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ACCEPTANCE SAMPLING PLANS FOR BURR TYPE X DISTRIBUTION

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ABSTRACT

In this paper, we develop acceptance sampling plans when the life test is terminated at fixed time. The minimum sample size necessary to ensure the specified average life is obtained by assuming that the lifetimes of the test units follow a Burr type X distribution. The operating characteristic values of the sampling plans as well as producer's risk are presented. The results are illustrated by taking a real data from software reliability.

Keywords: Burr Type X Distribution, Life Test, Minimum Sample Size, OC Function, Producer's Risk.

I. INTRODUCTION

The probability density function (p.d.f.) and cumulative distribution function (c.d.f.) of the Burr Type X Distribution (BTXD) with parameters k and λ, are given by

$$f(x;k) = 2k\frac{x}{\lambda^2}e^{-(x/\lambda)^2}(1-e^{-(x/\lambda)^2})^{k-1}\,; \quad x>0,\ k>0, \lambda>0 \tag{1.1}$$

$$F(x;k) = (1-e^{-(x/\lambda)^2})^{k}; \quad x>0,\ k>0, \lambda>0. \tag{1.2}$$

Acceptance sampling plans based on life tests are discussed by [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15] and [16].

A sampling inspection plans in the case that the sample observations are lifetimes of products put to test aims at verifying that the actual population average exceeds a required minimum. The population average stands for the average lifetime of the product, say μ. If μ_0 is a specified minimum value, then one would like to verify that $\mu \geq \mu_0$, this means that the true unknown population average lifetime of the product exceeds the specified value. On the basis of a random sample of size n, the lot is accepted, if by means of a suitable decision criterion, the acceptance sampling plan decides in favor of $\mu \geq \mu_0$. Otherwise the lot is rejected. The decision criterion is naturally based on the number of observed failures in the sample of n products during a specified time 't' from which a lower bound for the unknown average lifetime is derived. If the observed number of failures is large, say larger than a number c, the derived lower bound is smaller than μ_0 and the hypothesis $\mu \geq \mu_0$ is not verified. Hence, the lot cannot be accepted. Such a sampling plan is named Reliability test plan or Acceptance sampling plans on life tests.

In this paper, we assume that the lifetime of product follows a BTX distribution. For the case that a lot of such products are submitted for inspection, we develop a 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. RELIABILITY TEST PLAN

We assume that the lifetime of a product follows a BTX distribution defined in (1.1). A common practice in life testing is to terminate the life test by a pre-determined time 't' and note the number of failures (assuming that a failure is well defined). One of the objectives of these experiments is to set a lower confidence limit on the average life (mean or median) or any other percentile of the distribution. It is then to establish a specified mean or median life with a probability of at least p^* (consumer's risk). Here, we use median life of the distribution, because our distribution is skewed, as suggested in [12]. The decision to accept the specified average life occurs if and only if the number of observed failures at the end of the fixed time 't' does not exceed a given number 'c'- called the acceptance number. The test may get terminated before the time 't' is reached when the number of failures exceeds 'c' in which case the decision is to reject the lot. For such a life test and the associated decision rule; we are interested in obtaining the smallest sample size to arrive at a decision.

An acceptance sampling plan based on life tests consists of the following quantities:

- The number of units 'n' on test;
- The acceptance number 'c', such that if at most c failures out of n occur at the end of the prefixed time t, the lot is accepted and
- The ratio t/μ_0, where μ_0 is the specified median life and t is the maximum test duration.

We assume that the BTX distribution parameters k=2 and λ=1 are known. In this case, the median lifetime of the product depend on k and λ where λ is scale parameter and it is given by median $\mu = \lambda\sqrt{-ln[1-(1/2)^{1/k}]}$ for k= 2 and λ= 1. It is proved that the distribution is an IFR model and skewed distribution. Let, μ_0 represent the required minimum median lifetime, *i.e.*, μ = 1.108128 λ_0, where λ_0 is also the lot quality parameter**.**

Thus, an acceptance sampling plan based on life tests for the BTX distribution is $(n, c, x/\lambda_0)$.

