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Reliability Test Plan for Size Biased Lomax Model

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Abstract: *Sampling plans in which items that are put to test, to collect the life of the items in order to decide upon accepting or rejecting a submitted lot, are called reliability test plans. The basic probability model of the life of the product is specified as size biased Lomax model. For a given producer's risk, sample size, termination number and waiting time to terminate the test plans are computed. The preferability of the test plan over similar plans existing in the literature is established with respect to cost and time of the experiment.*

Keywords: *Size biased Lomax model, Reliability test plan, Acceptance number, Producer's risk, Experimental time.*

1. INTRODUCTION

The acceptance or rejection of submitted lot of large size of products depending upon its quality of product by inspecting a sample from the lot is given by accepting sampling plan. If we consider the quality of product to be the life time of product, then a sample of such products is under examination. There are two kinds of errors may arise when a lot is either accepted or rejected. Such accepting plan needs a probability model which gives the life time of product. If a good lot is rejected it is called producer's risk and a bad lot is accepted is known as consumer's risk. An acceptance sampling plan should be designed in such a way that both risks are minimal.

The acceptance sampling plans for exponential distribution are designed by Sobel and Tischendrof(1959). Similar models of sampling plans are constructed by many authors, few of them are K. Rosaiah and R.R.L. Kantam (2009) derived Reliability test plan for half logistic distribution, K. Rosaiah and R.R.L. Kantam (2007) discussed Exponentiated log-logistic distribution-An economic reliability test plan, K. Rosaiah and R.R.L. Kantam (2007) determined economic reliability test plan with inverse rayleigh variate, An economic reliability test plan: log-logistic distribution by R.R.L. Kantam, G.Srinivasa Rao and B. Sriraam (2006), Marshall-Olkin extended Lomax distribution: An economic reliability test plan developed by G. Srinivasa Rao, M.E. Ghitanty and R.R.L. Kantam (2009), an economic reliability test plan with Pareto distribution studied by K. Rosaiah, R.R.L. Kantam and Subba Rao (2007), economic reliability acceptance sampling based on truncated life tests in the Birnbaum-Saunders distribution constructed by Muhammad Aslam and R.R.L. Kantam (2008). R. Subba Rao, A. Naga Durgamamba and R.R.L. Kantam derived Acceptance sampling plans: size biased Lomax model (2014). Some more probabilistic models useful in reliability studies are studied by the authors to establish similar sampling plans. In sampling plans it is required to minimize the time and cost of the experiment in taking decision of accepting or rejecting a lot depends on sample of products taken from a lot. In this paper we produced sampling plans for size biased Lomax model in different manner from that of R. Subba Rao, A. Naga Durgamamba and R.R.L. Kantam (2014) and make a relative comparison of two approaches. The theory evolved in this approach is presented in Section 2 and comparative analysis of the two approaches given in Section 3.

2. THE SAMPLING PLAN

Let us assume that the life time of a random variable follows size biased Lomax model. The probability density function (p.d.f) and cumulative distribution function (c.d.f) are respectively given below

$$f(t)=\frac{\alpha\left(\alpha-1\right)}{\sigma}\frac{t}{\sigma}\left(1+\frac{t}{\sigma}\right)^{-\left(\alpha+1\right)} \quad ;\ t\geq 0,\alpha\succ 1,\sigma\succ 0 \qquad 1$$

$$\mathrm{F}\left(t\right)=1-\left(1+\frac{\alpha t}{\sigma}\right)\left(1+\frac{t}{\sigma}\right)^{-\alpha} \quad ;\ t\geq 0,\alpha\succ 1,\sigma\succ 0 \qquad 2$$

where α is shape parameter and σ is scale parameter.

We can decide about accepting or rejecting a submitted lot of products of large size depending upon this sample inspection. Let us take γ as producer's risk which should be minimum value. We can think of this decision making regarding accepting or rejecting a submitted lot in two ways.

