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Research Article

Process Monitoring for Gamma Distributed Product under Neutrosophic Statistics Using Resampling Scheme

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In this article, a repetitive sampling control chart for the gamma distribution under the indeterminate environment has been presented. The control chart coefficients, probability of in-control, probability of out-of-control, and average run lengths have been determined under the assumption of the symmetrical property of the normal distribution using the neutrosophic interval method. The performance of the designed chart has been evaluated using the average run length measurements under different process settings for an indeterminate environment. In-control and out-of-control nature of the proposed chart under different levels of shifts have been described. The comparison of the proposed chart has been made with the existing chart. A real-world example from the healthcare department has been included for the practical application of the proposed chart. It has been observed from the simulation study and real example that the proposed control chart is efficient in quick monitoring of the out-of-control process. It can be concluded that the proposed control chart can be applied effectively in uncertainty.

1. Introduction

The control chart is considered as the most efficient, fabulous, and powerful tool of statistical process control. The control charts have been widely used in various fields. Suman and Prajapati [1] discussed the application in the healthcare department. Zaman et al. [2] applied a control chart in the wind turbine field. Hossain et al. [3] discussed the application of a control chart for monitoring the glass fiber process. The effectiveness and efficiency of the control chart are judged by its reaction behavior against changes in its designed parameters. There are two types of changes observed in the control chart literature, i.e., common changes and special changes. Common changes also known as common causes are natural and have no threatening effect on the interested quality characteristic as compared to the special changes or special causes [4]. The early and quick detection of the special cause of variation is the prime property of any control chart which not only detects the out-of-control process quickly but also timely stops the process from producing a bulk of defective items which ultimately cause a bad impression for the producer and results in heavy losses [5]. The idea of the control chart was floated by Shewhart during the 1920s [6], and researchers are endeavoring to propose a robust control chart since its inception but remained unsuccessful. The proposed chart is an efficient struggle for the quick monitoring of the manufacturing process. The variable control chart is used when the data obtained from the measurement process and attribute control charts are applied when the data is obtained from the counting process. Abbas et al. [7] proposed the control chart for monitoring healthcare. Aslam et al. [8] designed the control chart for the process capability index. Nazir et al. [9] proposed the improved control chart for the industrial processes. Saghir et al. [10] proposed the improved control chart for modified gamma data. Saghir et al. [11] incorporated auxiliary information and repetitive sampling for the monitoring of the process.

Repetitive sampling scheme (RSS) is an efficient sampling scheme for the statistical process control techniques that attracted the attention of many researchers during the last two decades. The RSS was basically introduced by

Sherman [12] in the attribute acceptance sampling plans. The acceptance sampling plans for the normal distribution and the log-normal distribution using the variable RSS were proposed by Balamurali et al. [13]. Later on, the RSS for the variable acceptance sampling plan was developed by Balamurali and Jun [14]. The efficiency of the RSS for the average sample number is intermediate between the single sampling scheme and the probability to ratio sampling scheme Balamurali et al. [13]. Ahmad et al. [15] developed the Shewhart X-bar control chart for the RSS for monitoring the mean value of the process capability index C_p. Ahmad et al. [15] applied the RSS for the efficient monitoring of the coal quality. Azam et al. [16] developed plans for the exponentially weighted moving average regression estimators. Repetitive sampling plans based on one-sided specifications limits were presented by Yen et al. [17] Recently, Saghir et al. [10] developed a repetitive control chart for exponentially weighted moving average (EWMA) statistic using auxiliary information for monitoring process means. During the last few years, repetitive sampling has been explored by many authors including Adeoti and Olaomi [18], Aslam et al. [19], Aslam et al. [19], Aslam et al. [20], Balamurali and Jun [14], Balamurali et al. [13], Jun et al. [21], Liu and Wu [22], and Radhakrishnan and Sivakumaran [23].

In probability theory, the gamma distribution is considered as the family of two-parameter continuous probability distributions and is extremely useful in quality control literature when used under appropriate conditions. The normal probability distribution which is also very common in quality control literature but may lead to erroneous results when the shape of the underlying observations or the variable of quality of interest is unknown [24] or does not follow the normal distribution [25]. Another reason in which the normal distribution is inappropriate is the size of the collected data, particularly the single size data. However, these situations are handled by using the gamma distribution as an excellent substitute for the normal distribution in the study carried out by Khan et al. [26] and Saghir et al. [11]. In general, the gamma distribution is very common in modeling the waiting time of the events or modeling the failure time of the systems or the processes of Aksoy [27] and Saghir et al. [10]. Many other distributions such as chi-square distribution, Erlang distribution, and exponential distribution are the special cases of the gamma distribution. For larger values of the shape parameter, the gamma distribution approaches to the normal probability distribution [28]. The gamma distribution is considered as a better approximation of the interested quality characteristic when its distribution is skewed [29, 28]. Many control charts have been developed for monitoring the skewed statistic and proved to be effective and useful, for example, Jearkpaporn et al. [30] developed a monitoring scheme to detect a shift in the shape parameter, Zhang et al. [31] developed the gamma chart based on the random shift model for monitoring the out-of-control process, Chen and Yeh [32] developed an X-bar chart for nonnormal distribution using the gamma distribution, and Gonzalez and Viles [33] presented the method to monitor the variable quality characteristic using the r-chart under the gamma distribution.

Several control chart schemes have been developed for the processes having clear, certain, determined, and crisp observations of the interested quality characteristic. There are many situations when the observations are unclear, uncertain, vague, indeterminate, incomplete, and fuzzy. Bradshaw [34] developed a control chart for monitoring the observations from the fuzzy set theory. Williams and Zigli [35] proposed charts for fuzzy logic for the service industry. Taleb and Limam [36] constructed procedures for monitoring of linguistic data based on probability and fuzzy theory. Gülbay et al. [37] developed a fuzzy control chart for linguistic data. Hsieh et al. [38] explained a Poisson-based control chart for monitoring wafer defects for fuzzy theory. Sorooshian [39] investigated the fuzzy theory for monitoring attribute quality characteristics.

