Research Article

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Time truncated control chart using log logistic distribution

Abstract

In this article, a log logistic distribution considered to develop an attribute control chart for time truncated life tests with known or unknown shape parameter. The performance of the proposed chart is evaluated in terms of average run length (ARL) using the Monte Carlo simulation. The extensive tables are provided for the industrial use for various values of shape parameter, sample size, specified ARL and shift constants. The advantages of the proposed control chart are discussed over the existing truncated life test control charts. The performance of the proposed control chart is also studied using the simulated data sets for industrial purpose.

Keywords: Log logistic distribution, attribute control chart, truncated life test, average run length, simulation

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Introduction

Control charts are considered as important tools when producer wants to produce goods or services of high–quality. These charts help producers to manufacture products based on specified limits by monitoring the quality beforehand.[1] There are a number of control charts developed to monitor production process in different situations. One of the major characteristics of many control charts is that the production process should follow normal distribution. Ouyang et al.[2] and Pearn and Wu[3] they mentioned efficiency of process capability (PC) based on the production process which follows normally distributed processes. According to Aslam and Jun[1] there are also other control charts which are developed based on non–normal distributions which are being used when the production process follows other distributions rather than normal. Rao[4] developed a control chart for time truncated life tests using exponentiated half logistic distribution and Rao et al.[5] constructed attribute control charts for the Dagum distribution under truncated life tests.

If a quality characteristics of the production process does not follow normal distribution and the experimenter developed a control chart based on the assumption that it follows normal distribution, it will led to a wrong result. A number of non–normal control chart have being developed by Al–Oraini and Rahim.,[6]; Amin et al.,[7]; Lin and Chou., [8]; McCracken and Chakraborti,[9]; Ahmad et al.,[10]). On the other hand control charts are divided into variables or measurements and attributes.[11] Control charts for variables monitor characteristics that can be measured and have a continuous scale whereas control charts for attributes are used to measure quality characteristics that are counted rather than measured, such as a fraction defective or nonconformities per unit of product.

One among control charts for attributes include *np* chart based on the study conducted by Rodrigues et al.[12] and Epprecht et al.[13] considered usual Shewhart *np* control charts are used for monitoring the number of non–conforming products rather than proportion as in p–charts. Several authors have conducted studies on how control charts for attributes are being used in several situations such as Epprecht et al.,[13] Costa and Rahim,[14] Hsu[15,16], Wu et al.,[17] Wu and Wang[18] and Barbosa and Joekes.[19] In a study conducted by Kantam and Rosaiah[20] suggested sampling plan on life tests while the failure density model is half logistic distribution. Furthermore Kantam et al.[21] considered acceptance sampling mainly on life tests while the failure density model of the products was a log–logistic distribution. It is also noted that Kantam et al.[22] studied an economic reliability test plan using log–logistic distribution.

Based on the literature review made, it is noted that there is no study on log–logistic distribution based on truncated life tests. In this study we have developed attribute control chart of log–logistic distribution by incorporating the truncated life test.

Design of the control chart

Assume the failure time of a product follows a log logistic distribution in which its cumulative distribution function (cdf) is

$$F(t,\sigma,\beta)=\frac{(t/\sigma)^{\beta}}{1+(t/\sigma)^{\beta}} \quad ;t\geq 0,\ \sigma>0,\ \beta>1 \qquad (1)$$

whereas the pdf is given by

$$f(t;\sigma,\beta)=\frac{\beta}{\sigma}\frac{(t/\sigma)^{\beta-1}}{\left[1+(t/\sigma)^{\beta}\right]^{2}} \quad ;t>0,\ \sigma>0,\ \beta>1 \qquad (2)$$

where β is the shape parameter. The mean life of a product for a log–logistic distribution is given as:

$$\mu=\sigma\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right). \qquad (3)$$

