Economic Reliability Test Plan for Burr Type X Distribution

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Abstract: The Burr Type X distribution is considered as a probability model for the lifetime of the product. 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. A test plan to determine the termination time of the experiment for a given sample size, producer's risk and termination number is constructed. The preferability of the present test plan over similar plans exists in the literature is established with respect to time of the experiment. Results are illustrated by an example.

Keywords: Reliability Test Plans, Burr Type X Distribution, Operating Characteristic Function, Experimental Time.

1. INTRODUCTION

The variable sampling plans are developed by proposing a decision rule to accept or reject a submitted lot of products based on inspected measurable quality characteristic for a sample product taken from the lot. As required by the principles of statistical inference, it is necessary to specify the probability distribution of variable characteristic. In the absence of such specification, it is taken as the well-known normal distribution. However, if normal distribution is not a good fit to the data under consideration, the decision process constructed on this basis would be misleading. At the same time appeal to central limit theorem as a justification to normality assumption is not always valid as the sample size in quality control data is not large enough to adopt normality. In this backdrop, Sobel and Tischendrof (1959) developed reliability test plans for exponential distribution. Goode and Kao (1961) constructed sampling plans for Weibull distribution. Gupta and Groll (1961) constructed sampling plans for Gamma distribution. Sampling plans similar to those of Gupta and Groll (1961) are developed by Kantam and Rosaiah (1998) for half-logistic distribution and Kantam *et al.* (2001) for Log-logistic distribution, Rosaiah and Kantam (2005) for the inverse Raleigh distribution, Rosaiah *et al.* (2006) for exponentiated log-logistic distribution and Ravikumar *et al.* (2016) for Burr Type X distribution. Sampling plans in a new approach for log-logistic distribution are suggested by Kantam *et al.* (2006). An economic reliability test plans are constructed by some of the authors are Rosaiah *et al.* (2007a) for Pareto distribution, Rosaiah *et al.* (2007b) for Exponentiated Log-Logistic distribution, Rosaiah *et al.* (2007c) for Inverse Rayleigh distribution, Aslam and Kantam (2008) for truncated life tests in the Birnbaum-Saunders distribution, Srinivasa Rao *et al.* (2009) for Marshall - Olkin extended Lomax distribution, Kantam and Sriram (2013) for Rayleigh Distribution, Rosaiah *et al.* (2014) for Type – I

Generalized Half Logistic Distribution, Subbarao *et al.* (2015) for Size Biased Lomax Distribution and Subba Rao *et al.* (2016) for A New *T-X* Model Distribution. Our interest in this paper is working of a variable sampling plan parallel to the construction of a theoretical parametric test of hypothesis. Of these, the present paper deals with the construction of sampling plan with a new approach and its comparison with similar existing plans are given in Section 2. The operating characteristic is presented in Section 3. The results are illustrated by an example towards the end of Section 3.

In scaled densities, a null hypothesis about scale parameter such as 'the scale parameter is greater than or equal to a specified value' is equivalent to saying that the 'average life of a product governed by the given scaled density exceeds a specified average life'. Acceptance of this hypothesis by a test procedure means that the sample life times used for testing indicate that the lot from which the sample is drawn is a good lot. Similarly, rejection of the hypothesis implies that the lot is a bad lot. In this paper, we discussed the parallel between the testing of hypothesis in scaled densities and sampling plans.

In this paper, we assume that the lifetime of product follows a Burr Type X distribution (BTXD). For the case that a lot of such products are submitted for inspection, we develop a economic reliability test sampling plan, derive its operating characteristic function and give the corresponding decision rule. The proposed sampling plan, along with the operating characteristic, is given in Section 2. The description of tables is given in Section 3. The results are explained by an example in Section 4.

II. THE SAMPLING PLAN

We assume that the lifetime of a product follows Burr Type X Distribution. The probability density function and cumulative distribution function of the Burr Type X Distribution are given by,

$$f(x;k,\lambda) = 2k\frac{x}{\lambda^2}e^{-(x/\lambda)^2}(1-e^{-(x/\lambda)^2})^{k-1};\ x>0,\ k>0,\ \lambda>0 \quad (2.1)$$

$$F(x;k,\lambda) = (1-e^{-(x/\lambda)^2})^{k};\ x>0,\ k>0, \lambda>0 \quad (2.2)$$

where λ is the scale parameter and k are the shape parameter.