The neutrosophic logic which is the extension of the fuzzy logic was proposed by Smarandache [40]. The neutrosophic provides information about the measure of indeterminacy which fuzzy logic is unable to provide. Smarandache [41] discussed the generalization of intuitionistic fuzzy logic. Smarandache [42] introduced neutrosophic theory using the generalization form of the fuzzy set theory. Abu Qamar and Hassan [43] and Abu Qamar and Hassan [44] discussed Q-neutrosophic with appellations in decision-making. More information on the applications of neutrosophic logic can be found in the study carried out by Alhabib et al. [45], Abdel-Baset et al. [46], and Jana and Pal [47].

Smarandache [48] introduced the generalized class of the traditional statistics under the neutrosophic logic and called it the neutrosophic statistics. The neutrosophic statistics tend to transform to the classical statistics if all the observations are clear, certain, complete, or determined. Chen et al. [49] analyzed the scale effect and anisotropy for neutrosophic numbers of rock joint roughness coefficient based on neutrosophic statistics. Aslam [50] introduced a new sampling plan for the indeterminate environment under the process loss consideration. Aslam et al. [51] studied the indeterminate environment for testing of grouped product using the Weibull distribution. Aslam and Raza [8] developed a novel neutrosophic sampling plan for the multiple manufacturing lines using an exponentially weighted moving average and classical process capability index under the neutrosophic optimization solution method. Recently, Aslam et al. [52] designed the control chart for the gamma distribution using the indeterminate environment. More information regarding the control charts can be found in the study carried out by Intaramo and Pongpullponsak [53], Charongrattanasakul and Pongpullponsak [54], Panthong and Pongpullponsak [55], Aslam et al. [29], Aslam et al. [56], Fernández [57], Khan et al. [26], Aslam et al. [58], and Mashuri and Ahsan [59].

Average run length (ARL) is used very commonly in control chart literature as the evaluation tool of any proposed chart. ARL is defined as the average number of samples falling inside the control limits before the process shows an out-of-control condition Montgomery [4]. In a statistically controlled process, the values of neutrosophic ARL (NARL) must be larger, but for the shifted process, the

smaller NARL values are preferred under the indeterminate environment for quick indication of out-of-control process and thus resulting in a smaller amount of defective items. More information about ARL can be found in the study carried out by Woodall [60], Molnau et al. [61], Kim [62], Knoth [63], Li et al. [64], Chananet et al. [65], and Phanyaem et al. [66].

In this article, a control chart scheme has been developed for a repetitive sampling scheme using the gamma distribution for the indeterminate environment with the objective that it will be an efficient monitoring scheme. To the best of the author's knowledge, no work has been done on a repetitive sampling control chart for gamma distribution using the indeterminate environment. The rest of the paper is organized as follows. The Neutrosophic gamma distribution is introduced in Section 2. The design of the proposed neutrosophic gamma distribution chart has been given in Section 3. In Section 3, the control chart for $a_N \in [3,5]$ and $b_N \in [1.9, 2.1]$ and $a_N \in [5,10]$ and $b_N \in [1.45, 1.55]$ has been discussed. In addition, tables of NARLs have been generated and the simulation study of the neutrosophic statistics has been explained. In Section 4, a comparison of the proposed chart with an existing chart has been given. In Section 5, a real example has been explained for the practical application of the proposed chart. Conclusion and the direction for future research have been given in the Section 6.

2. Neutrosophic Gamma Distribution

Let the neutrosophic failure time be $T_N \in [T_L, T_U]$, where T_L and T_U represent the indeterminacy interval of lower and upper failures of an item that follows the neutrosophic gamma distribution with neutrosophic scale parameter $b_N \in [b_L, b_U]$ and neutrosophic shape parameter $a_N \in [a_L, a_U]$. Then, the neutrosophic probability density function (npdf) of the neutrosophic gamma distribution is given as

$$f(t_N) = \frac{b_N^{a_N}}{\Gamma(a_N)} t_N^{a_N-1} e^{-b_N t_N}; \quad t_N, a_N, b_N > 0;\ a_N \in [a_L, a_U],\ b_N \in [b_L, b_U], \tag{1}$$

where $\Gamma(x)$ describes the neutrosophic gamma function; for more details, readers may refer to [20].

The resultant neutrosophic cumulative distribution (ncd) of the neutrosophic Gamma distribution (NGD) is

$$P(T_N \le t_N) = 1 - \sum_{j=1}^{a_N-1} \frac{e^{-(t_N/b_N)} (t_N/b_N)^j}{j!}; \quad T_N \in [T_L, T_U],\ a_N \in [a_L, a_U],\ b_N \in [b_L, b_U]. \tag{2}$$

It is to be noted that the NGD under the classic statistics is the generalization of the traditional gamma distribution. The mean and variance of the neutrosophic statistics can be written as

$$\mu_N = \frac{a_N}{b_N}; \quad a_N \in [a_L, a_U],\ b_N \in [b_L, b_U],$$
$$\sigma_N^2 = \frac{a_N}{b_N^2}; \quad a_N \in [a_L, a_U],\ b_N \in [b_L, b_U]. \tag{3}$$

To construct control chart, we need the neutrosophic normal distribution which is developed using the approximation developed by [67] as $T_N^* = T_N^{1/3}$ and $T_N \in [T_L, T_U]$. More information regarding neutrosophic distribution can be found in the study carried out by Smarandache [48], Peng and Dai [68], Peng and Dai [69], Aslam et al. [51], Aslam et al. [51], Aslam and Raza [8], and Aslam [50]. Then, the mean and variance of the transformed neutrosophic distribution $T_N^* \in [T_L^*, T_U^*]$ can be written as

$$\mu_{T_N^*} = \frac{b_N^{1/3}\Gamma(a_N + 1/3)}{\Gamma(a_N)}, \quad a_N \in [a_L, a_U],\ b_N \in [b_L, b_U],$$
$$\sigma_{T_N^*} = \frac{b_N^{2/3}\Gamma(a_N + 2/3)}{\Gamma(a_N)} - \left(\frac{b_N^{1/3}\Gamma(a_N + 1/3)}{\Gamma(a_N)}\right)^2, \quad a_N \in [a_L, a_U],\ b_N \in [b_L, b_U]. \tag{4}$$

3. Design of the Proposed Control Chart

In this section, we described the designing of the proposed neutrosophic control chart for the transformed variable $T_N^* = T_N^{1/3}, T_N^* \in [T_L, T_U]$. According to Wilson and Hilferty [67], the random variable $T_N^* = T_N^{1/3}$, $T_N^* \in [T_L, T_U]$, has the symmetry property of the normal probability distribution. We developed the neutrosophic control chart using the neutrosophic statistical interval method under the condition that the interested quality characteristic follows the NGD.