In order to know the life times of the sample products which be terminated through life testing experiment, let us take *t* as pre assigned time so it is called as terminating time. The research articles of Gupta and Groll (1961), Dr. R. Subba Rao, A. Naga Durgamamba and Dr. R.R.L. Kantam (2014), suggest the minimum sample size *n* required and the corresponding acceptance number *c* such that if *c* or fewer failures occur out of *n* before the time *t* the lot would be accepted with a probability of $1-\gamma$. This approach basically counts the number of failures out of *n* within the terminating time *t*, and hence the life testing experiment would come to an end as soon as the time *t* is reached of $\left(c+1\right)^{th}$ failure is realized, whichever is earlier. Here, we are presenting acceptance sampling plans: size biased Lomax model of Dr. R. Subba Rao, A. Naga Durgamamba and Dr. R.R.L. Kantam (2014) as an example.

Table 1. *Minimum sample size required to accept/reject a submitted lot for a given acceptance number with producer's risk* γ

$p*$	c	t/σ_0							
		0.628	**0.942**	**1.257**	**1.571**	**2.356**	**3.141**	**3.927**	**4.712**
0.75	**0**	9	6	4	3	3	2	2	2
	1	18	11	8	7	5	4	4	3
	2	26	16	12	10	7	6	6	5
	3	34	21	16	13	10	8	7	7
	4	41	26	20	16	12	10	9	8
	5	49	31	23	19	14	12	11	10
	6	57	36	27	22	16	14	12	12
	7	64	40	30	25	19	16	14	13
	8	72	45	34	28	21	18	16	15
	9	79	50	37	31	23	20	18	16
	10	86	54	41	34	25	21	19	18
0.9	**0**	15	9	7	5	4	3	3	3
	1	25	16	12	9	7	6	5	4
	2	35	21	16	13	9	8	7	6
	3	44	27	20	16	12	10	9	8
	4	52	32	24	20	14	12	11	10
	5	61	38	28	23	17	14	13	12
	6	69	43	33	26	19	16	14	13
	7	77	48	36	29	22	18	16	15

	8	85	53	40	33	24	20	18	17
	9	93	58	44	36	26	22	20	18
	10	101	63	47	39	29	24	22	20
0.95	**0**	19	12	9	7	5	4	3	3
	1	30	19	14	11	8	7	6	5
	2	41	25	19	15	11	9	8	7
	3	50	31	23	19	14	11	10	9
	4	59	37	27	22	16	13	12	11
	5	68	42	31	26	19	16	14	13
	6	78	48	36	29	21	18	16	14
	7	86	53	40	32	24	20	18	16
	8	94	58	44	36	26	22	19	18
	9	103	64	48	39	29	24	21	19
	10	111	69	51	42	31	26	23	21
0.99	**0**	29	18	13	10	7	6	5	5
	1	42	26	19	15	11	9	8	7
	2	54	33	24	20	14	11	10	9
	3	64	39	29	24	17	14	12	11
	4	75	46	34	27	20	16	14	13
	5	84	52	38	31	23	19	16	15
	6	94	58	43	35	25	21	18	17
	7	103	64	47	38	28	23	20	19
	8	113	70	52	42	30	25	22	20
	9	122	75	56	45	33	27	24	22
	10	131	81	60	49	36	30	26	24

Suppose an experimenter is enthusiastic to find that the true unknown average life is at least 1000 hours with a confidence of 0.95. It is expected to stop the experiment at t = 0.628 hours then, for an acceptance number c = 2, the required sample size (n) from Table 1 is 41. So, 41 items have to put for testing of 628 hours, no more than 2 failures out of 41 items are observed then the experimenter can conclude, with a confidence level of 0.95, that the average life is at least 1000 hours. It means the lot is rejected if 3 or more failures occur within 628 hours.

Consequently, we can think of an upcoming approach of an economic reliability test plan. Let n indicates the number of sampled items to be determined and r stands for a natural number, such that out of n samples, if r failures occur before the terminated time t the lot would be rejected that is the experiment is comes to an end as soon as r^{th} failure is reached or termination time t is reached, whichever is the latest. In this aspect r is called as termination number. The sample size is depending upon the cost consideration and the expected time to reach a decision. If the sample size is large it may reduce the expected waiting time but increases the cost of consideration. Let us take sample size as a multiple of the termination number to balance between these two aspects. As we have to come know that the probability of r failures out of n tested items is given by $\binom{n}{r} p^r q^{n-r}$, where p = F (t,σ) given in Equation (2) and q =1-p. Thus the probability of accepting the lot is $\sum_{i=0}^{r-1} \binom{n}{i} p^i q^{n-i}$. For a producer's risk γ, the above equation gives $\sum_{i=0}^{r-1} \binom{n}{i} p^i q^{n-i} = 1-\gamma$. Because n is taken to be multiple of the termination number, it would be $n = kr$.

