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A Two Stage Group Acceptance Sampling Plans Based on Truncated Life Tests Using Log-Logistic and Gamma Distributions

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Abstract

In this paper, a two stage group acceptance sampling plan is developed for a truncated life test when the lifetime of an item follows Log – Logistic and Gamma distributions. The minimum number of groups required for a given group size and the acceptance number is determined when the consumer's risk and the test termination time are specified. The operating characteristic values according to various quality levels are obtained. The results are explained with examples.

Keywords Gamma distribution; Log – Logistic distribution; Group acceptance sampling; consumer's risk; Operating characteristics; Producer's risk; truncated life test.

1. Introduction

Acceptance Sampling is a quality control method for determining the acceptability of a batch of manufactured product after it has been produced. In this context the term batch refers to a collection of manufactured product made within a specified time frame under like conditions. The producer of the manufactured product (the Producer) must assure the buyer (the Consumer) that the batch meets or exceeds the consumer's requirements. An individual unit of product (unit) which does not meet the consumer's requirements is considered non – conforming, otherwise it is considered to be a conforming unit. One measure of the quality of a batch is the fraction of non conforming units, expressed as a percentage. Since it is very difficult to eliminate all process variation, the fraction non – conforming will vary from one batch to the next. The consumer wants the fraction non – conforming to be controlled but is usually willing to assign a maximum allowable fraction non – conforming that they are willing to tolerate.

Acceptance sampling is a methodology commonly used in quality control and improvement. The aim is to make an inference about the quality of a batch/lot of product from a sample. Depending on what is found in the sample, the whole lot is then either accepted or rejected, and rejected lots can then be scrapped or reworked.

Understanding and improving quality is a key factor leading to business success, growth and an enhanced competitive position. There is a substantial return on investment from improved quality and from successfully employing quality as an integral part of overall business strategy. Thus a specific plan that states the sample size or sizes to be used and the associated acceptance and non-acceptance criteria is an acceptance sampling plan.

The quality of the product is tested on the basis of few items taken from an infinite lot. The statistical test can be stated as: Let μ be the true average life and $\mu 0$ be the specified average life of a product. Based on the failure data, we want to test the hypothesis H0: $\mu \geq \mu 0$ against H1: $\mu < \mu 0$. A lot is considered as good if $\mu \geq \mu 0$ and bad if $\mu < \mu 0$. This hypothesis is tested using the acceptance sampling scheme as: In a life test experiment, a sample of size n selected from a lot of products is put on the test. The experiment is terminated at a pre – assigned time t0. when we set acceptance number as c, H0 is rejected if more than c failures are recorded before time t0 and H0 is accepted if there are c or fewer failures before t0. Probability of rejection of good lot is called the producer's risk and probability of accepting a bad lot is known as consumer's risk. If the confidence level is p*, then the consumers risk will be $\beta = 1\text{-}p^*$. A well acceptance sampling plan minimizes both the risks.

Many authors have discussed acceptance sampling based on truncated life tests. Abbur Razzaque Mughal, Muhammad Hanif, Azhar Ali Imran, Muhammad Rafi and Munir Ahmad (2011) have studied economic reliability two – stage group sampling plan for truncated life test having Weibull distribution. Aslam M., and Jun C.H. (2009) have studied a group acceptance sampling plans for truncated life tests based on the inverse Rayleigh and log-logistic distributions. Aslam M., and Shahbaz M.Q. (2007) have studied economic reliability test plans using the generalized exponential distributions. Epstein B. (1954) has studied truncated life tests in the exponential case. Gupta S. S. and Groll P. A. (1961) have studied Gamma distribution in acceptance sampling based on life tests. Gupta R.D. and Kundu D. (2003) have studied closeness between the gamma and generalized exponential distributions. Gupta R.D. and Kundu D. (2004) again studied discriminating between gamma and the generalized exponential distributions.

Here we apply two – stage GASP on the truncated life tests when a lifetime of the product assumed to follow Log – Logistic and Gamma distributions. In this type of tests, determining the sample size is equivalent to determining the number of groups.

2. Lifetime Distributions

Log – Logistic distribution

The cumulative distribution function (cdf) of the Log – Logistic distribution is given by

$$F(t,\sigma) = \frac{\left(\frac{t}{\sigma}\right)^{\lambda}}{1+\left(\frac{t}{\sigma}\right)^{\lambda}}, \quad t > 0 \qquad (1)$$

where σ is a scale parameter and λ is the shape parameter and it is fixed as 2.