As mentioned by Wilson and Hilferty [67], the transformed variable $T_N^* = T_N^{1/3}, T_N^* \in [T_L, T_U]$, has the symmetry property of the neutrosophic normal distribution. We propose the following control chart under the NISM when the quality of interest follows the NGD. The following two steps have been adopted to develop the neutrosophic control chart:

(1) Determine $T_N^* = T_N^{1/3}$, where T_N^* is the transformed random variable based on the randomly selected items from the manufacturing process.

(2) Using control limits, plot T_N^*; then, declare the process as out-of-control when $T_N^* \ge \mathrm{UCL}_{1N}$ or $T_N^* \le \mathrm{LCL}_{1N}$, where $\mathrm{LCL}_{1N} \in [\mathrm{LCL}_{1L}, \mathrm{LCL}_{1U}]$ and $\mathrm{UCL}_{1N} \in [\mathrm{UCL}_{1L}, \mathrm{UCL}_{1U}]$ are neutrosophic lower and upper control limits, respectively. Note here that the decision about the process is out-of-control and is taken if T_N^* is beyond the outer of neutrosophic control limits.

The proposed neutrosophic control chart under the neutrosophic statistical interval method is the extension of the Sheu and Lin [70] control chart under the classical statistics. The proposed chart converts to Sheu and Lin [70]

control chart when developed under the crisp, complete, or certain observations. Let the process lie in-control state under the neutrosophic scale parameter $b_{0N} \in [b_{0L}, b_{0U}]$. Then, the control limits of the proposed neutrosophic control chart can be developed as

$$\begin{aligned}
\mathrm{LCL}_{1N} &= \mu_{T_N^*} - k_{1N}\sigma_{T_N^*} = \frac{b_{0N}^{1/3}\Gamma(a_N + (1/3))}{\Gamma(a_N)} - k_{1N}\sqrt{\frac{b_{0N}^{2/3}\Gamma(a_N + 2/3)}{\Gamma(a_N)} - \mu_{T_N^*}^2},\\
\mathrm{LCL}_{2N} &= \mu_{T_N^*} - k_{2N}\sigma_{T_N^*} = \frac{b_{0N}^{1/3}\Gamma(a_N + (1/3))}{\Gamma(a_N)} - k_{2N}\sqrt{\frac{b_{0N}^{2/3}\Gamma(a_N + 2/3)}{\Gamma(a_N)} - \mu_{T_N^*}^2},\\
\mathrm{UCL}_{1N} &= \mu_{T_N^*} + k_{1N}\sigma_{T_N^*} = \frac{b_{0N}^{1/3}\Gamma(a_N + 1/3)}{\Gamma(a_N)} + k_{1N}\sqrt{\frac{b_{0N}^{2/3}\Gamma(a_N + 2/3)}{\Gamma(a_N)} - \mu_{T_N^*}^2},\\
\mathrm{UCL}_{2N} &= \mu_{T_N^*} + k_{2N}\sigma_{T_N^*} = \frac{b_{0N}^{1/3}\Gamma(a_N + 1/3)}{\Gamma(a_N)} + k_{2N}\sqrt{\frac{b_{0N}^{2/3}\Gamma(a_N + 2/3)}{\Gamma(a_N)} - \mu_{T_N^*}^2},
\end{aligned} \tag{5}$$

where $k_{1N} \in [k_{1L}, k_{1U}]$ and $k_{2N} \in [k_{2L}, k_{2U}]$ are the neutrosophic control limit coefficients.

Furthermore, we define

$$\begin{aligned}
\mathrm{LL}_{1N} &= \left[\frac{\Gamma(a_N + 1/3)}{\Gamma(a_N)} - k_{1N}\sqrt{\frac{\Gamma(a_N + 2/3)}{\Gamma(a_N)} - \left(\frac{\Gamma(a_N + 1/3)}{\Gamma(a_N)}\right)^2}\right],\\
\mathrm{LL}_{2N} &= \left[\frac{\Gamma(a_N + 1/3)}{\Gamma(a_N)} - k_{2N}\sqrt{\frac{\Gamma(a_N + 2/3)}{\Gamma(a_N)} - \left(\frac{\Gamma(a_N + 1/3)}{\Gamma(a_N)}\right)^2}\right],\\
\mathrm{UL}_{1N} &= \left[\frac{\Gamma(a_N + 1/3)}{\Gamma(a_N)} + k_{1N}\sqrt{\frac{\Gamma(a_N + 2/3)}{\Gamma(a_N)} - \left(\frac{\Gamma(a_N + 1/3)}{\Gamma(a_N)}\right)^2}\right],\\
\mathrm{UL}_{2N} &= \left[\frac{\Gamma(a_N + 1/3)}{\Gamma(a_N)} + k_{2N}\sqrt{\frac{\Gamma(a_N + 2/3)}{\Gamma(a_N)} - \left(\frac{\Gamma(a_N + 1/3)}{\Gamma(a_N)}\right)^2}\right].
\end{aligned} \tag{6}$$

Therefore, the neutrosophic control limits can be written as follows:

$$\begin{aligned}
\mathrm{LCL}_{1N} &= b_{0N}^{1/3}\mathrm{LL}_{1N},\\
\mathrm{LCL}_{2N} &= b_{0N}^{1/3}\mathrm{LL}_{2N},\\
\mathrm{UCL}_{1N} &= b_{0N}^{1/3}\mathrm{UL}_{1N},\\
\mathrm{UCL}_{2N} &= b_{0N}^{1/3}\mathrm{UL}_{2N}.
\end{aligned} \tag{7}$$