Let μ_0 be the center mean life when the production process is in control. The aim is to design a control chart for monitoring shift from center line by counting the number of failed items in a specified truncated time t_0. The probability that a product fails by time t_0 is given by

$$p=\frac{(t_0/\sigma)^{\beta}}{1+(t_0/\sigma)^{\beta}}_{0} \qquad (4)$$

By specifying the truncation time t_0 using a multiple in–control process mean in the cause of $t_0 = a\mu_0$ where a is constant (termed as a truncated time constant) then the equation (4) above can be rewritten as

$$p_0 = \frac{(a\eta_0)^{\beta_0}}{1+(a\eta_0)^{\beta_0}}. \quad (5)$$

where $\mu_0 = \sigma_0\eta_0$ and hence $\sigma_0 = \mu_0/\eta_0$ with

$$\eta_0 = \Gamma\left(1+\frac{1}{\beta_0}\right)\Gamma\left(1-\frac{1}{\beta_0}\right).$$

We have therefore proposed *np* control chart for a log–logistic distribution based on the number of failed items for each subgroup:

Step 1: Taking a sample of size n from a certain production process. If we count the number of failures by considering the specified time $t_0 = a\mu_0$ whereby a is a constant and μ_0 is the target mean when the production process is in control.

Step 2: Conclude the process is out of control when $D > UCL$ or $D < LCL$ and the production process said to in control when $LCL \le D \le UCL$.

It should be noted that the above chart is np chart because number of failures has being used instead of proportion of failures. When the production process is in control the random variable D follows a binomial distribution with parameters n and p_0. Thus the upper and lower control limits for the suggested np chart will be:

$$UCL = np_0 + L\sqrt{np_0(1-p_0)} \quad (6a)$$

$$LCL = \max\left[0, np_0 - L\sqrt{np_0(1-p_0)}\right] \quad (6b)$$

Where L is the control constant or coefficient of the control limits to be determined. The probability p_0 should be estimated when the process is in control from a preliminary sample, since its unknown. Thus, the UCL and LCL limits to be used in practice will be:

$$UCL = \overline{D} + L\sqrt{\overline{D}\left(1-\overline{D}/n\right)} \quad (7a)$$

$$LCL = \max\left[0, \overline{D} - L\sqrt{\overline{D}\left(1-\overline{D}/n\right)}\right] \quad (7b)$$

Where $\overline{D}$ is the average number of failures in a batch or lot over a preliminary sample.

It should be noted that in this study we have considered control limits in the form of equation [6a&6b]. The aim is to investigate of the new control chart proposed by using average run length. The proportion that production process is declared to be in control when in fact it is real in control is given by

$$P_{in}^0 = P\left(LCL \le D \le UCL \mid p_0\right)$$

$$= \sum_{d=LCL+1}^{UCL} \binom{n}{d} P_0^d (1-P_0)^{n-d}$$

$$= \sum_{d=[LCL]+1}^{[UCL]} \binom{n}{d} \left(\frac{(a\eta_0)^{\beta_0}}{1+(a\eta_0)^{\beta_0}}\right)^d \left\{1-\frac{(a\eta_0)^{\beta_0}}{1+(a\eta_0)^{\beta_0}}\right\}^{n-d} \quad (8)$$

During evaluation of the sum above it should be noted that the value of d should be 0 if $LCL = 0$. Average run length (ARL) is usually used to evaluate the performance of the control chart. When the process is in control ARL is always given by

$$ARL_0 = \frac{1}{1-P_{in}^0}. \quad (9)$$

ARL when scale parameter is shifted

The process is declared to be out–of–control when the process is shifted to a new scale parameter $\sigma_1 = c\sigma_0$, where *c* is a shift constant. In this case, the probability that an item is failed before the experiment time t_0 denoted by p_1, is obtained by

$$p_1 = F(t_0;\beta_0,\sigma_1) = \left(\frac{(t_0/\sigma_1)^{\beta_0}}{1+(t_0/\sigma_1)^{\beta_0}}\right) = \left(\frac{(a\eta_0/c)^{\beta_0}}{1+(a\eta_0/c)^{\beta_0}}\right). \quad (10)$$

It should be noted that mean μ_0 corresponds to the probability p_0 while when the process is out of control mean μ_1 corresponds to the probability p_1. Therefore the probability that, the process is said to be in control when the mean has shifted to μ_1 is given by

$$P_{in}^1 = \left(LCL \le D \le UCL \mid p_1\right)$$

$$= \sum_{d=LCL+1}^{UCL} \binom{n}{d} P_1^d (1-p_1)^{n-d}$$

$$\sum_{d=[LCL]+1}^{[UCL]} \binom{n}{d} \left(\frac{(a\eta_0/c)^{\beta_0}}{1+(a\eta_0/c)^{\beta_0}}\right)^d \left\{1-\frac{(a\eta_0/c)^{\beta_0}}{1+(a\eta_0/c)^{\beta_0}}\right\}^{n-d} \quad (11)$$

and when the process is out of control ARL is given by

$$ARL_1 = \frac{1}{1-P_{in}^1}. \quad (12)$$

We used the following algorithm to complete the tables for the proposed control chart.