We fix the consumer's risk, *i.e.*, the probability of accepting a bad lot (the one for which the true median life μ is below the specified life μ_0 or in terms of lot quality parameter $\lambda < \lambda_0$) not to exceed 1- p*, so that p* is a minimum confidence level with which a lot of true median life below μ_0 is rejected, by the sampling plan. For a fixed p* our sampling plan is characterized by $(n, c, x/\lambda_0)$. We assume that the lot size (N) is large enough to be considered infinite for example, n/N ≤ 0.10, [17], so that the binomial distribution can be applied. Thus, the acceptance and non acceptance criteria for the lot are equivalent to the decisions of accepting or rejecting the hypothesis $\lambda \geq \lambda_0$. The problem is to determine for given values of p* (0 < p* <1), λ_0 and c, the smallest positive integer 'n' such that

$$\sum_{i=0}^{c} \binom{n}{i} p^i (1-p)^{n-i} \leq 1 - p^* \quad (2.1)$$

Where p = $F_X(x)$ is given by (1.2) indicates the failure probability before time 'x', which depends only on the ratio x/λ_0. Thus, p = $F_X(x)$ = $F_X(x;\lambda)$ = $F_X(x/\lambda)$ depends only on the ratio x/λ , if we fix k. Hence, it is sufficient to specify just this ratio. Therefore, if the number of observed failures is at most c, from (2.1), we can establish with probability p* that

$$F_X(x/\mu) \leq F_X(x/\mu_0) \Leftrightarrow F_X(x/1.108128\,\lambda_0) \leq F_X(x/1.108128\,\lambda_0) \Leftrightarrow \lambda \geq \lambda_0.$$

The minimum values of n satisfying the inequality (2.1) are obtained and displayed in Table 2.1 for p* = 0.75, 0.90, 0.95, 0.99 and x/λ_0 = 0.628, 0.942, 1.257, 1.571, 2.356, 3.141, 3.927, 4.712 for k = 2. These choices of p* and x/λ_0 help us to compare our results with those obtained in other similar works.

If $p(\lambda) = F_X(x/\lambda)$ is small and n is large the binomial probability may be approximated by Poisson probability with parameter λ= n. p so that the left side of (2.1) can be written as

$$\sum_{i=0}^{c} \frac{e^{-\lambda}\lambda^i}{i!} \leq 1 - p^*, \quad (2.2)$$

Where, $\lambda = nG_X(x/\lambda_0)$. The minimum values of 'n' satisfying (2.2) are obtained for the same combination of p*, x/λ_0 values as those used for (2.1). The results are given in Table 2.2.

The operating characteristic (OC) function of acceptance sampling based on reliability life test plan $\left(n, c, \frac{x}{\lambda_0}\right)$ gives the probability that the lot can be accepted. This probability is given by

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

Where, p given in (2.1) is a monotonically decreasing function of $\lambda \geq \lambda_0$, for a fixed x, while L(p) is decreasing in p. Based on (2.3), the operating characteristic values, as a function of λ/λ_0, for a fixed k, is determined and are presented in Table 2.3 for the acceptance sampling based on reliability life test plan under $(n, c, x/\lambda_0)$, for a fixed c and different values of p^*. For a given p^* and $/\lambda_0$, the choice of c and n can be made on the basis of the OC function.

The producer's risk is the probability of rejecting a lot when $\lambda \geq \lambda_0$. For the sampling plan under consideration and a given value for the producer's risk, say α, one may be interested in knowing the value of λ/λ_0 that will ensure the producer's risk to be at most α. We note that (1.2) can be written as

$$F(x;k) = \left(1 - e^{-\left(\frac{x}{\lambda_0}/\frac{\lambda}{\lambda_0}\right)^2}\right)^k, \quad (2.4)$$

and it will be denoted by $F_x(\lambda/\lambda_0)$, for a fixed k. The probability $p = F_x(\lambda/\lambda_0)$, may be obtained as function of λ/λ_0. Then, λ/λ_0 is the smallest positive number for which $p = F_x(\lambda/\lambda_0)$ satisfies the inequality

$$\sum_{i=0}^{c} \binom{n}{i} p^i (1-p)^{n-i} \geq 1 - \alpha, \quad (2.5)$$

For a given sampling plan $(n, c, x/\lambda_0)$, at a specified confidence level p^*, the minimum values of λ/λ_0 satisfying (2.5) were determined and are presented in Table 2.4 for $k = 2$.

Table 2.1 : Minimum sample size necessary to assert that the median life exceeds a given value λ_0 , with confidence level p* and the corresponding acceptance number c, using the binomial approximation when k= 2.