For a shifted process, note that a shift occurs in the neutrosophic scale parameter, whereas the shape parameter remains constant. Then, the probability under the neutrosophic statistical interval method of the in-control process when the process shows the state of in-control can be calculated as

$$P_{\mathrm{out},N}^0 = P\left(T_N^* < \mathrm{LCL}_{1N} | b_N = b_{0N}\right) + P\left(T_N^* > \mathrm{UCL}_{1N} | b_N = b_{0N}\right), \tag{8}$$

$$\text{or } P_{\mathrm{out},N}^0 = 1 - \sum_{j=1}^{a_N - 1} \frac{e^{-\mathrm{LL}_{1N}^3}\left(\mathrm{LL}_{1N}^3\right)^j}{j!} + \sum_{j=1}^{a_N - 1} \frac{e^{-\mathrm{UL}_{1N}^3}\left(\mathrm{UL}_{1N}^3\right)^j}{j!},$$

$$P_{\mathrm{rep},N}^0 = P\left(\mathrm{LCL}_{1N} < T_N^* < \mathrm{LCL}_{2N} | b_N = b_{0N}\right) + P\left(\mathrm{UCL}_{1N} < T_N^* < \mathrm{UCL}_{2N} | b_N = b_{0N}\right), \tag{9}$$

$$P_{\mathrm{rep},N}^0 = \sum_{j=1}^{a_N - 1} \frac{e^{-\mathrm{UL}_{2N}^3}\left(\mathrm{UL}_{2N}^3\right)^j}{j!} - \sum_{j=1}^{a_N - 1} \frac{e^{-\mathrm{UL}_{1N}^3}\left(\mathrm{UL}_{1N}^3\right)^j}{j!} + \sum_{j=1}^{a_N - 1} \frac{e^{-\mathrm{LL}_{1N}^3}\left(\mathrm{LL}_{1N}^3\right)^j}{j!} - \sum_{j=1}^{a_N - 1} \frac{e^{-\mathrm{LL}_{2N}^3}\left(\mathrm{LL}_{2N}^3\right)^j}{j!}.$$

The probability of out-of-control under neutrosophic statistics is given by

$$P_{\mathrm{out}}^0 = \frac{P_{\mathrm{out},N}^0}{1 - P_{\mathrm{rep},N}^0}. \tag{10}$$

As mentioned earlier the ARL is used to evaluate the developed scheme for its efficiency to declare the shifted process as out-of-control quickly. So, the neutrosophic ARL (NARL) for the in-control process ARL_{0N} can be defined as

$$\mathrm{ARL}_{0N} = \frac{1}{P^0_{\mathrm{out}}}; \quad \mathrm{ARL}_{0N} \in \left[\mathrm{ARL}_{0L}, \mathrm{ARL}_{0U}\right]. \tag{11}$$

We will measure the efficiency of the proposed control chart under the neutrosophic average run length (NARL) which shows on the average when the process is out-of-control and is defined by

$$\mathrm{ARL}_{0N} = \frac{1}{P^0_{\mathrm{out}}}; \quad \mathrm{ARL}_{0N} \in \left[\mathrm{ARL}_{0L}, \mathrm{ARL}_{0U}\right]. \tag{12}$$

Let a shift occur in the process; then, the process is shifted from the targeted $b_{0N} \in [b_{0L}, b_{0U}]$ to $b_{1N} = cb_{0N}, b_{1N} \in [b_{1L}, b_{1U}]$, where the constant c shows the shift in the process. Then, the probability of the out-of-process under the neutrosophic statistical interval method can be developed as

$$P^1_{\mathrm{out},N} = P\left(T^*_N < \mathrm{LCL}_{1N} | b_N = cb_{0N}\right) + P\left(T^*_N > \mathrm{UCL}_{1N} | b_N = cb_{0N}\right), \tag{13}$$

$$\text{or } P^1_{\mathrm{out},N} = 1 - \sum_{j=1}^{a_N - 1} \frac{e^{\left(-\mathrm{LL}^3_{1N}/c\right)}\left(\mathrm{LL}^3_{1N}/c\right)^j}{j!} + \sum_{j=1}^{a-1} \frac{e^{\left(-\mathrm{UL}^3_{1N}/c\right)}\left(\mathrm{UL}^3_{1N}/c\right)^j}{j!},$$

$$P^1_{\mathrm{rep},N} = P\left(\mathrm{LCL}_{1N} < T^*_N < \mathrm{LCL}_{2N} | b_N = cb_{0N}\right) + P\left(\mathrm{UCL}_{1N} < T^*_N < \mathrm{UCL}_{2N} | b_N = cb_{0N}\right),$$

$$P^1_{\mathrm{rep},N} = \sum_{j=1}^{a_N - 1} \frac{e^{\left(-\mathrm{UL}^3_{2N}/c\right)}\left(\mathrm{UL}^3_{2N}/c\right)^j}{j!} - \sum_{j=1}^{a_N - 1} \frac{e^{\left(-\mathrm{UL}^3_{1N}/c\right)}\left(\mathrm{UL}^3_{1N}/c\right)^j}{j!} + \sum_{j=1}^{a_N - 1} \frac{e^{\left(-\mathrm{LL}^3_{1N}/c\right)}\left(\mathrm{LL}^3_{1N}/c\right)^j}{j!} - \sum_{j=1}^{a_N - 1} \frac{e^{\left(-\mathrm{LL}^3_{2N}/c\right)}\left(\mathrm{LL}^3_{2N}/c\right)^j}{j!}. \tag{14}$$

The probability of out-of-control under neutrosophic statistics for the shifted process is given by

$$P^1_{\mathrm{out}} = \frac{P^1_{\mathrm{out},N}}{1 - P^1_{\mathrm{rep},N}}. \tag{15}$$

Thus, the NARL for the shifted process ARL_{1N} is defined as

$$\mathrm{ARL}_{1N} = \frac{1}{P^1_{\mathrm{out},N}}; \quad \mathrm{ARL}_{1N} \in \left[\mathrm{ARL}_{1L}, \mathrm{ARL}_{1U}\right]. \tag{16}$$

Using the abovementioned equations, the R-language code program was written to estimate the neutrosophic parameters of the proposed chart for different process settings. Tables 1 and 2 have been generated for $a_N \in [3, 5]$ and $b_N \in [1.9, 2.1]$ and $a_N \in [5, 10]$ and $b_N \in [1.45, 1.55]$ with NARL values for different shifts from 1.0 to 4.0.