Thus, generalized Rayleigh distribution and Burr type X distributions are one and the same.

BTXD can be considered as a model for lifetimes, if the lifetimes show a large variability and is shown to be a decreasing or increasing failure rate model.

Consider a null hypothesis" H_0: $\lambda > \lambda_0$". If BTXD is assumed as the model of a variable representing lifetimes of some items that have life and eventual failure, the above hypothesis is regarding the average life of those items in the population. If the H_0 is accepted on the basis of some sample lifetimes collected through a life testing experiment from out of a submitted lot of such items using any admissible statistical test procedure, we may conclude that the submitted lot has a better average life than what is specified accordingly the lot that can be termed as a good lot and can be accepted. Ravikumar *et al.* (2016) constructed the minimum sample size required to make a decision about the lot given the waiting time in terms of λ_0 (i.e., x/λ_0) and acceptance number c, some risk probability, say α. With a specified λ_0 of λ, the probability of detecting c or less failures (probability of accepting the lot) in a sample of size n is given by

$$\sum_{i=0}^{c}\binom{n}{i}p^i(1-p)^{n-i}, \tag{2.3}$$

where $p = (x; k, \lambda_0)$.

For $\lambda > \lambda_0$, the above probability of acceptance should increase. Therefore, if α is a prefixed risk probability, this means

$$\sum_{i=0}^{c}\binom{n}{i}p^i(1-p)^{n-i} \geq 1-\alpha \tag{2.4}$$

For a given λ_0 and hence of x/λ_0, this is a single inequality in two unknowns n and c assuming that the parameter α is known. Because c is always less than n, inequality (2.4) can be solved for n with successive values of c from zero onwards. The earliest value of n that satisfies the inequality (2.4) are given for $k = 2$, $P^*=1-\alpha = 0.75, 0.90, 0.95, 0.99$ and $x/\lambda_0 = 0.628, 0.942, 1.257, 1.571, 2.356, 3.141, 3.927, 4.712$ by Ravikumar *et al.* (2016) along with the associated performance characteristics like operating characteristics, producer's risk, scope for variability of σ etc. A typical portion of tables of Ravikumar *et al.* (2016) for BTXD are reproduced in the Table 1 for k = 2.

In the present investigation, inequality (2.4) can be considered in a different way. Let us fix n and let r be a natural number less than n, so that as soon as the r^{th} ($r = c + 1$) failure is observed, the process is stopped, and the lot is rejected. Given $\lambda>\lambda_0$, the probability of such a rejection should be as small as possible. That is

$$\sum_{i=r}^{n}\binom{n}{i}p^i(1-p)^{n-i} < \alpha \tag{2.5}$$

Specifying n as a multiple of r, say lr (l = 1, 2, . . .), inequality (2.5) can be regarded as an inequality in a single unknown in terms of x/λ with known k. With the choice of r, l, α, inequality (2.5) can be solved for the earliest p, say p_0, from which the value of x/λ_0 can be obtained by inverting the $F(x; k, \lambda)$ given by (2.1). The specified population average in terms of λ_0 can be used here to get the value of x called the termination time. These are presented in Table 2 for various values of n, r = 1(1)10, k = 2 at $p^*=1-\alpha$ = 0.95, 0.99.

Table 1: Minimum sample sizes necessary to assert the average life to exceed a given value λ_0 with probability p^*, the corresponding acceptance number c and for k=2 using binomial probabilities.

p*	***c***	***x/λ₀***							
		0.628	**0.942**	**1.257**	**1.571**	**2.356**	**3.142**	**3.927**	**4.712**
0.95	0	27	8	4	2	1	1	1	1
	1	43	12	6	4	2	2	2	2
	2	58	16	8	5	3	3	3	3
	3	71	20	10	7	4	4	4	4
	4	84	24	12	8	5	5	5	5
	5	97	28	14	9	6	6	6	6
	6	109	32	16	11	8	7	7	7
	7	121	35	18	12	9	8	8	8
	8	133	39	20	13	10	9	9	9
	9	145	42	21	15	11	10	10	10
	10	157	46	23	16	12	11	11	11
0.99	0	42	11	5	3	1	1	1	1

	1	60	17	8	5	3	2	2	2
	2	76	21	10	6	4	3	3	3
	3	91	26	12	8	5	4	4	4
	4	106	30	14	9	6	5	5	5
	5	120	34	16	11	7	6	6	6
	6	133	38	19	12	8	7	7	7
	7	147	42	21	14	9	8	8	8
	8	160	46	22	15	10	9	9	9
	9	172	49	24	16	11	10	10	10
	10	185	53	26	18	12	11	11	11

Table 2: Life test termination in units of scale parameter (x/λ_0) for BTXD with k = 2.