Gamma Distribution

The cumulative distribution function (cdf) of the Gamma distribution is given by

$$F(t,\sigma) = 1 - e^{-\frac{t}{\sigma}} \sum_{j=0}^{\gamma-1} \left(\frac{t}{\sigma}\right)^{j} / j! \qquad (2)$$

where σ is a scale parameter and γ is the shape parameter.

The failure probability of an item by time t_0 is given by

$$p = F\,(t_{0\,:}\,\sigma) \qquad (3)$$

The quality of an item is usually represented by its true mean lifetime although some other options such as median lifetime or B_{10} life are sometimes used. Let us assume that the true mean μ can be represented by the scale parameter. In addition, it is convenient to specify the test time as a multiple of the specified life so that $a\mu_0$ and the quality of an item as a ratio of the true mean to the specified life (μ/μ_0).

Then we can rewrite (3) as a function of 'a' (termination time) and the ratio μ/μ_0.

$$p = F(a\,\mu_0 : \mu/\mu_0) \qquad (4)$$

Here when the underlying distribution is the Gamma distribution

$$p = 1 - e^{-\frac{a\gamma}{\mu/\mu_0}} \sum_{j=0}^{\gamma-1} \left(\frac{a\gamma}{\mu/\mu_0} \right)^j / j! \tag{5}$$

When the underlying distribution is the Log – Logistic distribution

$$p = \frac{(1.5708a)^2}{(\mu/\mu_0)^2 + (1.5708a)^2} \tag{6}$$

3 Design of the proposed sampling plan

The following two – stage group sampling plan having testers with the group size r,

1. (First stage) Draw the first random sample size n_1 from a lot, allocate r items to each of g_1 groups (or testers) so that $n_1 = rg_1$ and put them on test for the duration of t_0. Accept the lot if the number of failures from each group is c_1 or less. Truncate the test and reject the lot as soon as the number of failures in any group is larger than c_2 before t_0. Otherwise, go to the second stage.

2. (Second stage) Draw the second random sample of size n_2 from a lot, allocate r items to each of g_2 groups so that $n_2 = rg_2$ and put them on test for t_0. Accept the lot if the number of failures in each group is c_1 or less. Truncate the test and reject the lot if the number of failures in any group is larger than c_1 before t_0.

The two – stage economic reliability group sampling plan constitute the design parameters of g_1, g_2, c_1 and c_2 when the group size r and both risks are specified.

The probability of lot acceptance at the first stage can be evaluated as,

$$P_a^{\,1} = \left[\sum_{i=0}^{c_1} \binom{r}{i} p^i (1-p)^{r-i} \right]^{g_1} \tag{7}$$

The probability of lot rejection at the first stage is given by,

$$P_r^{\,1} = 1 - \left[\sum_{i=0}^{c_2} \binom{r}{i} p^i (1-p)^{r-i} \right]^{g_1} \tag{8}$$

where the probability of lot acceptance at the second stage is

$$P_a^{\,2} = \left[1 - (P_a^{\,1} + P_r^{\,1})\right] \left[\sum_{i=0}^{c_1} \binom{r}{i} p^i (1-p)^{r-i} \right]^{g_2} \tag{9}$$

Therefore, the probability of lot acceptance for the proposed two – stage economic reliability group sampling plan is given by

$$L(p) = P_a^{\,1} + P_a^{\,2} \tag{10}$$

Now here we used two – point approach for finding the design parameters of the proposed group sampling plan. Consider p_1, p_2 be the probability of failure corresponding to the consumer's and producer's risk respectively. Then, as minimum termination time for two stages and probability of lot acceptance satisfying the following two inequalities simultaneously.

$$L(p_1) = P_a^{\ 1} + P_a^{\ 2} \leq \beta$$

$$L(p_2) = P_a^{\ 1} + P_a^{\ 2} \geq 1-\alpha \qquad (11)$$

The plan parameters can be obtained from the solution of the following inequalities

$$L(p_1) = P_a^{\ 1} + P_a^{\ 2} \leq \beta$$

$$L(p_2) = P_a^{\ 1} + P_a^{\ 2} \geq 1-\alpha$$

$$1 \leq g_2 \leq g_1$$

$$0 \leq c_1 \leq c_2 \qquad (12)$$

The minimum number of groups required can be determined by considering the consumer's risk when the true median life equals the specified median life ($\mu = \mu_0$) (worst case) by means of the following inequality:

$$L(p_0) \leq \beta \qquad (13)$$

where p_0 is the failure probability at $\mu = \mu_0$. Here minimum group size (g) is obtained using (5) and (6) in (12) at worst case.