Table 1 provides NARL values for the in-control $\mathrm{NARL}_0 = 200$, 300, and 370 with ka_N = [4.594878, 5.233344], [5.282686, 5.430229], and [5.000939, 5.409798] and kr_N = [1.527915, 2.881848], [0.3242994, 2.66222], and [0.9223276, 4.060355]. Figure 1 has been given for the plotting of $a_N \in [3, 5]$ and $b_N \in [1.9, 2.1]$.

From Tables 1 and 2, we made the following trends in NARL:

(1) As the values of the shift c increase from 1.0 to 4.0, the indeterminacy intervals $\mathrm{ARL}_{1N} \in [\mathrm{ARL}_{1L}, \mathrm{ARL}_{1U}]$ decrease

(2) As the values of $a_N \in [a_L, a_U]$ and $b_N \in [b_L, b_U]$ increase from $a_N \in [3, 5]$ and $b_N \in [1.9, 2.1]$ to $a_N \in [5, 10]$ and $b_N \in [1.45, 1.55]$, the indeterminacy intervals decrease

4. Comparison of the Proposed Chart with the Existing Chart

In this section, the comparative advantages and efficiency of the proposed chart over the existing chart of the traditional chart for gamma distribution under the indeterminacy environment have been discussed with the help of the simulated data. For the purpose of fair comparison, we fixed the same values of the process parameters. Table 3 shows the in-control NARL_0 and out-of-control NARL_1 values for different shifts from 1.0 to 4.0.

A simple comparison shows that the proposed chart has smaller NARL_1 values as compared to the existing chart [52]. From example, when $c = 1.1$, the indeterminacy intervals of NARL for the existing chart is $\mathrm{ARL}_{1N} \in [89.86, 101.98]$ and for the proposed chart is $\mathrm{ARL}_{1N} \in [80.02, 86.99]$. From this comparison, it can be concluded that the proposed control chart will indicate the shift in the process between 80^{th} to 86^{th} samples. On the contrary, the chart proposed by Aslam et al. [8] will indicate the shift in the process between 89^{th} and 101^{st} samples. Therefore, the proposed control chart has the ability to detect a shift in the process earlier than the existing control chart.

We will now discuss the efficiency of the proposed control chart over the existing control chart using the simulated data. According to the proposed chart, the process is said to out-of-control if $T^*_N \geq \mathrm{UCL}_{1N}$ or $T^*_N \leq \mathrm{LCL}_{1N}$. The first 20 observations are generated from the neutrosophic gamma distribution when the process is an in-control state.

Table 1: Neutrosophic average run length of the proposed chart for $a_N \in [3, 5]$ and $b_N \in [1.9, 2.1]$.

ka_N	[4.594878, 5.233344]	[5.282686, 5.430229]	[5.000939, 5.409798]
kr_N	[1.527915, 2.881848]	[0.3242994, 2.66222]	[0.9223276, 4.060355]
a_N	[3, 5]	[3, 5]	[3, 5]
b_N	[1.9, 2.1]	[1.9, 2.1]	[1.9, 2.1]
c		ARL_N	
1.0	[200, 200.01]	[300.01, 300]	[370, 370]
1.1	[80.02, 86.99]	[101.62, 111.28]	[149.4, 138.84]
1.2	[37.51, 43.40]	[41.19, 48.86]	[71.14, 61.11]
1.3	[19.92, 24.14]	[19.33, 24.49]	[38.39, 30.54]
1.4	[11.71, 14.68]	[10.28, 13.69]	[22.84, 16.95]
1.5	[7.50, 9.62]	[6.11, 8.40]	[14.7, 10.29]
1.6	[5.18, 6.72]	[4.01, 5.58]	[10.1, 6.75]
1.7	[3.81, 4.96]	[2.88, 3.99]	[7.32, 4.75]
1.8	[2.97, 3.85]	[2.23, 3.03]	[5.56, 3.55]
1.9	[2.42, 3.11]	[1.84, 2.43]	[4.39, 2.80]
2.0	[2.05, 2.60]	[1.59, 2.03]	[3.58, 2.31]
2.3	[1.55, 1.88]	[1.28, 1.51]	[2.44, 1.66]
2.5	[1.32, 1.54]	[1.15, 1.29]	[1.88, 1.37]
2.8	[1.18, 1.33]	[1.08, 1.16]	[1.53, 1.21]
3.0	[1.13, 1.25]	[1.06, 1.11]	[1.39, 1.15]
4.0	[1.03, 1.08]	[1.01, 1.03]	[1.12, 1.04]

Table 2: Neutrosophic average run length of the proposed chart for $a_N \in [5, 10]$ and $b_N \in [1.45, 1.55]$.