Given γ, r, k, above equation can be solved t/σ_0 for *p*, using cumulative probabilities of binomial distribution. The values of *p* so derived when using Equation (2), it would give the respective values of t/σ .This is recommended in solving the termination time *t* for a specified population average life and hence a specified σ_0 . The values of t/σ_0 for *r* = 1(1)10, *n* = 2(1)10, γ = 0.25, 0.10, 0.05 and 0.01 are presented in Table 2.

Table 2. *Life test termination time in units of scale parameter (t/σ_0) in size biased Lomax model with producer's risk* γ

r	n=2r	3r	4r	5r	6r	7r	8r	9r	10r
					γ =0.25				
1	0.57736	0.43347	0.35765	0.30969	0.27612	0.25104	0.23144	0.21561	0.20251
2	0.97229	0.67072	0.53214	0.45031	0.39539	0.35553	0.32504	0.30082	0.28101
3	1.19733	0.79264	0.61788	0.51765	0.45154	0.40413	0.36817	0.33979	0.31671
4	1.34554	0.86893	0.67042	0.55843	0.48529	0.43318	0.39386	0.36293	0.33785
5	1.45209	0.92212	0.70661	0.58634	0.50829	0.45292	0.41126	0.37858	0.35213
6	1.53321	0.96179	0.73339	0.6069	0.52519	0.46739	0.424	0.39002	0.36255
7	1.59752	0.99279	0.7542	0.62283	0.53825	0.47857	0.43383	0.39885	0.37059
8	1.65009	1.01784	0.77095	0.63563	0.54873	0.48752	0.4417	0.4059	0.37701
9	1.69399	1.0386	0.7848	0.64618	0.55736	0.49489	0.44818	0.4117	0.38229
10	1.7314	1.05617	0.79648	0.65508	0.56463	0.50109	0.45362	0.41659	0.38973
					γ =0.10				
1	0.29289	0.22817	0.19224	0.16878	0.15199	0.13925	0.12916	0.12093	0.11407
2	0.60661	0.4374	0.35497	0.30466	0.27018	0.24474	0.22506	0.20927	0.19626
3	0.81235	0.56216	0.44777	0.38012	0.33462	0.30153	0.27615	0.25595	0.2394
4	0.95907	0.64656	0.50909	0.4293	0.37623	0.33794	0.30874	0.2856	0.26672
5	1.07052	0.7085	0.55344	0.46457	0.40592	0.36379	0.3318	0.30653	0.28595
6	1.15898	0.7565	0.58747	0.49145	0.42843	0.38336	0.34923	0.32232	0.30044
7	1.23147	0.79514	0.61463	0.51283	0.44629	0.39885	0.36299	0.33476	0.31187
8	1.29233	0.82712	0.63698	0.53036	0.46091	0.41149	0.37422	0.34491	0.32115
9	1.3444	0.85417	0.6558	0.54507	0.47315	0.42209	0.3836	0.35339	0.32892
10	1.38963	0.87744	0.67193	0.55766	0.4836	0.4311	0.39159	0.3606	0.33552
					γ =0.05				
1	0.18924	0.1497	0.12726	0.11238	0.10165	0.09343	0.0869	0.08154	0.07704
2	0.4544	0.33458	0.27451	0.23727	0.21143	0.19225	0.1773	0.16525	0.15528
3	0.64301	0.45486	0.36629	0.31308	0.2769	0.25039	0.22995	0.21361	0.20017
4	0.78319	0.53966	0.42944	0.36449	0.32087	0.28915	0.26486	0.24552	0.22968
5	0.89264	0.60355	0.47628	0.40227	0.35296	0.31732	0.29013	0.26855	0.25093
6	0.98129	0.654	0.51284	0.43155	0.37772	0.33898	0.30951	0.28619	0.26717
7	1.0551	0.69519	0.54242	0.45513	0.3976	0.35633	0.325	0.30026	0.28012
8	1.11788	0.72968	0.56703	0.47467	0.41402	0.37063	0.33776	0.31183	0.29075
9	1.17219	0.75913	0.58793	0.4912	0.42789	0.38268	0.3485	0.32156	0.29968
10	1.21979	0.78466	0.60598	0.50544	0.43981	0.39303	0.3577	0.3299	0.30733
					γ =0.01				
1	0.0762	0.06139	0.05274	0.04692	0.04266	0.03938	0.03675	0.03457	0.03274
2	0.25776	0.1956	0.16307	0.14242	0.12784	0.11689	0.10828	0.10129	0.09546
3	0.41061	0.30035	0.24602	0.21254	0.1894	0.17223	0.15888	0.14811	0.1392