Specify the values of ARL, say r_0 and shape parameters β_0.

Determine the values of control chart parameters and sample size *n* for which the ARL_0 from Equation (9) is close to r_0.

Use the values of control chart parameters obtained in step 2 to find ARL_1 according to shift constant *c* using Equation (12).

We determined the control chart parameters and ARL_1 for various values of β_0, r_0 and *n* and placed in Tables 1–4.

From these tables, we note that a rapidly decreasing trend in ARLs as the shift constant decreases. Same is observed for various parametric combinations that we considered in this article.

ARL when shape parameter is shifted

In this section, we will present the designing of the proposed chart when the shape is shifted due to some extraneous factors. Let us assume that the shape parameter is shifted to $\beta_1 = f\beta_0$ for a shift constant f. In this case, the probability that an item is failed before the experiment time t_0, denoted by p_2, is obtained by

Table 1 ARLs for the proposed chart for r_0=200 when scale parameter is shifted

β_0	1.5	2	2.5	3
n	25	25	26	26
LCL	9	9	5	7
UCL	22	22	19	21
a	0.6296	0.8727	0.7238	0.8845
L	2.8072	2.8175	2.8582	2.8815
c	ARL1	ARL1	ARL1	ARL1
1.00	200.01	200.05	200.03	200.03
0.95	188.09	174.69	157.04	174.87
0.90	140.55	109.30	73.46	72.63
0.85	92.64	61.31	31.91	28.49
0.80	58.48	34.27	14.69	12.34
0.75	36.71	19.69	7.37	6.04
0.70	23.26	11.75	4.09	3.37
0.65	14.97	7.31	2.52	2.14
0.60	9.83	4.76	1.74	1.54
0.55	6.61	3.26	1.34	1.24
0.50	4.56	2.36	1.14	1.10
0.40	2.40	1.45	1.01	1.01
0.30	1.48	1.12	1.00	1.00
0.20	1.11	1.02	1.00	1.00
0.10	1.01	1.00	1.00	1.00

Table 2 ARLs for the proposed chart for r_0=250 when scale parameter is shifted

β_0	1.5	2	2.5	3
n	23	25	23	25
LCL	7	4	2	4
UCL	20	18	15	18
a	0.5723	0.5732	0.6126	0.7711
L	2.8991	2.8934	2.8183	2.8923
c	ARL1	ARL1	ARL1	ARL1
1.00	250.01	250.05	250.04	250.03
0.95	235.18	221.78	196.08	176.32
0.90	175.36	128.02	94.33	67.43
0.85	114.89	63.86	41.05	25.45
0.80	71.86	31.74	18.57	10.70
0.75	44.60	16.38	9.04	5.14
0.70	27.90	8.91	4.82	2.85
0.65	17.70	5.16	2.85	1.83
0.60	11.43	3.21	1.88	1.35
0.55	7.55	2.17	1.40	1.14
0.50	5.12	1.59	1.16	1.04
0.40	2.59	1.12	1.01	1.00
0.30	1.55	1.01	1.00	1.00
0.20	1.13	1.00	1.00	1.00
0.10	1.01	1.00	1.00	1.00