4 Operation Characteristic Functions

The probability of acceptance can be regarded as a function of the deviation of the specified value μ_0 of the median from its true value μ. This function is called Operating Characteristic (OC) function of the sampling plan. Once the minimum sample size is obtained, one may be interested to find the probability of acceptance of a lot when the quality (or reliability) of the product is sufficiently good. As mentioned earlier, the product is considered to be good if $\mu \geq \mu_0$. Te probabilities of acceptance are displayed in Table 3 and 4 for various values of the median ratios μ/μ_0, producer's risks β and time multiplier a.

5 Notations

g1	-	Number of groups in first stage
g2	-	Number of groups in second stage
r1	-	Number of items in a group in first stage
r2	-	Number of items in a group in second stage
n1	-	First sample size
n2	-	Second sample size
c1	-	Acceptance number of sample first
c2	-	Acceptance number of sample second
t_0	-	termination time
a	-	test termination time multiplier
σ	-	scale parameter
γ	-	shape parameter

β	-	consumer's risk
p	-	failure probability
L(p)	-	Probability of acceptance
μ	-	Mean life
μ_0	-	Specified life

6 Description of tables and examples

6.1 Example 1

Suppose that an electrical circuit producing company wants to test their product that if the mean is greater than 1,000 hours based on a testing time of 700 hours and using testers equipped with 3 items each. It is assumed that $c_1 = 0$ and $c_2 = 2$ and $\beta = 0.25$. Based on the consumer's risk values and the test termination time multiplier, the number of groups, g_1 and g_2 are determined using the two – stage group acceptance sampling plan for different lifetime distributions. Following are the results obtained when the lifetime of the test items follows the log – logistic distribution and the gamma distribution, respectively.

Log – Logistic distribution

Suppose that the lifetime of an item follows log – logistic distribution, then for the above condition, $g_1 = 1$ and $g_2 = 1$ from Table 5.5. We will implement the above sampling plan as, draw the first sample of size $n_1 = 3$ items ($n_1 = rg_1$), if no failure occur during 700 hours we accept the lot. The test is terminated and the lot is rejected if more than 2 failures occurs otherwise if 1 or 2 failures occurs, then we move on to the second stage, where the second sample of size $n_2 = 3$ ($n_2 = rg_2$) is chosen and tested. For the above conditions the probability of acceptance will be 0.694913.

Gamma distribution

Suppose that the lifetime of an item follows gamma distribution, then for the above condition, $g_1 = 2$ and $g_2 = 1$ from Table 5.6. We will implement the above sampling plan as, draw the first sample of size $n_1 = 6$ items ($n_1 = rg_1$), if no failure occur during 700 hours we accept the lot. The test is terminated and the lot is rejected if more than 2 failures occurs otherwise if 1 or 2 failures occurs, then we move on to the second stage, where the second sample of size $n_2 = 3$ ($n_2 = rg_2$) is chosen and tested. For the above conditions the probability of acceptance will be 0.741279.

Example 2

Consider the ordered failure times of the release of software given in terms of hours from the starting of the execution of the software denoting the times at which the failure of the software is experimented (A. Wood 1996). Let the required average lifetime be 1,000 hrs, testing time be 700 hrs, number of testers be 3 with $\beta = 0.25$ and acceptance numbers $c_1 = 0$ and $c_2 = 2$. Following are the results obtained when the lifetime of the test items follows the log – logistic distribution and the gamma distribution, respectively.