***p**=(1-α)**	**r**	**n=2r**	**n=3r**	**n=4r**	**n=5r**	**n=6r**	**n=7r**	**n=8r**	**n=9r**	**n=10r**
	1	0.41631	0.37349	0.34609	0.32635	0.31113	0.29887	0.28866	0.27997	0.27243
	2	0.61204	0.53723	0.49251	0.46141	0.43796	0.41933	0.40401	0.39107	0.37993
	3	0.70465	0.6123	0.55866	0.52189	0.49441	0.47272	0.45495	0.44	0.42716
	4	0.76053	0.65693	0.59773	0.55748	0.52753	0.50397	0.48473	0.46856	0.4547
0.95	5	0.79874	0.68719	0.62412	0.58145	0.54981	0.52498	0.50472	0.48773	0.47317
	6	0.8269	0.70937	0.64342	0.59897	0.56607	0.54029	0.51929	0.50168	0.48661
	7	0.84872	0.7265	0.6583	0.61245	0.57859	0.55207	0.53049	0.51241	0.49694
	8	0.86627	0.74023	0.67021	0.62325	0.58859	0.56149	0.53944	0.52098	0.50519
	9	0.88076	0.75154	0.68002	0.63213	0.59683	0.56924	0.5468	0.52803	0.51198
	10	0.89298	0.76107	0.68828	0.6396	0.60375	0.57575	0.55299	0.53395	0.51768
***p**=(1-α)**	**r**	**n=2r**	**n=3r**	**n=4r**	**n=5r**	**n=6r**	**n=7r**	**n=8r**	**n=9r**	**n=10r**
	1	0.27099	0.24408	0.22671	0.21413	0.20439	0.19651	0.18994	0.18434	0.17947
	2	0.47889	0.42267	0.38868	0.36488	0.34685	0.33248	0.32063	0.3106	0.30194
	3	0.58654	0.51248	0.46899	0.439	0.41647	0.39863	0.38399	0.37164	0.36101
	4	0.65374	0.56769	0.518	0.48401	0.45862	0.43859	0.42218	0.40838	0.39652
0.99	5	0.70059	0.60579	0.55167	0.51485	0.48744	0.46587	0.44823	0.43341	0.4207
	6	0.73557	0.63407	0.57657	0.53762	0.50869	0.48596	0.4674	0.45182	0.43846
	7	0.76295	0.65609	0.59593	0.55529	0.52517	0.50152	0.48224	0.46607	0.45221
	8	0.78513	0.67387	0.61153	0.56951	0.53841	0.51403	0.49416	0.47751	0.46324
	9	0.80356	0.68859	0.62443	0.58127	0.54936	0.52437	0.50401	0.48695	0.47235
	10	0.81919	0.70105	0.63533	0.5912	0.5586	0.53308	0.51231	0.49491	0.48002

III. COMPARATIVE STUDY

In order to compare the present sampling plan with that of Ravikumar *et al.* (2016), the entries common for both the approaches are presented for $k = 2$; $\alpha = 0.05, 0.01$ in Table 3. The entries given in the first row are corresponding to present test plan and those given in the second row are obtained by Ravikumar *et al.* (2016). All the entries in Table 3 show that for a given n, $r(r = c + 1)$, the values of x/λ_0-the scaled termination time is uniformly smaller for the present reliability test plans than those of Ravikumar *et al.* (2016), resulting in savings in experimental time.