*p**	*c*	x/λ_0							
		0.628	**0.942**	**1.257**	**1.571**	**2.356**	**3.142**	**3.927**	**4.712**
0.75	0	13	4	2	1	1	1	1	1
	1	25	7	4	3	2	2	2	2
	2	36	11	6	4	3	3	3	3
	3	48	14	7	5	4	4	4	4
	4	58	17	9	7	5	5	5	5
	5	69	21	11	8	6	6	6	6
	6	80	24	13	9	7	7	7	7
	7	90	27	14	10	8	8	8	8
	8	101	30	16	12	9	9	9	9
	9	111	33	18	13	10	10	10	10
	10	122	36	19	14	11	11	11	11
0.90	0	21	6	3	2	1	1	1	1
	1	36	10	5	3	2	2	2	2
	2	49	14	7	5	3	3	3	3
	3	62	18	9	6	4	4	4	4
	4	74	21	11	7	5	5	5	5
	5	86	25	13	9	6	6	6	6
	6	97	28	15	10	7	7	7	7
	7	109	32	16	11	8	8	8	8
	8	120	35	18	13	9	9	9	9
	9	132	39	20	14	10	10	10	10
	10	143	42	22	15	11	11	11	11
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

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Table 2.2 : Minimum sample size necessary to assert that the median life exceeds a given value λ_0 , with confidence level p* and the corresponding acceptance number c, using the Poisson approximation when k= 2.

p*	c	x/λ_0							
		0.628	**0.942**	**1.257**	**1.571**	**2.356**	**3.142**	**3.927**	**4.712**
0.75	0	14	5	3	2	2	2	2	2
	1	26	8	5	4	3	3	3	3
	2	37	12	7	5	4	4	4	4
	3	49	15	9	7	6	6	6	6
	4	60	19	10	8	7	7	7	7
	5	70	22	12	9	8	8	8	8
	6	81	25	14	11	9	9	9	9
	7	92	28	16	12	10	10	10	10
	8	102	32	18	13	11	11	11	11
	9	113	35	19	15	13	12	12	12
	10	123	38	21	16	14	14	14	14
0.90	0	22	7	4	3	3	3	3	3
	1	37	12	7	5	4	4	4	4
	2	51	16	9	7	6	6	6	6
	3	63	20	11	8	7	7	7	7
	4	76	24	13	10	9	9	8	8
	5	88	27	15	12	10	10	10	10
	6	100	31	17	13	11	11	11	11
	7	111	35	19	15	12	12	12	12
	8	123	38	21	16	14	13	13	13
	9	134	42	23	17	15	15	15	15
	10	146	45	25	19	16	16	16	16
0.95	0	29	9	5	4	4	3	3	3
	1	45	14	8	6	5	5	5	5
	2	60	19	10	8	7	7	7	7
	3	74	23	13	10	8	8	8	8
	4	87	27	15	11	10	10	10	10
	5	99	31	17	13	11	11	11	11
	6	112	35	19	15	12	12	12	12
	7	124	38	21	16	14	14	14	14
	8	136	42	23	18	15	15	15	15
	9	148	46	25	19	16	16	16	16
	10	160	50	27	21	18	18	17	17
0.99	0	44	14	8	6	5	5	5	5
	1	63	20	11	8	7	7	7	7
	2	80	25	14	11	9	9	9	9
	3	95	30	16	12	11	11	11	11
	4	110	34	19	14	12	12	12	12
	5	124	38	21	16	14	14	14	14
	6	138	43	24	18	15	15	15	15
	7	151	47	26	20	17	17	17	17
	8	164	51	28	21	18	18	18	18
	9	177	55	30	23	19	19	19	19

	10	190	59	32	25	21	21	21	21

Table 2.3: Values of the Operating Characteristic Function of the sampling plan (n,c,x/λ_0) for given p* when c=2, with k=2.

