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A GROUP ACCEPTANCE SAMPLING PLANS BASED ON TRUNCATED LIFE TESTS FOR MARSHALL – OLKIN EXTENDED LOMAX DISTRIBUTION

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Abstract: *In this paper, a group acceptance sampling plan is developed for a truncated life test when the lifetime of an item follows Marshall - Olkin extended Lomax distribution. 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 found and the minimum ratios of the true average life to the specified life at the specified producer's risk are obtained. The results are explained with examples.*

Keywords: *Marshall - Olkin extended Lomax distribution, Group acceptance sampling, Consumer's risk, Operating characteristics, Producer's risk, Truncated life test.*

1. Introduction

Quality control has become one of the most important tools to differentiate between the competitive enterprises in a global business market. Two important tools for ensuring quality are the statistical quality control and acceptance sampling. The acceptance sampling plans are concerned with accepting or rejecting a submitted lots of a size of products on the basis of the quality of the products inspected in a sample taken from the lot. An acceptance sampling plan is a specified plan that establishes the minimum sample size to be used for testing. In most acceptance sampling plans for a truncated life test, the major issue is to determine the sample

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size from a lot under consideration. It is implicitly assumed in the usual sampling plan that only a single item is put in a tester.

However, testers accommodating a multiple number of items at a time are used in practice because testing time and cost can be saved by testing those items simultaneously. Items in a tester can be regarded as a group and the number of items in a group is called as the group size. The acceptance sampling plan based on these groups of items will be called a group acceptance sampling plan (GASP). If the GASP is implemented on the truncated life tests we may call it as GASP based on truncated life test when a lifetime of product assumed to follow a certain statistical distribution. In this type of tests, determining the sample size is equivalent to determining the number of groups. This type of testers is frequently used in sudden death testing. The sudden death tests are discussed by Pascual and Meeker (1998) and Vleek *et. al.* (2003). Most recently, Jun *et. al.* (2006) proposed the sudden death test under the assumption that the lifetime of items follows the Weibull distribution with known shape parameter. They developed the single and double group acceptance sampling plans in sudden death testing. More recently, Aslam and Jun (2009) proposed the group acceptance sampling plan based on truncated life test when the lifetime of an item follows the inverse Rayleigh and log-logistic distribution.

Acceptance sampling based on truncated life tests having single-item group for a variety of distributions were discussed by Epstein (1954), Sobel and Tischendrof (1959), Goode and Kao (1961), Gupta and Groll (1961), Gupta (1962), Fertig and Mann (1980), Kantam and Rosaiah (1998), Kantam *et. al.* (2001), Baklizi (2003), Baklizi and El Masri (2004), Rosaiah and Kantam (2005), Rosaiah *et. al.* (2006, 2007 & 2007), Tsai and Wu (2006), Balakrishnan *et. al.* (2007), Aslam (2007), Aslam and Shahbaz (2007), Aslam and Kantam (2008) and Srinivasa Rao *et.al*. (2008).

The purpose of this paper is to propose a GASP based on truncated life tests when the lifetime of a product follows the Marshall- Olkin extended Lomax distribution introduced by Ghitany *et. al.* (2007) with known shape parameter. The probability density function (p.d.f.) and cumulative distribution function (c.d.f) of the Marshall – Olkin extended Lomax distribution respectively, are given by

$$g(t;\nu,\sigma,\theta)=\frac{\frac{\nu\theta}{\sigma}(1+t/\sigma)^{\theta-1}}{\left[(1+t/\sigma)^{\theta}-\bar{\nu}\right]^{2}},\quad t>0,\ \ \nu,\sigma,\theta>0,\ \bar{\nu}=1-\nu, \tag{1}$$

$$G_T(t;\nu,\sigma,\theta)=\frac{(1+t/\sigma)^{\theta}-1}{\left[(1+t/\sigma)^{\theta}-\bar{\nu}\right]},\quad t>0,\nu,\sigma,\theta>0,\ \bar{\nu}=1-\nu. \tag{2}$$

Where σ is scale parameter, θ is shape parameter and ν is index parameter. The mean of this distribution is given by μ =1.570796 σ when $\nu=2,\theta=2$ {mean and variance cannot be express in closed form see Ghitany *et. al.* (2007)}. Srinivasa Rao *et. al.* (2008, 2009) studied single acceptance sampling plans based on the Marshall- Olkin extended Lomax distribution. In Section 2, we describe the proposed GASP. The operating characteristics values in Section 3. The results are explained with some examples in Section 4, and finally, some conclusions are given in Section 5.