Table 3 ARLs for the proposed chart for r_0=300 when scale parameter is shifted

β_0	1.5	2	2.5	3
n	28	24	27	24
LCL	8	4	6	4
UCL	23	18	21	18
a	0.5222	0.5979	0.7655	0.7931
L	2.9063	2.9645	2.9613	2.9635
c	ARL1	ARL1	ARL1	ARL1
1.00	300.00	300.04	300.02	300.02
0.95	228.91	268.57	281.24	214.41
0.90	144.20	156.30	131.34	82.71
0.85	84.94	78.36	53.82	31.28
0.80	49.58	39.02	23.25	13.08
0.75	29.27	20.10	10.95	6.19
0.70	17.64	10.86	5.69	3.35
0.65	10.90	6.22	3.29	2.09
0.60	6.94	3.81	2.13	1.49
0.55	4.58	2.51	1.54	1.20
0.50	3.15	1.79	1.24	1.07
0.40	1.73	1.18	1.03	1.00
0.30	1.19	1.02	1.00	1.00
0.20	1.02	1.00	1.00	1.00
0.10	1.00	1.00	1.00	1.00

Table 4 ARLs for the proposed chart for r_0=370 when scale parameter is shifted

β_0	1.5	2	2.5	3
n	13	30	17	23
LCL	2	5	0	5
UCL	12	21	11	19
a	0.5651	0.5603	0.552	0.8671
L	2.8593	2.9793	2.9876	2.9981
c	ARL1	ARL1	ARL1	ARL1
1.00	370.03	370.05	370.00	370.05
0.95	314.20	323.07	316.82	329.65
0.90	240.56	166.74	175.21	136.60
0.85	173.40	74.71	82.38	52.22
0.80	121.40	33.99	38.34	21.69
0.75	83.98	16.31	18.53	10.02
0.70	57.90	8.37	9.48	5.20
0.65	39.94	4.66	5.21	3.04
0.60	27.64	2.84	3.11	2.01
0.55	19.22	1.91	2.05	1.49
0.40	6.76	1.06	1.08	1.03
0.30	3.57	1.00	1.00	1.00
0.20	2.03	1.00	1.00	1.00
0.10	1.29	1.00	1.00	1.00
0.50	13.45	1.43	1.50	1.22

$$p_2 = F(t_0;\beta_1,\sigma_0) = \left(\frac{(t_0/\sigma_0)^{\beta_1}}{1+(t_0/\sigma_0)^{\beta_1}}\right) = \left(\frac{(a\eta_1)^{\beta_1}}{1+(a\eta_1)^{\beta_1}}\right) \quad (13)$$

where $\eta_1 = \Gamma\left(1+\frac{1}{\beta_1}\right)\Gamma\left(1-\frac{1}{\beta_1}\right)$.

The probability of in control for the shifted process is given as follows:

$$P_{in}^2 = P\left(LCL \le D \le UCL \mid p_2\right) = \sum_{d=[LCL]+1}^{[UCL]} \binom{n}{d} \left(\frac{(a\eta_1)^{\beta_1}}{1+(a\eta_1)^{\beta_1}}\right)^d \left\{1-\frac{(a\eta_1)^{\beta_1}}{1+(a\eta_1)^{\beta_1}}\right\}^{n-d} \quad (14)$$

The efficiency of the control chart is measured using the ARL. The ARL for the shifted process is given as follows:

$$ARL_2 = \frac{1}{1-p_{in}^2} \quad (15)$$

We determined the control chart parameters and ARL_2 for various values of β_0, r_0 and n and placed in Tables 5–8.

From these tables, we noticed that the decreasing trend in ARLs as the shift constant f increases. We observed the same trend for other combination of parameters we considered.

Table 5 ARLs for the proposed chart for r_0=300 when shape parameter is shifted when β_0 =2

n	36	21	26	17	18
LCL	12	5	9	5	6
UCL	29	18	23	16	17
a	0.7633	0.7253	0.8466	0.8787	0.9422
L	2.971	3.02	3.017	2.987	2.866
f	ARL1	ARL1	ARL1	ARL1	ARL1
1.0	300.05	300.03	300.05	300.02	300.00
1.1	144.00	148.18	153.29	171.87	200.53
1.2	53.97	59.03	75.19	99.86	127.77
1.3	24.26	30.12	41.38	62.82	85.67
1.4	12.83	17.33	25.26	42.47	60.98
1.5	7.69	10.95	16.72	30.41	45.65
1.6	5.08	7.45	11.79	22.78	35.59
1.7	3.63	5.38	8.74	17.69	28.65
1.8	2.76	4.09	6.74	14.14	23.68
1.9	2.21	3.24	5.38	11.57	19.98
2.0	1.85	2.66	4.41	9.67	17.16
2.5	1.16	1.44	2.20	4.84	9.58
3.0	1.02	1.12	1.49	3.04	6.38
3.5	1.00	1.03	1.21	2.18	4.70