*p**	*n*	x/λ_0	λ/λ_0					
			2	**4**	**6**	**8**	**10**	**12**
0.75	36	0.628	0.996064	0.999999	1.000000	1.000000	1.000000	1.000000
	11	0.942	0.991944	0.999996	1.000000	1.000000	1.000000	1.000000
	6	1.257	0.981156	0.999986	1.000000	1.000000	1.000000	1.000000
	4	1.571	0.967943	0.999966	1.000000	1.000000	1.000000	1.000000
	3	2.356	0.821527	0.999365	0.999991	1.000000	1.000000	1.000000
	3	3.142	0.412191	0.990471	0.99981	0.999991	0.999999	1.000000
	3	3.927	0.120466	0.94398	0.998211	0.999904	0.999991	0.999999
	3	4.712	0.023082	0.821527	0.990488	0.999365	0.999938	0.999991
0.90	49	0.628	0.990668	0.999996	1.000000	1.000000	1.000000	1.000000
	14	0.942	0.983737	0.999991	1.000000	1.000000	1.000000	1.000000
	7	1.257	0.969611	0.999976	1.000000	1.000000	1.000000	1.000000
	5	1.571	0.932441	0.999917	0.999999	1.000000	1.000000	1.000000
	3	2.356	0.821527	0.999365	0.999991	1.000000	1.000000	1.000000
	3	3.142	0.412191	0.990471	0.99981	0.999991	0.999999	1.000000
	3	3.927	0.120466	0.94398	0.998211	0.999904	0.999991	0.999999
	3	4.712	0.023082	0.821527	0.990488	0.999365	0.999938	0.999991
0.95	58	0.628	0.985257	0.999994	1.000000	1.000000	1.000000	1.000000
	16	0.942	0.976408	0.999987	1.000000	1.000000	1.000000	1.000000
	8	1.257	0.955168	0.999963	1.000000	1.000000	1.000000	1.000000
	5	1.571	0.932441	0.999917	0.999999	1.000000	1.000000	1.000000
	3	2.356	0.821527	0.999365	0.999991	1.000000	1.000000	1.000000
	3	3.142	0.412191	0.990471	0.99981	0.999991	0.999999	1.000000
	3	3.927	0.120466	0.94398	0.998211	0.999904	0.999991	0.999999
	3	4.712	0.023082	0.821527	0.990488	0.999365	0.999938	0.999991
0.99	76	0.628	0.970085	0.999986	1.000000	1.000000	1.000000	1.000000
	21	0.942	0.951571	0.999968	1.000000	1.000000	1.000000	1.000000
	10	1.257	0.918196	0.999921	0.999999	1.000000	1.000000	1.000000
	6	1.571	0.885815	0.999837	0.999998	1.000000	1.000000	1.000000
	4	2.356	0.587559	0.997626	0.999966	0.999999	1.000000	1.000000
	4	3.142	0.125953	0.967943	0.999271	0.999966	0.999997	1.000000
	3	3.927	0.120466	0.94398	0.998211	0.999904	0.999991	0.999999
	3	4.712	0.023082	0.821527	0.990488	0.999365	0.999938	0.999991

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Table 2.4: Minimum ratio of the median life to specified median life for the acceptance of a lot with producer's risk of 0.05 for k=2.

p*	c	λ/λ_0							
		0.628	**0.942**	**1.257**	**1.571**	**2.356**	**3.142**	**3.927**	**4.712**
0.75	0	1.01	1.06	1.13	1.1	1.66	2.21	2.76	3.32
	1	1	1	1.08	1.19	1.44	1.92	2.4	2.88
	2	1	1.02	1.07	1.09	1.34	1.79	2.24	2.69
	3	1	1	1	1.03	1.28	1.71	2.14	2.57
	4	1	1	1.02	1.11	1.24	1.66	2.08	2.49
	5	1	1.01	1.03	1.07	1.21	1.62	2.02	2.43
	6	1	1.02	1.03	1.04	1.19	1.59	1.98	2.38
	7	1	1	1	1.01	1.17	1.56	1.95	2.34
	8	1	1	1.01	1.06	1.15	1.54	1.92	2.31
	9	1	1	1.02	1.04	1.14	1.52	1.9	2.28
	10	1	1	1	1.02	1.13	1.5	1.88	2.26
0.90	0	1	1.03	1.09	1.18	1.36	1.82	2.27	2.73
	1	1	1.01	1.04	1.04	1.23	1.64	2.05	2.46
	2	1	1.01	1.03	1.1	1.17	1.56	1.95	2.34
	3	1	1.01	1.03	1.04	1.13	1.5	1.88	2.26
	4	1	1	1.03	1	1.1	1.47	1.83	2.2
	5	1	1	1.03	1.06	1.08	1.44	1.8	2.16
	6	1	1	1.03	1.03	1.06	1.42	1.77	2.13
	7	1	1	1	1	1.05	1.4	1.45	1.74
	8	1	1	1.01	1.04	1.03	1.2	1.73	1.73
	9	1	1	1.01	1.02	1.02	1.15	1.71	2.05
	10	1	1	1.01	1.01	1.01	1.35	1.69	2.03
0.95	0	1	1.04	1.1	1.07	1.22	1.63	2.04	2.45
	1	1	1	1.04	1.1	1.12	1.5	1.88	2.25
	2	1	1	1.03	1.03	1.07	1.43	1.79	2.15
	3	1	1	1.02	1.07	1.04	1.39	1.74	2.09
	4	1	1	1.02	1.03	1.02	1.36	1.7	2.05
	5	1	1	1.02	1	1	1.34	1.68	2.01
	6	1	1.01	1.02	1.04	1.21	1.32	1.65	1.98
	7	1	1	1.02	1.02	1.19	1.31	1.63	1.96
	8	1	1	1.02	1	1.17	1.29	1.62	1.94
	9	1	1	1	1.03	1.16	1.28	1.6	1.92
	10	1	1	1	1.01	1.15	1.27	1.59	1.91
0.99	0	1	1	1.02	1.06	1.02	1.36	1.7	2.04
	1	1	1.01	1.03	1.07	1.25	1.28	1.6	1.92
	2	1	1	1.01	1.01	1.2	1.24	1.55	1.86
	3	1	1.01	1	1.04	1.16	1.21	1.51	1.82
	4	1	1	1	1.01	1.13	1.19	1.49	1.79
	5	1	1	1	1.04	1.11	1.18	1.47	1.77
	6	1	1	1.02	1.01	1.09	1.16	1.45	1.75
	7	1	1	1.02	1.04	1.08	1.15	1.44	1.73
	8	1	1	1	1.02	1.06	1.14	1.43	1.72
	9	1	1	1	1	1.05	1.14	1.42	1.7
	10	1	1	1	1.02	1.04	1.13	1.41	1.69