2. The Group Acceptance Sampling Plan (GASP)

Let μ represent the true average life of a product and μ_0 denote the specified life of an item, under the assumption that the lifetime of an item follows Marshall- Olkin extended Lomax distribution. A product is considered as good and accepted for consumer's use if the sample information supports the hypothesis $H_0 : \mu \geq \mu_0$. On the other hand, the lot of the product is rejected. In acceptance sampling schemes, this hypothesis is tested based on the number of failures from a sample in a pre-fixed time. If the number of failures exceeds the acceptance number *c* we reject the lot. We will accept the lot if there is enough evidence that $\mu \geq \mu_0$ at certain level of consumer's risk. Otherwise, we reject the lot. Let us propose the following GASP based on the truncated life test:

1) Select the number of groups g and allocate predefined r items to each group so that the sample size for a lot will be $n = g\,r$.
2) Select the acceptance number c for a group and the experiment time t_0.
3) Perform the experiment for the *g* groups simultaneously and record the number of failures for each group.
4) Accept the lot if at most c failures occur in each of all groups.
5) Terminate the experiment if more than *c* failures occur in any group and reject the lot.

The proposed sampling plan is an extension of the ordinary sampling plan available in literature such as in Srinivasa Rao *et. al*. (2008), for r =1 when n = g. We are interested in determining the number of groups *g* required for Marshall- Olkin extended Lomax distribution and various values of acceptance number c, whereas the group size r and the termination time t_0 are assumed to be specified. Since it is convenient to set the termination time as a multiple of the specified life μ_0, we will consider $t_0 = a\mu_0$ for a specified constant *a* (termination ratio).

The probability of rejecting a good lot is called the producer's risk (α), whereas the probability of accepting a bad lot is known as the consumer's risk (β). When determining the parameters of the proposed sampling plan, we will use the consumer's risk. Often, the consumer's risk is expressed by the consumer's confidence level. If the confidence level is p^*, then the consumer's risk will be $\beta = 1 - p^*$. We will determine the number of groups in the proposed sampling plan so that the consumer's risk does not exceed β. If the lot size is large enough and decision about the lot lies in two categories (accept or reject), we can use the binomial distribution to develop GASP. For more justification one may refer to Stephens (2001). According to GASP the lot of products is accepted only if there were at most *c* failures occurred in each of g groups. So, the lot acceptance probability will be

$$L(p) = \left[\sum_{i=0}^{c} \binom{r}{i} p^i (1-p)^{r-i} \right]^g \qquad (3)$$

where p is the probability that an item in a group fails before the termination time. The probability p for the Marshall- Olkin extended Lomax distribution with $\nu = 2, \theta = 2$ is given by:

$$p = G_T(t_0) = \frac{[1+1.5708\,a/(\mu/\mu_0)]^{\theta} - 1}{\left\{[1+1.5708\,a/(\mu/\mu_0)]^{\theta} - \bar{v}\right\}} \tag{4}$$

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

$$L(p_0) \le \beta \tag{5}$$

where p_0 is the failure probability at $\mu = \mu_0$, and it is given by:

$$p_0 = \frac{[1+1.5708\,a)]^{\theta} - 1}{\left\{[1+1.5708\,a]^{\theta} - \bar{v}\right\}}. \tag{6}$$

Particularly for c=0 (so-called zero failure test), g can be determined by the minimum integer satisfying the following inequality:

$$g \ge \frac{\ln \beta}{r \ln(1 - p_0)}. \tag{7}$$

Table 1 shows the minimum number of groups required for the proposed sampling plan for the Marshall - Olkin extended Lomax distribution with $\nu = 2, \theta = 2$ according to various values of consumer's risk (β =0.25, 0.10, 0.05, 0.01), group size (*r*), acceptance number (*c*) and the test termination time multiplier (*a*=0.7, 0.8, 1.0, 1.2, 1.5,2.0).
It can be seen from this table that the number of groups required for the Marshall- Olkin extended Lomax distribution are smaller than the groups required for inverse Rayleigh distribution and for the log-logistic distribution proposed by Aslam and Jun (2009). As compared with single acceptance sampling plan proposed by Srinivasa Rao *et. al.* (2008) the sample sizes ($n = g\,r$) for a lot are equal or more in all consumer's risk (β =0.25, 0.10, 0.05, 0.01), group size (*r*), acceptance number (*c*) and the test termination time multiplier (*a*=0.7, 0.8, 1.0, 1.2, 1.5, 2.0).