Table 6 ARLs for the proposed chart for r_0=300 when shape parameter is shifted when β_0 =3

n	31	24	24	35	18
LCL	1	1	4	10	3
UCL	15	14	18	27	15
a	0.5878	0.6459	0.8092	0.8872	0.8771
L	2.9290	2.8670	3.0190	2.9440	2.9370
f	ARL1	ARL1	ARL1	ARL1	ARL1
1.0	300.02	300.02	300.03	300.02	300.02
1.1	242.63	247.56	252.66	257.17	294.45
1.2	85.33	106.27	143.13	154.28	223.16
1.3	34.59	48.32	78.67	89.34	154.51
1.4	16.71	24.92	45.88	54.44	106.55
1.5	9.31	14.34	28.55	35.18	75.23
1.6	5.82	9.04	18.82	23.94	54.66
1.7	3.99	6.14	13.04	17.03	40.82
1.8	2.96	4.45	9.42	12.57	31.24
1.9	2.33	3.40	7.07	9.58	24.43
2.0	1.92	2.72	5.48	7.51	19.48
2.5	1.18	1.41	2.25	3.05	7.83
3.0	1.04	1.12	1.42	1.79	4.11
3.5	1.01	1.03	1.14	1.32	2.59

Table 7 ARLs for the proposed chart for r_0=370 when shape parameter is shifted when β_0 =2

n	17	20	24	22	17
LCL	0	4	8	8	6
UCL	11	17	22	21	17
a	0.4291	0.6909	0.8438	0.9213	0.9867
L	3.4100	3.0580	3.0960	3.1400	3.1020
f	ARL1	ARL1	ARL1	ARL1	ARL1
1.0	370.00	370.05	370.01	370.03	370.04

Table Continued...

1.1	157.05	157.01	157.87	178.64	202.24
1.2	59.85	66.56	76.70	98.85	127.82
1.3	27.73	32.80	42.70	61.36	89.08
1.4	15.06	18.34	26.37	41.48	66.52
1.5	9.23	11.32	17.61	29.88	52.26
1.6	6.22	7.57	12.50	22.59	42.65
1.7	4.51	5.39	9.30	17.73	35.85
1.8	3.48	4.05	7.20	14.34	30.85
1.9	2.80	3.18	5.75	11.88	27.05
2.0	2.35	2.60	4.72	10.05	24.08
2.5	1.41	1.40	2.34	5.32	15.72
3.0	1.15	1.11	1.57	3.47	11.91
3.5	1.06	1.03	1.25	2.55	9.75

Table 8 ARLs for the proposed chart for r_0=370 when shape parameter is shifted when β_0 =3

n	42	30	29	34	35
LCL	3	5	7	10	12
UCL	20	21	23	27	29
a	0.5997	0.7595	0.8493	0.8982	0.9521
L	2.966	2.979	3.002	3.077	3.061
f	ARL1	ARL1	ARL1	ARL1	ARL1
1.0	370.03	370.04	370.01	370.04	370.03
1.1	183.21	184.26	194.68	261.96	275.94
1.2	52.23	78.73	100.45	151.78	182.43
1.3	19.26	37.66	56.16	89.61	122.16
1.4	8.90	20.24	33.98	56.15	85.37
1.5	4.93	11.99	21.96	37.24	62.27
1.6	3.14	7.71	14.99	25.93	47.12
1.7	2.24	5.31	10.72	18.80	36.76
1.8	1.75	3.88	7.97	14.10	29.42
1.9	1.46	2.99	6.13	10.89	24.05
2.0	1.29	2.40	4.86	8.63	20.01
2.5	1.02	1.28	2.14	3.58	9.67
3.0	1.00	1.05	1.39	2.06	5.74
3.5	1.00	1.01	1.13	1.47	3.85

Industrial application of proposed chart

The industrial application of the proposed control chart can be implemented as follows: Presume that the lifetime of an electronic equipment follows the log logistic distribution with shape parameter β_0=3. Assume that the target average life of electronic equipment is μ_0 = 1000 hours and r_0= 370. Then from Equation (5) we have p_0 = 0.5355. Also, from Table 4 we obtain the sample size of n = 23, a = 0.8671, L = 2.9981, LCL = 5 and UCL = 19. Thus the inspection time t_0=867 hours. Therefore, the proposed control chart works as follows:

Step 1. Take a sample of size 23 at each subgroup and put them on the life test during 867 hours. Plot the number of failed items (D) during the test.