4	0.53323	0.38025	0.30776	0.26399	0.23409	0.2121	0.19511	0.18148	0.17027
5	0.63364	0.44337	0.35572	0.30353	0.2682	0.24239	0.22251	0.20665	0.19362
6	0.71781	0.49486	0.39436	0.33514	0.29533	0.26637	0.24418	0.22647	0.21197
7	0.78978	0.53796	0.42637	0.36118	0.31758	0.28599	0.26182	0.24261	0.2269
8	0.85229	0.57474	0.45349	0.38313	0.33628	0.30243	0.27659	0.2561	0.23936
9	0.90733	0.60666	0.47684	0.40196	0.35229	0.31647	0.2892	0.26759	0.27996
10	0.95632	0.63472	0.49727	0.41837	0.3662	0.32867	0.30013	27754	0.25914

As an example of this new approach, let us think that we have to derive a life test sampling plan with an acceptance probability of 0.95 for lots with an acceptable mean life of 1000 hours and 10, 5 as sample size, termination number r (= c+1) respectively. From Table 2, the entry against r = 5 under column 2r is 0.89264. Since the acceptable mean life is 1000 hours, for size biased Lomax model. From Table 2, the respective value of t/σ_0 = 0.89264 which implies the termination time t = 892.64 hours.

In this test plan, we select 10 items from the submitted lot and put to test. We reject the lot, when the 5th failure is occured before 892.64 hours, otherwise we accept the lot. In either case terminating the experiment as soon as the 5th failure occurs or the termination time 892.64 hours is reached whichever is earlier.

3. Comparative Study

With a view of comparing the present sampling plan with that of Dr. R. Subba Rao et al. (2014), the entries common for both the approaches are given for α = 2, γ = 0.05,0.01 in Table 3. The entries given in the first row are relevant to present test plan and those given in the second row are considered from Dr. R. Subba Rao et al. (2014). All the entries in the Table 3 shows that for a given n, r (= c+1), the values of t/σ_0 –the proportion time of termination is uniformly smaller for the reliability test plans determined by us than those derived by Dr. R. Subba Rao, A. Naga Durgamamba et al. (2014). The present approach of test plan results saving more experimental time and cost, so that we can prefer our plans to that of Dr. R. Subba Rao et al. (2014).

Table 3. *Comparison of proportion of termination time for sampling plans of Dr. R. Subba Rao, A. Naga Durgamamba et al. (2014)and the present sampling plans with producer's risk* γ

r\n	**2r**	**3r**	**4r**	**5r**	**6r**	**7r**	**8r**	**9r**	**10r**
	γ **=0.05**								
		0.1497	0.12726	0.11238		0.09343		0.08154	
1		3.927	3.141	2.356		1.571		1.257	
		0.33458	0.27451			0.19225			
2		3.327	2.356			1.257			
		0.45486		0.31308					
3		3.141		1.571					
						0.33898			
6						0.942			
	1.0551								
7	4.712								
	1.11788	0.72968	0.56703	0.47467					
8	4.712	2.356	1.571	1.257					
	1.17219		0.58793						
9	4.712		1.571						
	γ **=0.01**								
				0.04692	0.04266	0.03938			0.03274
1				3.927	3.141	2.356			1.571