Log – logistic distribution

Suppose that the lifetime of an item follows log – logistic distribution, then for the above condition, $g_1 = 1$ and $g_2 = 1$ from Table 5.5. The following data can be regarded as an ordered sample of size $n_1 = 3$ items ($n_1 = rg_1$) with 1 group and 3 testers,

{xi : i = 1, 2, ……, 6} = {254, 788, 1054}

There should no failure before 700 hrs to accept the lot, but the above data shows a single failure before the time period. Thus the lot cannot be accepted. On the other hand, the lot cannot be rejected as there are not more than 2 failures. Thus the second data is considered. The following data can be regarded as an ordered sample of size $n_2 = 3$ ($n_2 = rg_2$) with 1 group and 3 testers,

{yi : i = 1, 2, ……, 6} = {384, 1186, 1471}

Based on the observations, we have to decide whether to accept the product or reject it. The lot will be accepted if no more than 2 failures occur before 700 hrs in the second group. From above data there is a failure in this group. Thus there are only less than or equal to 2 failures in the second group. Thus the lot can be accepted.

Gamma distribution

Suppose that the lifetime of an item follows gamma distribution, then for the above condition, $g_1 = 2$ and $g_2 = 1$ from Table 5.6. The following data can be regarded as an ordered sample of size $n_1 = 6$ items ($n_1 = rg_1$) with 2 group and 3 testers,

{xi : i = 1, 2, ……, 6} = {254, 788, 1054}

{yi : i = 1, 2, ……, 6} = {384, 1186, 1471}

There should be no failure before 700 hrs in each of the above groups to accept the lot, but the above data shows a single failure in before the time period. Thus the lot cannot be accepted. On the other hand, the lot cannot be rejected as there are not more than 2 failures. Thus the second data is considered. The following data can be regarded as an ordered sample of size $n_2 = 3$ ($n_2 = rg_2$) with 1 group and 3 testers,

{zi : i = 1, 2, ……, 4} = {384, 1186, 1471}

Based on the observations, we have to decide whether to accept the product or reject it. The lot will be accepted if no more than 2 failures occur before 700 hrs in the second group. From above data there is a failure in this group. Thus there are only less than or equal to 2 failures in the second group. Thus the lot can be accepted.

Both the life time distributions when compared gives more or less the same and better results. Here the minimum number of groups g_1 and g_2 are very less and the probability of acceptance is also higher. Both the distributions under two stage acceptance sampling plan is very profitable and provides more satisfaction for the producer. This is clearly shown using the following figure.

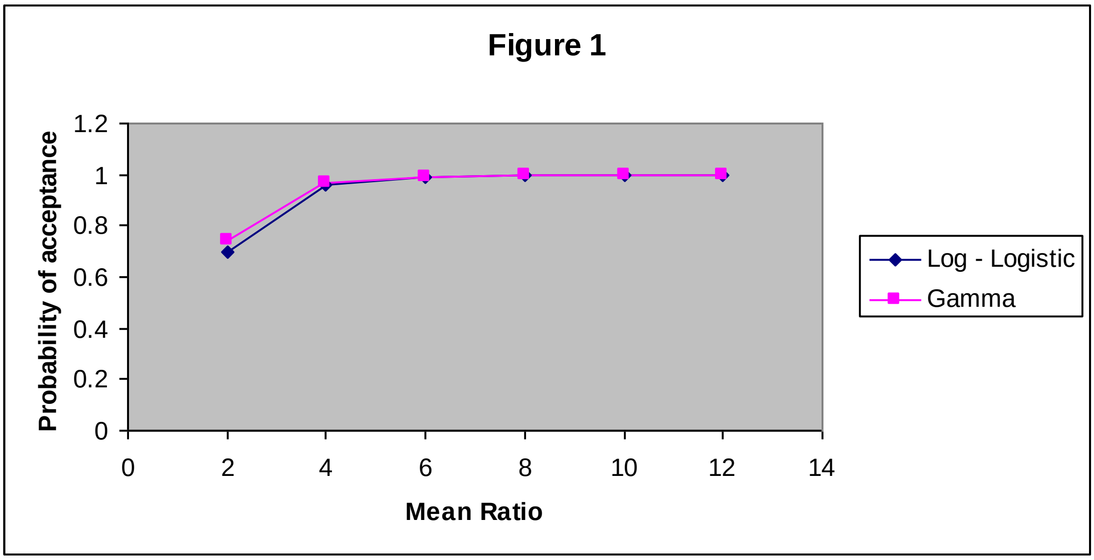

Figure 1: Operating Characteristic curve for the two – stage group sampling plan when the lifetime of an item follows log – logistic and gamma distributions with $c_1 = 0$ and $c_2 = 2$ and $a = 0.7$