Table 3: Proportion of life test termination time for sampling plans of Ravikumar *et al.* (2016) and the present sampling plans with producer's risk α = 0.05, 0.01.

n	**n=2r**	**n=3r**	**n=4r**	**n=5r**	**n=6r**	**n=7r**	**n=8r**	**n=9r**	**n=10r**
r	**α=0.05**								
1	0.41631 1.571		0.34609 1.257				0.28866 0.942		
2	0.61204 1.571	0.53723 1.257			0.43796 0.942				
4				0.55748 0.942					
r	**α=0.01**								
1		0.24408 1.571		0.21413 1.257					
2			0.38868 1.257						
3	0.58654 1.571					0.39863 0.942			
4	0.65374 1.571	0.56769 1.257							
5					0.48744 0.942				

IV. OPERATING CHARACTERISTIC FUNCTION

If the true but unknown life of the product deviates from the specified life of the product it should result in a considerable change in the probability of acceptance of the lot based on the sampling plan. Hence 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 function of the sampling plan. Specifically, if $F(x/\lambda)$ is the cumulative distribution function of the lifetime random variable of the product, λ_0 corresponds to specified life, we can write

$$F(x/\lambda) = F[(x/\lambda_0).(\lambda_0/\lambda)] \quad (3.1)$$

where λ corresponds to true but unknown average life. The ratio λ_0/λ in the right-hand side (R.H.S) of equation (3.1) can be taken as a measure of changes between true and specified lives.

For instance $(\lambda_0/\lambda) < 1$ implies that the true mean life is more than the declared life leading to more acceptance probability or less failure risk. Similarly, $(\lambda_0/\lambda) > 1$ implies less acceptance probability or more failure risk. Hence giving a set of hypothetical values, say $\lambda_0/\lambda = 0.1(0.1)1.9$, we can have the corresponding acceptance probability for the given sampling plan. Here we have selected some plans and the operating characteristic (O.C.) values of these plans are given in Table 4 and the corresponding O.C. curves are also drawn as shown in Fig.1.

Table 4: Operating Characteristic (O.C.) values of sampling plans ($n,r,x/\lambda_0$) for k=2.

λ/λ_0	**n=2,r=1**		**n=6,r=2**		**n=10,r=2**		**n=12,r=3**		**n=8,r=4**	
	x/λ_0		**x/λ_0**		**x/λ_0**		**x/λ_0**		**x/λ_0**	
	0.41631	**0.27099**	**0.53723**	**0.42267**	**0.46141**	**0.36488**	**0.55866**	**0.46899**	**0.76053**	**0.65374**
	1-α=0.95 (Graph - 1)	**1-α=0.99 (Graph - 2)**	**1-α=0.95 (Graph - 3)**	**1-α=0.99 (Graph - 4)**	**1-α=0.95 (Graph - 5)**	**1-α=0.99 (Graph - 6)**	**1-α=0.95 (Graph - 7)**	**1-α=0.99 (Graph - 8)**	**1-α=0.95 (Graph - 9)**	**1-α=0.99 (Graph - 10)**
0.1	0.99999	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
0.2	0.99990	0.99998	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
0.3	0.99952	0.99991	0.99999	1.00000	0.99999	1.00000	1.00000	1.00000	1.00000	1.00000
0.4	0.99850	0.99973	0.99994	0.99999	0.99994	0.99999	1.00000	1.00000	1.00000	1.00000
0.5	0.99641	0.99934	0.99965	0.99995	0.99968	0.99995	0.99996	0.99999	0.99999	1.00000
0.6	0.99270	0.99864	0.99861	0.99978	0.9987	0.99979	0.99971	0.99996	0.99990	0.99999
0.7	0.98679	0.9975	0.99567	0.99927	0.99589	0.9993	0.99844	0.99977	0.99921	0.99990
0.8	0.97808	0.99579	0.98875	0.99802	0.98914	0.99807	0.9938	0.99900	0.99572	0.99938
0.9	0.96598	0.99334	0.97480	0.99529	0.97522	0.99535	0.98054	0.99653	0.98324	0.99716
1.0	0.95000	0.99000	0.95000	0.99000	0.95000	0.99000	0.94999	0.99000	0.95000	0.99000
1.1	0.92970	0.98559	0.91055	0.98065	0.90912	0.9804	0.89186	0.97531	0.88148	0.97156
1.2	0.90482	0.97996	0.85370	0.96543	0.84927	0.96456	0.79894	0.94676	0.76914	0.93284
1.3	0.87522	0.97294	0.77884	0.94242	0.76954	0.94029	0.67264	0.89822	0.61935	0.86507
1.4	0.84098	0.96438	0.68814	0.90985	0.6723	0.90551	0.52533	0.82525	0.45394	0.76455
1.5	0.80233	0.95415	0.58649	0.86645	0.56332	0.85873	0.37674	0.7276	0.30032	0.63648
1.6	0.75968	0.94212	0.48066	0.81178	0.45069	0.79941	0.24632	0.61054	0.17867	0.49467
1.7	0.71362	0.92821	0.37791	0.74648	0.34309	0.7283	0.14614	0.48425	0.09556	0.35682
1.8	0.66485	0.91234	0.28458	0.67229	0.24782	0.64755	0.07848	0.36109	0.04603	0.23812
1.9	0.61417	0.89448	0.20506	0.59190	0.16952	0.56050	0.03810	0.25214	0.02004	0.14686