			0.16307						
2			3.927						
		0.30035					0.15888		
3		4.712					1.257		
		0.38025			0.23409				
4		3.927			1.571				
			0.35572						
5			2.356						
		0.53796		0.36118					
7		3.141		1.571					
							0.27659		
8							0.942		

4. OPERATING CHARACTERISTIC

If the true but unknown average life of the product varies from the specified life of the product it should result in a considerable change in the probability of acceptance. Hence, the probability of acceptance can be considered as a function of variation of specified average from the true average. This function is called the operating characteristic, lies between 0 and 1. Particularly, if $p = F(t,\sigma)$ is the cumulative distribution function of the life time random variable of an item, σ_0 is specified life, then the probability *p* may be defined as a function of σ/σ_0, that is, $F(t/\sigma) = F\left[(t/\sigma_0)(\sigma_0/\sigma)\right]$, where σ is true but unknown average life. The ratio of σ_0/σ can be considered as a measure of changes between true and specified life times. For example if $\sigma_0/\sigma \prec 1$ it suggests that true mean life is greater than the declared life leading to more acceptance probability or less failure risk. Hence, presenting a set of hypothetical values for σ_0/σ say σ_0/σ =0.1(0.1)0.9 we can have the relevant acceptance probabilities for the given sampling plan. The graph between σ_0/σ and the corresponding probability of acceptance given by equation $P_a = \sum_{i=0}^{c} \binom{n}{i} p^i q^{n-i}$ for a sampling plan forms the operating characteristic curve and for some selected sampling plans, these results are given Table 4.

Table 4. *Operating characteristic (O.C) values of sampling plan (n,r,t/σ_0) for a given γ*

	n=2, r=1		n=6,r=2		n=10,r=2	
	t/σ_0		t/σ_0		t/σ_0	
	0.18924	**0.0762**	**0.33458**	**0.1956**	**0.23727**	**0.14242**
σ_0/σ	$1-\gamma$ =0.95	$1-\gamma$ =0.99	$1-\gamma$ =0.95	$1-\gamma$ =0.99	$1-\gamma$ =0.95	$1-\gamma$ =0.99
0.1	0.99931	0.99988	0.99998	0.99999	0.99999	0.99999
0.2	0.99734	0.99955	0.99977	0.99997	0.99981	0.99997
0.3	0.99424	0.999	0.99898	0.99986	0.99914	0.99987
0.4	0.99012	0.99825	0.99719	0.99959	0.99756	0.99963
0.5	0.98511	0.9973	0.99401	0.99907	0.99464	0.99914
0.6	0.97931	0.99618	0.98912	0.99823	0.99001	0.99833
0.7	0.97282	0.9948	0.98234	0.99696	0.98338	0.99709
0.8	0.96572	0.99341	0.97356	0.99521	0.97455	0.99534
0.9	0.95809	0.99178	0.96275	0.99291	0.96343	0.993
1	0.94999	0.98999	0.94999	0.98999	0.94999	0.98999

1.1	0.94151	0.98807	0.9354	0.98645	0.9343	0.98627
1.2	0.93268	0.98601	0.91913	0.98222	0.91649	0.98177
1.3	0.92355	0.98382	0.90135	0.97731	0.89671	0.97647
1.4	0.91419	0.9815	0.88226	0.97171	0.87519	0.97803
1.5	0.90462	0.97906	0.86207	0.96542	0.85214	0.96338
1.6	0.89489	0.97652	0.84096	0.95846	0.8278	0.95559
1.7	0.8985	0.97387	0.81914	0.95084	0.80242	0.94697
1.8	0.87505	0.97112	0.79678	0.94258	0.77622	0.93754
1.9	0.86501	0.96827	0.77403	0.93373	0.74942	0.92734