Table 1: Minimum number of groups (g_1 and g_2) for the two – stage group sampling plan with $c_1 = 0$ and $c_2 = 2$ when the lifetime of the items follows the log – logistic distribution

β	r	a											
		0.7		0.8		1.0		1.2		1.5		2.0	
0.25	2	2	1	2	1	1	1	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	1	1	1
	4	1	1	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	1	1	1	1	1	1	1	1
	6	1	1	1	1	1	1	1	1	1	1	1	1
0.10	2	2	2	2	2	2	1	1	1	1	1	1	1
	3	2	1	1	1	1	1	1	1	1	1	1	1
	4	1	1	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	1	1	1	1	1	1	1	1
	6	1	1	1	1	1	1	1	1	1	1	1	1
0.05	2	3	3	2	2	2	2	2	2	1	1	1	1
	3	2	2	2	1	1	1	1	1	1	1	1	1
	4	2	1	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	1	1	1	1	1	1	1	1
	6	1	1	1	1	1	1	1	1	1	1	1	1
0.01	2	4	4	3	3	3	2	2	2	2	2	2	1
	3	3	2	2	2	2	2	2	1	1	1	1	1
	4	2	2	2	1	1	1	1	1	1	1	1	1
	5	2	1	2	1	1	1	1	1	1	1	1	1
	6	2	1	1	1	1	1	1	1	1	1	1	1

Table 2: Minimum number of groups (g_1 and g_2) for the two – stage group sampling plan with c_1 = 0 and c_2 = 2 when the lifetime of the items follows the gamma distribution

β	r	a											
		0.7		0.8		1.0		1.2		1.5		2.0	
0.25	2	3	2	2	2	2	1	1	1	1	1	1	1
	3	2	1	2	1	1	1	1	1	1	1	1	1
	4	1	1	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	1	1	1	1	1	1	1	1
	6	1	1	1	1	1	1	1	1	1	1	1	1
0.10	2	4	3	3	2	2	2	2	2	1	1	1	1
	3	3	2	2	2	2	1	1	1	1	1	1	1
	4	2	1	2	1	1	1	1	1	1	1	1	1
	5	2	1	1	1	1	1	1	1	1	1	1	1
	6	1	1	1	1	1	1	1	1	1	1	1	1
0.05	2	4	4	3	3	3	2	2	2	2	1	1	1
	3	3	2	2	2	2	1	1	1	1	1	1	1
	4	2	2	2	1	1	1	1	1	1	1	1	1
	5	2	1	2	1	1	1	1	1	1	1	1	1
	6	2	1	1	1	1	1	1	1	1	1	1	1
0.01	2	6	5	5	4	3	3	3	2	2	2	2	1
	3	4	3	3	3	2	2	2	2	2	1	1	1
	4	3	2	2	2	2	1	2	1	1	1	1	1
	5	2	2	2	2	2	1	1	1	1	1	1	1
	6	2	2	2	1	1	1	1	1	1	1	1	1

Table 3: Operating characteristic values of the group sampling plan for r = 3 using Log – Logistic distribution

β	a	g_1	g_2	μ/μ₀					
				2	4	6	8	10	12
0.25	0.7	1	1	0.694913	0.961185	0.991068	0.997013	0.998744	0.999386
	0.8	1	1	0.592894	0.938934	0.985332	0.995015	0.997888	0.998963
	1.0	1	1	0.404061	0.876188	0.967258	0.988445	0.995015	0.997526
	1.2	1	1	0.259534	0.792333	0.938934	0.977485	0.990075	0.995015
	1.5	1	1	0.127069	0.643940	0.876188	0.950826	0.977485	0.988445
	2.0	1	1	0.038756	0.404061	0.728337	0.876188	0.938934	0.967258
0.10	0.7	2	1	0.553742	0.929935	0.982975	0.994189	0.997533	0.998787
	0.8	1	1	0.592894	0.938934	0.985332	0.995015	0.997888	0.998963
	1.0	1	1	0.404061	0.876188	0.967258	0.988445	0.995015	0.997526
	1.2	1	1	0.259534	0.792333	0.938934	0.977485	0.990075	0.995015
	1.5	1	1	0.127069	0.643940	0.876188	0.950826	0.977485	0.988445
	2.0	1	1	0.038756	0.404061	0.728337	0.876188	0.938934	0.967258
0.05	0.7	2	2	0.362928	0.874182	0.967619	0.988707	0.995157	0.997605
	0.8	2	1	0.437774	0.892756	0.972429	0.990380	0.995873	0.997958
	1.0	1	1	0.404061	0.876188	0.967258	0.988445	0.995015	0.997526
	1.2	1	1	0.259534	0.792333	0.938934	0.977485	0.990075	0.995015
	1.5	1	1	0.127069	0.643940	0.876188	0.950826	0.977485	0.988445
	2.0	1	1	0.038756	0.404061	0.728337	0.876188	0.938934	0.967258
0.01	0.7	3	2	0.271238	0.829062	0.953678	0.983518	0.992863	0.996452
	0.8	2	2	0.247098	0.812987	0.948319	0.981465	0.991943	0.995985
	1.0	2	2	0.102769	0.664992	0.891948	0.958686	0.981465	0.990599
	1.2	2	1	0.137999	0.677083	0.892756	0.958321	0.981133	0.990380
	1.5	1	1	0.127069	0.643940	0.876188	0.950826	0.977485	0.988445
	2.0	1	1	0.038756	0.404061	0.728337	0.876188	0.938934	0.967258