Step 2. Declare the process as in–control if $5\leq D \leq 19$ otherwise process as out–of–control.

Simulation study

To demonstrate the performance of the proposed control chart methodology, the following steps depicts the generation of data using simulation from log logistic distribution and constructing the control chart:

Step 1: Choose a subgroup sample size *n*.

Step 2: Generate log logistic random variable X of size n with scale parameter σ =1, shape parameters $\beta_0 = 2$.

Step 3: Obtain the chart statistic, the number of failures D for each subgroup.

Step 4: Repeat step 1 to step 3 until desired number of sample groups (m=20) are attained.

Step 5: Construct the control limits for the proposed chart.

Step 6: Plot all statistics D against their sample groups.

For this design, the first 20 samples of subgroup size 24 are generated from log logistic distribution with in–control parameters σ =1, $\beta_0 = 2$ and the second set of the 20 samples of subgroup size 24 are from log logistic distribution with parameters σ =0.75, $\beta_0 = 2$ (i.e. out–of–control situation having a shift of c=0.75). From Table 3, when ARL at 300 and in–control parameters we find control chart coefficient L is 2.9645, a is 0.5979 and n is 24. The life test termination time be t_0=0.5979x0.46868=0.2802.

The values of D for in–control and shifted cases for each subgroup are reported as follows:

In–control: 2, 1, 1, 3, 2, 2, 1, 1, 2, 1, 2, 3, 1, 2, 3, 1, 2, 1, 3, 2.

Shifted : 2, 2, 3, 2, 4, 6, 1, 2, 3, 5, 5, 3, 3, 2, 1, 3, 7, 2, 3, 2.

The average of failure $\bar{D}$ is 1.6, using Eq. (7) the control limits for the proposed control chart is found as UCL=5.2227 and LCL=0. Figure 1 is the proposed control chart based on simulated data, along with chart statistics and control limits, can detect an out–of–control process after 26 samples, i.e. after the 6th sample of the shifted process as ARL_1 is estimated to be 20.1 for a shift of 0.75. Thus the proposed chart efficiently detects the shift in the process.

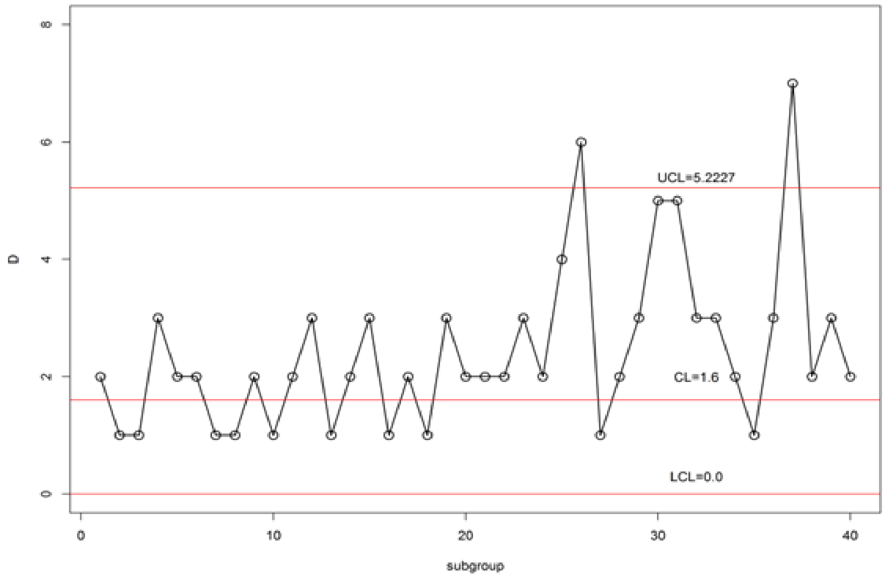

Figure 1 The proposed control chart for simulated data.