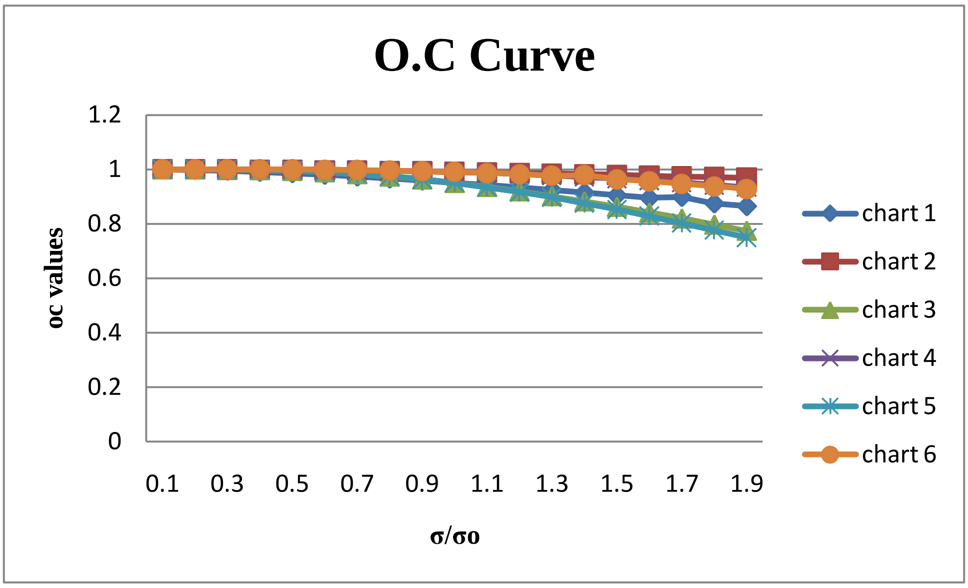

Illustration: Consider the following ordered failure times of the product, gathered from software development project [Wood (1996)]. This data can be determined as an ordered sample of size 16 with observations x_i, i= 1,2,….16.

519, 968,1430,1893,2490,3058,3625,4422,5218,5823, 6539,7083,7487,7846,8205,8564

The confidence level of the decision processes confirmed by the sampling plan only if the life times follow size biased Lomax model. We have examined this for the above sample data by Q-Q plot = 70.22% when α = 2.

Suppose the specified average life to be 1000 hours and the testing time is 942 hours, this leads to ratio of $t/\sigma_0 = 0.942$ with the corresponding n and c as 16,1 from Table 1 for $p^* = 0.10$ (this sampling plan derived by Dr. R. Subba Rao, A. Naga Durgamamba and Dr. R.R.L. Kantam (2014). Therefore the sampling plan for the above sample data is (n = 16, c = 1, $t/\sigma_0 = 0.942$). Depending upon the life times, we have to decide whether to accept the product or deny it. The approval of the product is possible only, if the number of failures before 942 hours is less than or equal to 1.

Anyhow, the confidence level can be assured by the sampling plan only if the given life times follow size biased Lomax model. Comparison of the sample quantiles with the corresponding population quantiles is found to reach a satisfactory agreement. The adoption of the decision rule of the sampling plan seems to be justified. In the sample of 16 failures there is only one failure 519 hours before 942 hours. Therefore approve the product (by using the sampling plan determined by Dr. R. Subba Rao, A. Naga Durgamamba and Dr. R.R.L. Kantam (2014).

The same data of failure times is considered for accepting or rejecting the product by using the present sampling plan. In this sampling plan, the sample size n is represented by kr, where k = 2(1)10 and r = c+1 = 2. From Table 2, for n = 16, r = 2, p^* = 0.10 we have k = 8, then the corresponding $t/\sigma_0 = 0.22506$, that is t = 225.06 hours. Based on the life times, we have to conclude whether to accept the product or reject it. We accept the product only, if the number of failures before 225.06

hours should not be 2 or more. In the above sample of 16 failures there is no failure before 225.06 hours. Therefore we also accept the product by using the present sampling plan. Here, we note that the termination time *t* is smaller by using present sampling plan than that of the sampling plan suggested by Dr.R. Subba Rao, A. Naga Durgamamba and Dr.R.R.L. Kantam (2014). Hence, the cost and the experimental time can be saved considerably by using our present sampling plans.

5. Conclusion

In the present paper, reliability test plans under the assumption that the life of items follow a size biased Lomax model were determined. It gives the minimum termination ratio that are required to test the items to decide upon whether a submitted lot is good having more mean life or not. The operating characteristic values of the plan against a specified producer's risk are also presented. The plan proposed here by is useful in reducing the producer's risk. The proposed plan can use further to save the time and cost of the experiment in order to reach the final decision about a lot of the product.

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