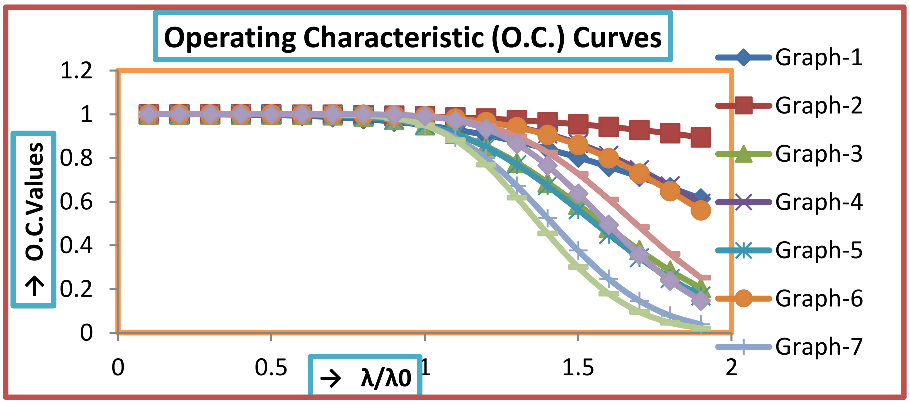

Figure 1: Operating Characteristic Curves of Sampling Plan ($n,r,x/\lambda_0$) at k=2.

Illustration: Consider the following 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 experienced (Wood, 1996). This data can be regarded as an ordered sample of size n = 12 with observations:

$\{x_i : i = 1, 2, . . . 16\} = \{519, 968, 1430, 1893, 2490, 3058, 3625, 4422, 5218, 5823, 6539, 7083\}$.

The confidence level of the decision processes assured by the sampling plan only if the lifetimes follow BTXD. We have verified this for the above sample data by $Q - Q$ plot at k= 2, the value is 0.996624.

Case I: Let the required average lifetime be 1000 hours and the testing time be x = 942 hours, this leads to ratio of $x/\lambda_0 = 0.942$ with a corresponding sample size n = 12 and an acceptance number c = 1, which are obtained from Table 1 for $1 - \alpha = 0.95$. Therefore, the sampling plan for the above sample data is (n = 12, c = 1, $x/\lambda_0 = 0.942$). Based on the observations, we have to decide whether to accept the product or reject it. We accept the product only if the number of failures before 942 hours is less than or equal to 1. In the above sample of 12 only one failure occurred at 519 hours before x = 942 hours. Therefore, we accept the product using the sampling plan constructed by Ravikumar *et al.* (2016).

Case II: From Table 2, the entry against r = 2 ($r = c + 1$) under the column 6r is 0.43796. Since the acceptable mean life is given to be 1000 hours for Burr Type X distribution. If the termination time is given by 'x_0' the table value says that $x_0 = 0.43796$ that is $x_0 = 0.43796 \times 1000 = 437.96 = 438$ hours (approx.).

Using the present sampling plan, this test plan will be implemented as follows: Select 12 items from the submitted lot and put them to test. If the 2nd failure is realized before 438th hour of the test, reject the lot otherwise accept the lot in either case terminating the experiment as soon as the 2nd failure is reached or 438th hour of the test time is reached whichever is earlier. In the case of acceptance, the assurance is that the average life of the submitted products is at least 1000 hours.

In this approach, we see that in the sample of 12 failures there is no failure before 438th hour, therefore we accept the product.

In both approaches the sample size, acceptance number (termination number), the risk probability and the final decision about the lot are the same. But the decision on the first approach can be reached at the 519th hour and that in the second approach reached at the 438th hour, thus second approach (the present sampling plan) requiring a less waiting time and also minimum experimental cost. Hence, the present sampling plan is preferred.

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