   | 36   | 37   | 38   | 39   | 40   |
| DN  | [21,21] | [22,23] | [19,21] | [22,42] | [19,28] | [28,24] | [19,18] | [20,19] | [20,33] | [23,25] |

FIGURE 1. The control chart display of the proposed chart, chart by [28] and traditional Shewhart np chart, respectively.

and [3.69,3.995] and \( k_{2N} \) is estimated as [1.794,2.201], [2.083,2.151] and [2.16,2.307] with \( p_{N0} = [0.202,0.211], [0.224,0.238] \) and [0.21,0.221] respectively. Likewise, the NARL are determined for different specific NARL\(_0\) = 200, 300 and 370 and the shifted NARL\(_1\) are generated for several shift levels as 0, 0.01, 0.02, 0.05, 0.08, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.95 and 1.00 under different samples as 50, 100 and 150 respectively. It is worth mentioning here that the smaller NARL\(_1\) values show that the process is quickly announced or declared an out-of-control process.

From Table 2, for example, the proposed chart detected the out-of-control process in just [3.63, 2.37], [3.32, 2.91] and [3.94, 3.41] samples for a shift of 0.05 when specified NARL\(_0\) are 200, 300 and 370 respectively.

From Table 1 through 3 it can be observed that
1. As the shift size increases the values of NARL\(_1\) are going to decrease.
2. As the specified NARL\(_0\) increases the values NARL\(_1\) also increases for all shift levels.

III. COMPARISON IN NARL

In this section, the comparison of the proposed Nnp attribute chart for the MDS sampling using the neutrosophic statistics has been discussed. Table 4 has been generated for the comparison of the proposed chart with the traditional Shewhart np attribute chart and Shewhart np attribute chart based upon neutrosophic statistics proposed by [28]. From Table 4 it can be observed very easily that the proposed chart is efficient in quick detection of the out-of-control process. For instance, the proposed chart detects a shift of 0.10 from 73\(^{rd}\) sample to 99\(^{th}\) sample. The Shewhart np attribute under neutrosophic statistics detects the shift from 126\(^{th}\) sample to 151\(^{st}\) sample. On the other hand, the traditional Shewhart under classical statistics detects the shift at 127\(^{th}\) sample. The same pattern can be observed at all other levels of different shifts. So it can be stated very clearly that the proposed chart is efficient in quickly detecting the out-of-control process as compared to the existing control charts.
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IV. COMPARISON BY SIMULATION

The application of the proposed chart has been given using a simulated example in this section. We have used \( n_N \epsilon [150, 150] \), \( p_{NO} \epsilon [0.1195, 0.1418] \), \( K_{IN} \epsilon [3.4894, 4.7995] \) and \( K_{2N} \epsilon [2.165, 2.2717] \) for shift \( c = 0.20 \) and the specified \( NARL_{NO} = 370 \). The simulated values for these settings have been placed in Table 5. Figure 1 shows the three control charts. On observing Figure 1 it can be seen that the conventional chart is unable to detect the out-of-control situation. Shewhart \( np \) attribute under neutrosophic statistics by [28] shows only one observation at sample number 32 which falls outside the upper limit. The proposed control chart indicates that several points are outside the control limits. In addition, it can be seen that the proposed control chart shows out-of-control earlier than the two existing control charts. From this simulation, it is concluded that the proposed chart is efficient in detecting the shift in the process earlier as compared to the existing control charts.

V. APPLICATION

In this section, we will present a real-world example for the illustration and the practical application of the proposed chart. For this purpose, we used the data of the orange juice. According to [48] “Frozen orange juice concentrate is packed in 6-oz cardboard cans. These cans are formed on a machine by spinning them from cardboard stock and attaching a metal

| Sample number | No. of nonconforming units | Sample number | No. of nonconforming units |
|---------------|---------------------------|---------------|---------------------------|
| 1             | [12,13]                   | 16            | [8,8]                     |
| 2             | [15,15]                   | 17            | [10,10]                   |
| 3             | [8,10]                    | 18            | [5,8]                     |
| 4             | [10,10]                   | 19            | [13,13]                   |
| 5             | [4,4]                     | 20            | [11,13]                   |
| 6             | [7,7]                     | 21            | [20,20]                   |
| 7             | [16,16]                   | 22            | [18,20]                   |
| 8             | [9,11]                    | 23            | [24,24]                   |
| 9             | [14,14]                   | 24            | [15,15]                   |
| 10            | [10,10]                   | 25            | [9,12]                    |
| 11            | [5,8]                     | 26            | [12,12]                   |
| 12            | [6,8]                     | 27            | [7,10]                    |
| 13            | [17,17]                   | 28            | [13,15]                   |
| 14            | [12,15]                   | 29            | [9,9]                     |
| 15            | [22,22]                   | 30            | [6,9]                     |

FIGURE 2. The control chart display of the proposed chart, chart by [28] and traditional Shewhart \( np \) chart for a real data, respectively.
bottom panel. By inspection of a can, we may determine whether, when filled, it could possibly leak either on the side seam or around the bottom joint. Such a nonconforming can have an improper seal on either the side seam or the bottom panel. The data has been shown in Table 6 for ready reference. For this data set the $D_{KE}[D_L, D_U]$ values are plotted in Figure 2. On observing Figure 2 it can be seen that the proposed chart indicates that several points are beyond the control limits. The control chart proposed by [28] shows only 4 observations in the outside of the upper control limit. The traditional Shewhart np shows that three points are beyond the upper limit. From this study, it is concluded that the proposed control chart is the most efficient chart as several observations fall outside the upper control limit. By comparing the three charts, the proposed control chart clearly indicates some issues in the cans process.

VI. CONCLUSION

In this article, an attribute control chart using the MDS sampling scheme for the neutrosophic statistics was proposed. The control chart coefficients have been determined for different parametric settings under different shift levels. The proposed chart detects shift quickly as compared to the existing chart. The proposed chart is an efficient addition in the literature of the control charts for uncertain and vague observations. The proposed chart can further be extended for the multivariate case as future research.

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