Table 4: Operating characteristic values of the group sampling plan for r = 3 using Gamma distribution

β	a	g_1	g_2	μ/μ_0					
				2	4	6	8	10	12
0.25	0.7	2	1	0.741279	0.963834	0.990942	0.996803	0.998607	0.999301
	0.8	2	1	0.653516	0.944619	0.985527	0.994791	0.997705	0.998841
	1.0	1	1	0.630604	0.938470	0.983541	0.993991	0.997327	0.998640
	1.2	1	1	0.486066	0.894486	0.969697	0.988556	0.994810	0.997327
	1.5	1	1	0.302020	0.807722	0.938470	0.975514	0.988556	0.993991
	2.0	1.	1	0.115347	0.630604	0.858654	0.938470	0.969697	0.983541
0.10	0.7	3	2	0.496808	0.906147	0.974676	0.990799	0.995933	0.997943
	0.8	2	2	0.477573	0.899233	0.972359	0.989862	0.995492	0.997710
	1.0	2	1	0.479189	0.891998	0.969179	0.988445	0.994791	0.997330
	1.2	1	1	0.486066	0.894486	0.969697	0.988556	0.994810	0.997327
	1.5	1	1	0.302020	0.807722	0.938470	0.975514	0.988556	0.993991
	2.0	1	1	0.115347	0.630604	0.858654	0.938470	0.969697	0.983541
0.05	0.7	3	2	0.496808	0.906147	0.974676	0.990799	0.995933	0.997943
	0.8	2	2	0.477573	0.899233	0.972359	0.989862	0.995492	0.997710
	1.0	2	1	0.479189	0.891998	0.969179	0.988445	0.994791	0.997330
	1.2	1	1	0.486066	0.894486	0.969697	0.988556	0.994810	0.997327
	1.5	1	1	0.302020	0.807722	0.938470	0.975514	0.988556	0.993991
	2.0	1	1	0.115347	0.630604	0.858654	0.938470	0.969697	0.983541
0.01	0.7	4	3	0.316971	0.836728	0.952719	0.982329	0.992080	0.995962
	0.8	3	3	0.271169	0.809977	0.943044	0.978350	0.990200	0.994973
	1.0	2	2	0.286314	0.811770	0.942458	0.977819	0.989862	0.994763
	1.2	2	2	0.155754	0.705027	0.899233	0.959062	0.980732	0.989862
	1.5	2	1	0.169762	0.697844	0.891998	0.954827	0.978329	0.988445
	2.0	1	1	0.115347	0.630604	0.858654	0.938470	0.969697	0.983541

7. Conclusion

In this paper, a two – stage group acceptance sampling plan for a truncated life test is proposed for Log – Logistic distribution and Gamma distribution. The number of groups are determined for r = 1, 2, …., 6 when the consumer's risk (β) and the other plan parameters are specified. It is observed that the lot acceptance probability increases as the mean ratio increases and the number of groups tends to increase as the test duration decreases. Moreover, the operating characteristic function increases disproportionately when the quality improves. This two – stage group acceptance sampling plan can be used when a multiple number of items are tested simultaneously. Clearly, such a tester would be beneficial in terms of test time and test cost.

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