Table 1. Minimum number of groups (g) and acceptance number (c) for the proposed plan for the Marshall- Olkin extended Lomax distribution with $\nu = 2, \theta = 2$.

			a					
β	r	c	0.7	0.8	1.0	1.2	1.5	2.0
0.25	2	0	1	1	1	1	1	1
0.25	3	1	2	2	1	1	1	1
0.25	4	2	2	2	2	1	1	1
0.25	5	3	3	3	2	2	1	1
0.25	6	4	5	4	2	2	2	1
0.25	7	5	7	5	3	2	2	1
0.10	4	0	1	1	1	1	1	1
0.10	5	1	1	1	1	1	1	1
0.10	6	2	2	1	1	1	1	1
0.10	7	3	2	2	1	1	1	1
0.10	8	4	3	2	2	1	1	1
0.10	9	5	3	3	2	2	1	1
0.05	5	0	1	1	1	1	1	1
0.05	6	1	1	1	1	1	1	1
0.05	7	2	2	1	1	1	1	1
0.05	8	3	2	2	1	1	1	1
0.05	9	4	2	2	2	1	1	1
0.05	10	5	3	2	2	1	1	1
0.01	7	0	1	1	1	1	1	1
0.01	8	1	1	1	1	1	1	1
0.01	9	2	2	1	1	1	1	1
0.01	10	3	2	2	1	1	1	1
0.01	11	4	2	2	2	1	1	1
0.01	12	5	3	2	2	1	1	1

For example at β =0.05, a = 1.0 (equal to t/σ_0 =1.571) and c= 0, 1, 2, 3, 4 and 5 the sample sizes in Srinivasa Rao *et. al.* (2008) are 3, 5, 6, 8, 10 and 11 whereas in GASP the sample sizes ($n = g\,r$) are 5, 6, 7, 8, 18 and 20. The choice of parameters are used for the comparison of our results with Srinivasa Rao *et. al.* (2008) and Aslam and Jun (2009). The other parametric values like $\theta = 2,3,4,5$ *and* $\nu = 2,3,4$ are available with author. As parametric values increases the group sizes are decreases.

3. Operating Characteristics

The probability of acceptance can be regarded as a function of the deviation of specified average from the true average. This function is called operating characteristic (OC) function of the sampling plan. Once the minimum number of groups is obtained, one may be interested to find the probability of acceptance of a lot when the quality (or reliability) of the product is good enough. As mentioned earlier, the product is considered to be good if $\mu > \mu_0$ or $\mu / \mu_0 > 1$.

The probabilities of acceptance based on (3) for various mean lifetimes (μ / μ_0 =2, 4, 6, 8, 10, 12) under the plan parameters β=0.25, 0.10, 0.05, 0.01; a=0.7, 0.8, 1.0, 1.2, 1.5, 2.0; c=2 and different chosen values of r and g are reported in Table 2 for the Marshall- Olkin extended Lomax distribution with $\nu = 2, \theta = 2$.

Table 2. Operating characteristics values of the group sampling plan with c =2 for Marshall- Olkin extended Lomax distribution with $\nu = 2, \theta = 2$.