ka_N	[4.006202, 4.571112]	[3.939843, 4.788404]	[4.14799, 4.867394]
kr_N	[1.086602, 2.200099]	[2.939107, 1.818469]	[1.414571, 1.799174]
a_N	[5, 10]	[5, 10]	[5, 10]
b_N	[1.45, 1.55]	[1.45, 1.55]	[1.45, 1.55]
c		ARL_N	
1.0	[200.01, 200]	[300.01, 300.01]	[370, 370.02]
1.1	[58.89, 72.91]	[77.12, 125.12]	[91.79, 130.98]
1.2	[21.72, 31.51]	[25.26, 61.28]	[29.13, 55.15]
1.3	[9.65, 15.64]	[10.15, 33.91]	[11.36, 26.64]
1.4	[5.06, 8.74]	[4.93, 20.64]	[5.36, 14.42]
1.5	[3.09, 5.42]	[2.87, 13.56]	[3.04, 8.60]
1.6	[2.15, 3.68]	[1.97, 9.48]	[2.04, 5.60]
1.7	[1.68, 2.72]	[1.53, 6.98]	[1.57, 3.93]
1.8	[1.42, 2.15]	[1.31, 5.37]	[1.33, 2.95]
1.9	[1.27, 1.79]	[1.19, 4.29]	[1.20, 2.35]
2.0	[1.18, 1.57]	[1.12, 3.54]	[1.12, 1.96]
2.3	[1.07, 1.27]	[1.04, 2.45]	[1.04, 1.46]
2.5	[1.03, 1.15]	[1.02, 1.90]	[1.02, 1.25]
2.8	[1.01, 1.08]	[1.01, 1.56]	[1.01, 1.13]
3.0	[1.01, 1.05]	[1, 1.42]	[1, 1.09]
4.0	[1, 1.01]	[1, 1.13]	[1, 1.02]

The next 20 observations are from the out-of-control process when $c = 1.4$. The proposed control chart for simulated data is shown in Figure 1. The existing control chart for the simulated data is shown in Figure 2. From Table 1, it is expected that the shift should be detected between 16^{th} sample to 22^{nd} sample. From Figure 1, it can be seen that the proposed control chart detects a shift in the process according to expectation. The determinate part (lower value) of the statistic T_N^* is beyond UCL_{1N} between 16^{th} samples to 22^{nd} sample. We also note that several observations are within indeterminacy interval and resampling areas. On the contrary, the existing control chart does not show any shift in the process. From this simulation study, it is concluded that the proposed chart has the ability to detect a shift in the process as compared to the existing control chart.

5. Application of the Proposed Chart

In this section, we will discuss the application of the proposed control chart in the healthcare department. A large hospital management is interested to track the urinary tract infections (UTIs) patients. According to Santiago and Smith [71], "data were provided from a large hospital system concerned with a very high rate of hospital-acquired UTIs. Specifically, the hospital would like to track the frequency of patients being discharged who had acquired a UTI while in the hospital as a way to quickly identify an increase in infection rate or, conversely, monitor whether the forthcoming process or material changes result in fewer infections because the root cause often differs based on gender, male and female patients." The UTIs' data of male

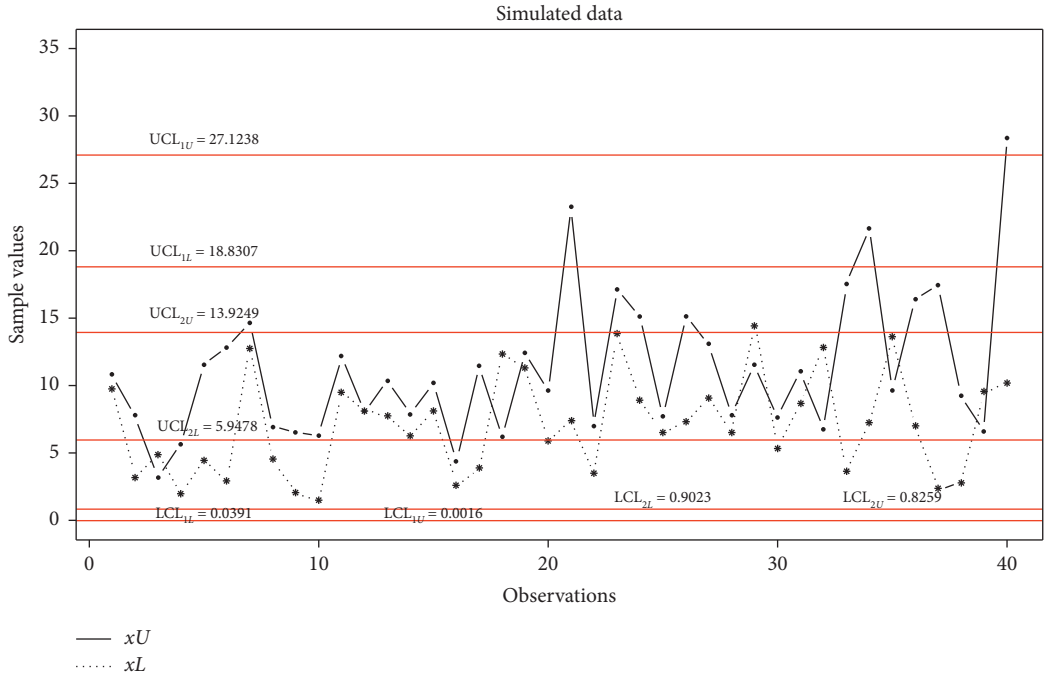

Figure 1: The proposed control for simulated data when $a_N \in [3,5], b_N \in [1.9,2.1], n_N \in [20,20], k_{1N} \in [4.5948,5.2333]$, and $k_{2N} \in [1.5279,2.8818]$.

Table 3: Comparison of proposed control chart with neutrosophic Shewhart control chart.