III. DESCRIPTION OF THE TABLES

Assume that the lifetime distribution is Burr Type X distribution with $k = 2$. The numerical results are presented in Tables 2.1- 2.4. Table 2.1 presents the minimum sample size necessary to assert that the median life exceeds a given value, λ_0 with probability p* and the corresponding acceptance number, c, using binomial probabilities. Table 2.2 presents the minimum sample size necessary to assert that the median life exceeds a given value, λ_0 with probability p* and the corresponding acceptance number c, using Poisson probabilities. Table 2.3 presents the operating characteristics values for the sampling plan (n, c, x/ λ_0) for a given p* when c = 2. Finally, Table 2.4 presents the minimum ratios of true median life to specified median life for the acceptance of a lot with producer's risk of 0.05. Use of these tables is illustrated in the following example.

Suppose an experimenter specifies that the minimum average life for his products is 1000 hours in order to test this hypothesis by conducting a life test experiment and wants to decide the acceptance or rejection of this hypothesis on the basis of number of failed items out of *n* items to be tested. If the consumer's risk is specified as 0.1 the problem is to find how many items are to be tested and what would be the acceptance number for that test.

In the notation of working of this procedure it may be noted that we are given the following information: x=628 hours, λ_0=1000, p^*=0.90. Further suppose that the experimenter cannot bear the loss of more than 3 failures in a sample. We have to find *n* namely the size of the sample.

From Table 2.1 against p^*=0.90 corresponding to x/ λ_0 =0.628, c=3 the value of *n* is 62. That is 62 products are to be used in conducting the life testing experiment for 628 hours. If the number of failures observed in the life testing experiment exceeds 3 before reaching 628th hour we have to reject the lot. If all the items failed before 628th hour reject the lot. If no item fails before 628th hour accept the lot.

IV. NUMERICAL EXAMPLE

Consider the following ordered failure times in hours (T) of the software reliability provided by [18]. We assume that while the software is operating, the development of intangible cumulative degradation deteriorates the performance of this software. Then, it is reasonable to suppose that the random variable T follows a BTX distribution. Through T, it will be possible to classify one unit of the software release like defective or non-defective. Let the specified median life be λ_0 = 1000 hours. Let consumer's risk be 0.10, if the times of 16 failures are given as (t_i; i = 1, 2, ..., 16): 519, 968, 1430, 1893, 2490, 3058, 3625, 4422, 5218, 5823, 6539, 7083, 7487, 7846, 8205 and 8564 based this life time data we have to find a termination time and decide whether the software product is to be accepted or not. Here we are given n=16 and p^*=0.90 with the help of these two from Table 2.1. We see that x/ λ_0 is 1.257 against p^*=0.90 and n=16, c=7. The meaning of these table readings can be explained as follows.

x/λ_0=1.257 ; λ_0 =1000 which implies x=1257.

That is the termination of the experiment is 1257. In the data of 16 failure times we see that two failures occurred at a time less than 1257. But the table says that c=7 which means maximum allowable failures is 7. Since our data contains less failures than what is allowable namely 7, that is number of failures observed is less than c, we accept the software with the recorded sample 16 failures.

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