β	r	g	c	a	μ / μ_0					
					2	4	6	8	10	12
0.25	4	2	2	0.7	0.6506	0.9132	0.9678	0.9849	0.9917	0.9950
0.25	4	2	2	0.8	0.5707	0.8824	0.9549	0.9784	0.9881	0.9928
0.25	4	2	2	1.0	0.4266	0.8112	0.9225	0.9617	0.9784	0.9867
0.25	4	1	2	1.2	0.5574	0.8557	0.9394	0.9694	0.9826	0.9892
0.25	4	1	2	1.5	0.4338	0.7812	0.9007	0.9478	0.9694	0.9806
0.25	4	1	2	2.0	0.2836	0.6532	0.8233	0.9007	0.9394	0.9605
0.10	6	2	2	0.7	0.2697	0.7204	0.8792	0.9388	0.9650	0.9783
0.10	6	1	2	0.8	0.4369	0.8035	0.9154	0.9568	0.9752	0.9845
0.10	6	1	2	1.0	0.3027	0.7071	0.8632	0.9269	0.9568	0.9725
0.10	6	1	2	1.2	0.2065	0.6104	0.8035	0.8904	0.9335	0.9568
0.10	6	1	2	1.5	0.1155	0.4769	0.7071	0.8265	0.8904	0.9269
0.10	6	1	2	2.0	0.0448	0.3027	0.5488	0.7071	0.8035	0.8632
0.05	7	2	2	0.7	0.1551	0.6092	0.8175	0.9038	0.9438	0.9646
0.05	7	1	2	0.8	0.3120	0.7212	0.8721	0.9324	0.9603	0.9748
0.05	7	1	2	1.0	0.1915	0.6022	0.7998	0.8886	0.9324	0.9562
0.05	7	1	2	1.2	0.1158	0.4912	0.7212	0.8371	0.8980	0.9324
0.05	7	1	2	1.5	0.0544	0.3510	0.6022	0.7511	0.8371	0.8886
0.05	7	1	2	2.0	0.0161	0.1915	0.4246	0.6022	0.7212	0.7998
0.01	9	2	2	0.7	0.0440	0.4016	0.6751	0.8147	0.8866	0.9263
0.01	9	1	2	0.8	0.1463	0.5542	0.7697	0.8699	0.9204	0.9480
0.01	9	1	2	1.0	0.0697	0.4115	0.6609	0.7960	0.8699	0.9127
0.01	9	1	2	1.2	0.0329	0.2967	0.5542	0.7156	0.8115	0.8699
0.01	9	1	2	1.5	0.0108	0.1754	0.4115	0.5935	0.7156	0.7960
0.01	9	1	2	2.0	0.0019	0.0697	0.2359	0.4115	0.5542	0.6609

From this table we see that OC values increase more quickly as the quality increases. For example, when $\beta = 0.25$, r=4, c=2 and *a*= 0.7, the number of groups required is g=2. If the true mean lifetime is twice the specified mean lifetime ($\mu/\mu_0 = 2$) the producer's risk is approximately 0.3494, while it is about 0.0868 when the true mean life is 4 times the specified mean life.

Table 3. Minimum ratio of true mean life to specified mean life for the producer's risk of α = 0.05 under Marshall- Olkin extended Lomax distribution with $\nu = 2, \theta = 2$.

			a					
β	r	c	0.7	0.8	1.0	1.2	1.5	2.0
0.25	2	0	42.92	49.19	61.50	74.02	92.00	123.15
0.25	3	1	11.11	12.66	10.85	13.02	16.29	21.74
0.25	4	2	5.06	5.76	7.23	6.55	8.20	10.98
0.25	5	3	3.68	4.21	4.64	5.55	5.52	7.34
0.25	6	4	3.09	3.33	3.45	4.14	5.17	5.62
0.25	7	5	2.62	2.77	3.06	3.32	4.15	4.60
0.10	4	0	85.91	99.01	123.15	147.06	186.22	246.91
0.10	5	1	13.82	15.79	19.77	23.69	29.63	39.56
0.10	6	2	8.76	7.59	9.49	11.39	14.25	19.01
0.10	7	3	5.35	6.15	6.11	7.34	9.20	12.32
0.10	8	4	4.31	4.42	5.52	5.45	6.84	9.11
0.10	9	5	3.34	3.82	4.33	5.20	5.45	7.28
0.05	5	0	107.23	122.55	153.35	184.09	230.26	306.28
0.05	6	1	16.93	19.35	24.19	29.06	36.39	48.40
0.05	7	2	10.59	9.11	11.39	13.81	17.21	22.83
0.05	8	3	6.41	7.34	7.28	8.76	10.98	14.71
0.05	9	4	4.57	5.23	6.55	6.46	8.06	10.85
0.05	10	5	3.92	4.08	5.08	5.14	6.41	8.59
0.01	7	0	150.06	171.59	214.50	257.67	322.58	429.18
0.01	8	1	23.14	26.52	33.08	39.73	49.73	66.45
0.01	9	2	14.05	12.21	15.26	18.30	22.91	30.53
0.01	10	3	8.43	9.69	9.69	11.68	14.47	19.42
0.01	11	4	5.95	6.84	8.51	8.43	10.59	14.03
0.01	12	5	5.06	5.26	6.60	6.64	8.35	11.11