Existing	Proposed	Existing	Proposed	Existing	Proposed
[200, 200]	[200, 200.01]	[300, 300]	[300.01, 300]	[370.01, 370.01]	[370, 370]
[89.86, 101.98]	[80.02, 86.99]	[128.26, 146.33]	[101.62, 111.28]	[154.21, 176.4]	[138.84, 149.4]
[47.25, 58.86]	[37.51, 43.40]	[64.73, 81.41]	[41.19, 48.86]	[76.20, 96.30]	[61.11, 71.14]
[27.98, 37.33]	[19.92, 24.14]	[37.02, 50.05]	[19.33, 24.49]	[42.82, 58.27]	[30.54, 38.39]
[18.15, 25.47]	[11.71, 14.68]	[23.32, 33.26]	[10.28, 13.69]	[26.57, 38.20]	[16.95, 22.84]
[12.64, 18.42]	[7.50, 9.62]	[15.84, 23.51]	[6.11, 8.40]	[17.82, 26.68]	[10.29, 14.70]
[9.32, 13.95]	[5.18, 6.72]	[11.43, 17.45]	[4.01, 5.58]	[12.72, 19.61]	[6.75, 10.1]
[7.2, 10.97]	[3.81, 4.96]	[8.66, 13.49]	[2.88, 3.99]	[9.54, 15.02]	[4.75, 7.32]
[5.77, 8.90]	[2.97, 3.85]	[6.83, 10.77]	[2.23, 3.03]	[7.46, 11.90]	[3.55, 5.56]
[4.77, 7.41]	[2.42, 3.11]	[5.56, 8.85]	[1.84, 2.43]	[6.03, 9.70]	[2.80, 4.39]
[4.04, 6.30]	[2.05, 2.60]	[4.65, 7.43]	[1.59, 2.03]	[5.01, 8.10]	[2.31, 3.58]
[2.92, 4.53]	[1.55, 1.88]	[3.27, 5.21]	[1.28, 1.51]	[3.47, 5.61]	[1.66, 2.44]
[2.30, 3.52]	[1.32, 1.54]	[2.53, 3.97]	[1.15, 1.29]	[2.66, 4.23]	[1.37, 1.88]
[1.88, 2.80]	[1.18, 1.33]	[2.02, 3.10]	[1.08, 1.16]	[2.10, 3.27]	[1.21, 1.53]
[1.69, 2.48]	[1.13, 1.25]	[1.81, 2.72]	[1.06, 1.11]	[1.87, 2.85]	[1.15, 1.39]
[1.27, 1.69]	[1.03, 1.08]	[1.31, 1.79]	[1.01, 1.03]	[1.33, 1.85]	[1.04, 1.12]

patients are selected from [8] and shown in Table 4. From the UTIs' data, it is clear that the data is presented in the interval. Therefore, the existing control chart proposed by [71] cannot apply for the monitoring of UTIs patients. The hospital management can apply the proposed control chart for tracking UTIs patients. Suppose that $\mathrm{ARL}_{0N} \in [370,370]$, $a_N \in [7.6666,7.7777], b_N \in [1.0959,1.1559]$, and $n_N \in [50,50]$. The control limit coefficients are $k_{1N} \in [3.3590,3.7703]$ and $k_{2N} \in [0.1637,2.0479]$. Figure 3 shows the proposed control chart for UTIs patients. From Figure 3, it can be seen that two points are outside the upper control limits. Aslam et al. [8] presented a control chart for UTIs data. The neutrosophic control chart proposed by Aslam et al. [8] shows that all points are within the control limits. In addition, it can be noted from the proposed chart that several points are within the indeterminacy interval and between repetitive areas. It means that the hospital management can be indeterminate about the several observations in the UTIs data and need to repeat the process from those observations in the repetitive areas. By comparing the proposed UTIs chart with the UTIs chart proposed by Aslam et al. [8], it can be concluded that the proposed control chart clearly indicates some issues in tracking the UTIs' patient, and therefore, the hospital management should take action to bring back the process to in-control state. The proposed control chart can be applied to any other data in the same way.

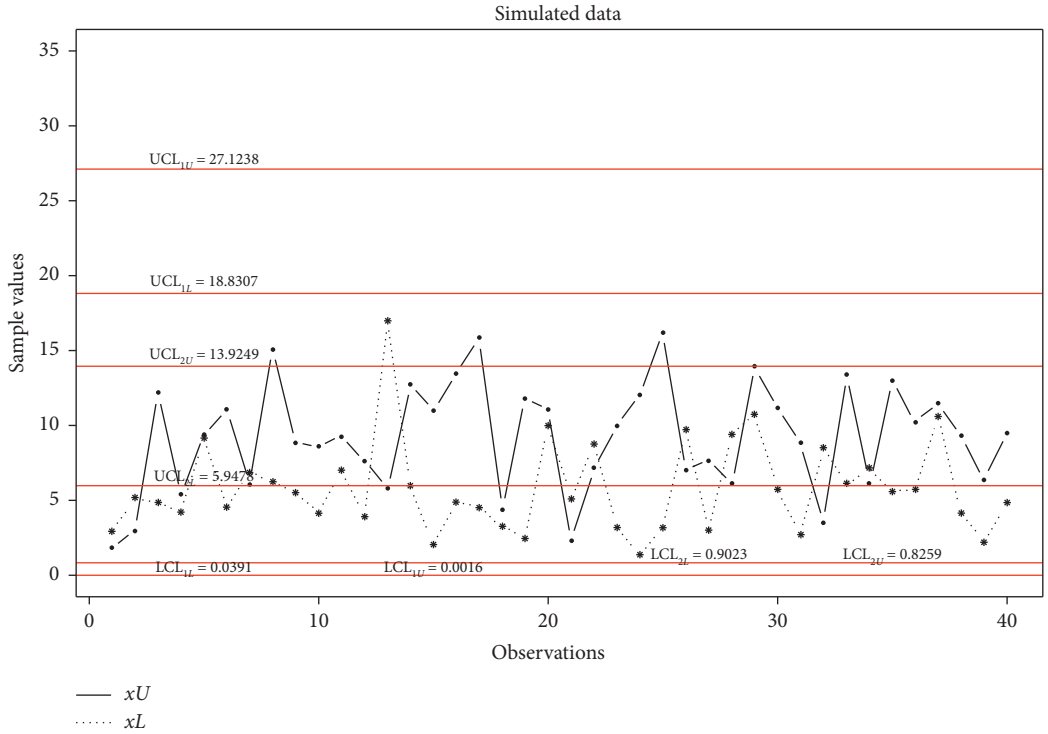

Figure 2: The existing control chart for simulated data when $a_N \in [3,5], b_N \in [1.9,2.1], n_N \in [20,20], k_{1N} \in [4.5948,5.2333]$, and $k_{2N} \in [1.5279,2.8818]$.

Table 4: The neutrosophic UTIs' data.