Conclusion

This paper proposed a new *np* control chart assuming that the lifetime of the manufactured goods follows to log logistic distribution. The chart constants and extensive tables are given for the industrial use. Through simulated data the methodology has explained. We notice the decreasing trend in ARLs values as the shift constant increases. The recommended control chart can be used in the electronic appliances industries for mentoring of non–conforming products. The proposed control chart can be extended for some other non normal distributions as a future research.

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Conflicts of interest

No potential conflict of interest was reported by the authors.

References

1. Aslam, M, Jun CH. Attribute control charts for the weibull distribution under truncated life tests. *Quality Engineering*. 2015;27(3):283–288.
2. Ouyang L–Y, Hsu C–H, Yang C–M. A new process capability analysis chart approach on the chip resistor quality management. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 2013;227(7):1075–1082.
3. Pearn WL, Wu C. Production quality and yield assurance for processes with multiple independent characteristics. *European Journal of Operational Research*. 2005;173(2):637–647.
4. Rao GS. A control chart for time truncated life tests using exponentiated half logistic distribution. *Applied Mathematics & Information Sciences: An International Journal*. 2018;12(1):125–131.
5. Rao GS, Fulment AK, Josephat PK. Attribute control charts for the Dagum distribution under truncated life tests. *Life Cycle Reliability and Safety Engineering*. 2019;8(4):329–335.
6. Al–Oraini HA, Rahim MA. Economic statistical design of control charts X for systems with gamma (λ, 2) in–control times. *Journal of Applied Statistics*. 2003;30:397–409.
7. Amin R, Reynolds Jr. MR, Bakir ST. Nonparametric quality control charts based on the sign statistic. *Communications in Statistics*. 1995;24(6):1597–1623.
8. Lin YC, Chou CY. Non–normality and the variable parameters X bar control charts. *European Journal of Operational Research*. 2007;176:361–373.
9. McCracken AK, Chakraborti S. Control charts for joint monitoring of mean and variance: An overview. *Quality Technology and Quantitative Management.* 2013;10(1):17–36.
10. Ahmad S, Riaz M, Abbasi SA. et al. On efficient median control charting. *Journal of the Chinese Institute of Engineers.* 2014; 37(3):358–375.
11. Montgomery DC. *Introduction to Statistical Quality Control*, John Wiley & Sons, Sixth Edition. 2009.
12. Rodrigues AD, Epprecht EK, De Magalhaes MS. Double–sampling control charts for attributes. *Journal of Applied Statistics*. 2011;38(1):87–112.
13. Epprecht EK, Costa AFB, Mendes FCT. Adaptive control charts for attributes. *IIE Transactions*. 2003;35(6):567–582.
14. Costa AFB, Rahim MA. Joint X bar and R charts with two stage samplings. *Quality and Reliability Engineering International*. 2004; 20(7):699–708.
15. Hsu LF. Note on Design of Double– and Triple–Sampling Control Charts Using Genetic Algorithms. *International Journal Production Research*. 2004;42(5):1043–1047.
16. Hsu LF. Note on Construction of Double Sampling s–Control Charts for Agile Manufacturing. *Quality and Reliability Engineering International*. 2007;23(2):269–272.

17. Wu Z, Luo H, Zhang X. Optimal np control chart with curtailment. *European Journal of Operational Research*. 2006;174(3): 1723–1741.

18. Wu Z, Wang Q. An *np* control chart using double inspections. *Journal of Applied Statistics*. 2007;34(7):843–855.

19. Barbosa EP, Joekes S. An improved attribute control chart for monitoring non–conforming proportion in high quality processes. *Control Engineering Practice*. 2013;21(4):407–412.

20. Kantam RRL, Rosaiah K. Half logistic distribution in acceptance sampling based on life tests. *Indian Association for Productivity Quality & Reliability Transactions.* 1998;23(2):117–125.

21. Kantam, RRL, Rosaiah K, Rao GS. Acceptance sampling based on life tests: log–logistic model. *Journal of Applied Statistics.* 2001; 28(1):121–128.

22. Kantam RRL, Rao GS, Sriram B. An economic reliability test plan: Log–Logistic Distribution. *Journal of Applied Statistics*. 2006;33(3):291–296.