The producer may be interested in enhancing the quality level of the product so that the acceptance probability should be greater than a specified level. At the producer's risk α the minimum ratio μ/μ_0 can be obtained by satisfying the following inequality:

$$\left[\sum_{i=0}^{c} \binom{r}{i} p^{i}(1-p)^{r-i} \right]^{g} \geq 1-\alpha \quad (8)$$

where p is given by equation (4) and g is chosen at the consumer's risk β when μ/μ_0 =1. Table 3 shows the minimum ratio of μ/μ_0 for Marshall- Olkin extended Lomax distribution with $\nu = 2, \theta = 2$ at the producer's risk of α =0.05 under the plan parameters chosen before. For example, when β =0.25, r=4, g=2, c=2 and *a*=0.7, the manufacturer requires to increase the true mean 5.06 times the specified life in order for the lot to be accepted with the producer's risk at 5 percent.

4. Description of Tables and Examples

The design parameters of GASP are found at the various values of the consumer's risk (β=0.25, 0.10, 0.05, 0.01) and the test termination time multiplier a=0.7, 0.8, 1.0, 1.2, 1.5, 2.0 in Table 1. It should be noted that if one needs the minimum sample size, it can be obtained by $n = r \times g$. In this table, note that, as the test termination time multiplier a increases, the number of groups decrease. We need a smaller number of groups and the acceptance number if the test termination time multiplier increases at a fixed group size. For an example, from Table 1, if β=0.01, r=6, c=2 and a changes from 0.7 to 0.8, the required values of design parameters of GASP have been changed from g=2 to g=1. However, the trend is not monotonic since it depends on the acceptance number as well. The probability of acceptance for the lot at the mean ratio corresponding to the producer's risk is also given in Table 2. Finally, Table 3 presents the minimum ratios of true mean life to specified mean life for the acceptance of a lot with producer's risk of 5 percent for chosen parameters.

As an example consider the lifetime of a product follows the Marshall- Olkin extended Lomax distribution with $\nu = 2, \theta = 2$. It is desired to design a GASP to test that the mean life is greater than 1,000 hours and experimenter wants to run an experiment for 700 hours using testers equipped with 4 items each. It is assumed that c=2 and β=0.25. This leads to the termination multiplier *a*=0.700 and from Table 1 the minimum number of groups required is g=2. Thus, we will draw a random sample of size 8 items and allocate 4 items to each of 2 groups to put on test for 700 hours. This indicates that a total of 8 products are needed and that 4 items are allocated to each of 2 testers. We will accept the lot if no more than 2 failure occurs before 700 hours in each of 2 groups. We truncate the experiment as soon as the 3rd failure occurs before the 700th hours. For this proposed sampling plan the probability of acceptance is 0.9132 when the true mean is 4,000 hours. This shows that, if the true mean life is 4 times of 1000 hours, the producer's risk is 0.0868. If we need the ratio corresponding to the producer's risk of 0.05, we can obtain it from Table 3. For example, when r=4, g=2, c=2, *a*=0.700, the ratios of μ/μ_0 is 5.06.

5. Conclusion

In this paper, a group acceptance sampling plan from the truncated life test was proposed, the number of groups and the acceptance number was determined for Marshall- Olkin extended Lomax distribution with $\nu = 2, \theta = 2$ when the consumer's risk (β) and the other plan parameters are specified. It can be observed that the minimum number of groups required is decreases as test termination time multiplier increases and also the operating characteristics values increases more rapidly as the quality improves. This GASP can be used when a multiple number of items at a time are adopted for a life test and it would be beneficial in terms of test time and cost because a group of items will be tested simultaneously.

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