Sr#	T_N	T_N^*
1	[13.13, 13.56]	[2.35, 2.38]
2	[3.57, 15.55]	[1.52, 2.49]
3	[4.31, 16.50]	[1.62, 2.54]
4	[2.76, 25.53]	[1.40, 2.94]
5	[7.75, 15.38]	[1.97, 2.48]
6	[11.45, 13.18]	[2.25, 2.36]
7	[9.20, 15.18]	[2.09, 2.47]
8	[5.51, 9.77]	[1.76, 2.13]
9	[8.18, 13.07]	[2.01, 2.35]
10	[7.07, 19.91]	[1.91, 2.71]
11	[7.35, 14.89]	[1.94, 2.46]
12	[5.62, 11.09]	[1.77, 2.23]
13	[8.38, 16.72]	[2.03, 2.55]
14	[9.49, 10.06]	[2.11, 2.15]
15	[4.90, 23.67]	[1.69, 2.87]
16	[4.45, 14.68]	[1.64, 2.44]
17	[7.11, 16.44]	[1.92, 2.54]
18	[9.37, 15.95]	[2.10, 2.51]
19	[12.00, 16.38]	[2.28, 2.53]
20	[7.41, 16.62]	[1.95, 2.55]
21	[10.64, 15.15]	[2.19, 2.47]
22	[6.63, 11.21]	[1.87, 2.23]
23	[2.87, 14.27]	[1.42, 2.42]
24	[6.87, 10.37]	[1.90, 2.18]
25	[6.16, 18.85]	[1.83, 2.66]
26	[6.53, 12.47]	[1.87, 2.31]
27	[6.85, 12.13]	[1.89, 2.29]
28	[8.08, 22.69]	[2.00, 2.83]
29	[11.61, 17.14]	[2.26, 2.57]

Table 4: Continued.

Sr#	T_N	T_N^*
30	[3.98, 17.16]	[1.58, 2.57]
31	[6.81, 17.25]	[1.89, 2.58]
32	[4.42, 12.53]	[1.64, 2.32]
33	[6.53, 13.96]	[1.86, 2.40]
34	[8.73, 9.30]	[2.05, 2.10]
35	[5.37, 9.43]	[1.75, 2.11]
36	[8.44, 6.35]	[2.03, 1.85]
37	[11.79, 17.01]	[2.27, 2.57]
38	[5.33, 14.90]	[1.74, 2.46]
39	[4.20, 21.20]	[1.61, 2.76]
40	[5.74, 11.95]	[1.79, 2.28]
41	[5.24, 11.09]	[1.73, 2.23]
42	[5.10, 10.10]	[1.72, 2.16]
43	[9.11, 24.54]	[2.08, 2.90]
44	[8.39, 10.21]	[2.03, 2.16]
45	[5.33, 18.03]	[1.74, 2.62]
46	[7.90, 11.43]	[1.99, 2.25]
47	[3.62, 13.00]	[1.53, 2.35]
48	[5.01, 13.62]	[1.71, 2.38]
49	[4.09, 12.88]	[1.60, 2.34]
50	[9.38, 17.45]	[2.10, 2.59]

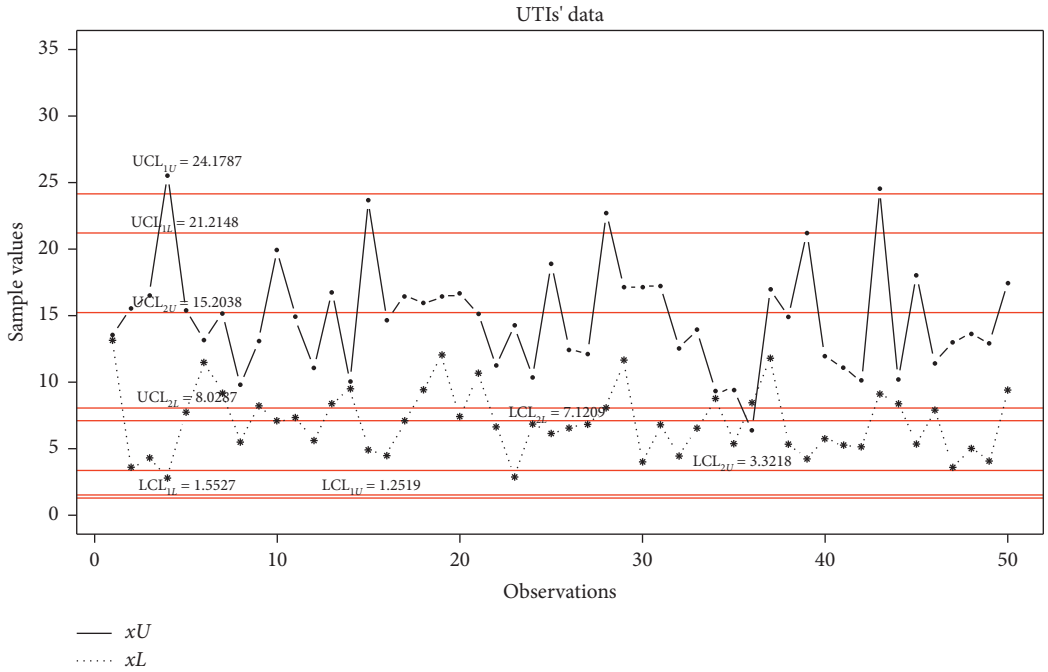

Figure 3: The proposed control chart for UTIs' patients.

6. Concluding Remarks

In this article, we presented the control chart using repetitive sampling under neutrosophic statistics when the data follow the gamma distribution. We presented some necessary measures to evaluate the proposed control chart. A simulation study and real example from the healthcare were included to show the efficiency of the proposed control chart over the existing control chart. From the study, it is observed that the proposed chart is an efficient addition in the tool kit of the quality control personnel. The proposed scheme can be extended for the multivariate case as future research. The proposed control using some other transformation for nonnormal distribution and different datasets can be considered as future research. The proposed chart using the cost model can be studied as future research. The proposed

control chart for monitoring imbalanced data can be considered as future research.

Data Availability

The data use to support the findings of the study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest regarding this paper.

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