Journal of Computer and Mathematical Sciences, *Vol.9(12),1851-1860 December 2018* *ISSN 0976-5727 (Print)*
(An International Research Journal), *www.compmath-journal.org* *ISSN 2319-8133 (Online)*

An Economic Reliability Test Plans for Exponential Pareto Distribution

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(Received on: November 29, 2018)

ABSTRACT

Exponential Pareto distribution (EPD) is introduced by Kareema and Mohammad[2] is considered as a probability model for the life time of products. 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. For a given sample size, producer's risk and termination number, a test plan to determine waiting time to terminate the experiment is constructed for EPD. The preferability of the present test plan over the existing plans is established with respect to termination time of the experiment. The methodology is explained by a real data.

AMS Subject Classification: 62N05, 90B25.

Keywords: Exponential Pareto distribution, Economic reliability test plan, Experimental time.

1. INTRODUCTION

In today's manufacturing world, the path from raw materials to final product often takes place over multiple companies and across multiple continents. A company selling laptop computers has likely sub-contracted different parts to different sub-contractors. The assembling of parts might take place in yet another plant and the packing and shipping, from yet another location. In order to assure a certain quality level, companies use inspection at the different supply chain stages. Acceptance sampling, also known as sampling inspection consists of quality assurance schemes designed to test whether the quality of batches of products or services confirm with requirements, based on inspecting only a sample from each batch. The use of sampling inspection relies on the premise that products need not confirm 100% with specification requirements and it is often more economical to allow a small percentage of non-conforming items to pass on for later rejection than to bear the expense of 100% inspection.

Acceptance sampling provides criteria and decision rules for determining whether to accept or reject a batch based on a sample. Civilian ISO acceptance sampling plans and their military counterparts (MIL-STD) are commonly used standards in industry. These plans dictate the sample size to be drawn from each batch and the requirements that the sample must meet to assure that the entire batch is of acceptable quality. Acceptance sampling is useful for testing the quality of batch of items, especially when a large number of items must be processes in a short time. An acceptance sampling plans is concerned with accepting or rejecting a submitted lot of product on the basis of quality of products inspected from the sample taken from the lot. It is the scheme that establishes the minimum sample size to be used for testing. This becomes particularly important if the quality of the product is defined by its lifetime. If a decision is to accept or reject a lot are subject to risks associated with two types of errors. This procedure is termed as reliability test plan or acceptance sampling plan based on life test.

Skewed probability distributions are the basis for reliability test plans. These distributions are used to find the reliability sampling plans which will be more economical for the experimenter. Economic reliability test plans based on life test for different distributions have studied by several authors, which are: Rosaiah *et al*.[8] studied reliability test plans for exponentiated log-logistic distribution. Jun *et al*.[4] studied variable sampling plans for Weibull distributed life times under sudden death testing. Kantam *et al*.[16] studied an economic reliability test plan under log-logistic distribution. Aslam and Shahbaz[13] studied economic reliability test plans using the generalized exponential distribution. Aslam and Kantam[14] studied economic reliability acceptance sampling plan based on truncated life tests in Birnbaum-Saunders distribution. Rosaiah *et al*.[9] studied economic reliability test plan for inverse Rayleigh distribution. Mughal *et al*.[1] proposed economic reliability sampling plans from truncated life tests based on the Burr-type XII percentiles. Rao *et al*.[6] proposed an economic reliability test plan for Marshall-Olkin extended exponential distribution. Rao *et al*.[7] studied economic reliability test plan for generalized log-logistic distribution. Ramkumar and Sajana[17] and[18] considered economic reliability test plan for Burr distribution and four parametric Burr distributions. Rosaiah *et al.*[11] and[10] developed economic reliability test plan for Type-I and Type-II generalized half logistic distributions. Rao[5] studied economic reliability test plan based on truncated life tests for Marshall-Olkin extended Weibull distribution. Recently, Rosaiah *et al.*[12] developed economic reliability test plans based on truncated life tests for exponentiated Fréchet distribution.

Probability distributions have been in use to develop the reliability test plans. Under these plans, we can find the termination time of experiment. In reliability test plan, we terminate the experiment if the termination time *t* ends or the r^{th} failure occur, if we put the *n* sample units on test, whichever occurs first. Sample size selection is an important factor in life test experiments to reduce the experimental time and cost. The sample size is selected keeping in view the cost of experiment and the expected waiting time to reach the decision, for more details see Kantam *et al*.[16]. These reasons motivate to develop economic reliability test plans for exponential Pareto distribution.

In this article, we discussed the design of an economic reliability test plan for exponential Pareto distribution (EPD) under a truncated life test and description of the proposed sampling plan in Section 2. The Operating characteristic values of the present sampling plans are presented in Section 3. The results are illustrated by an example in Section 4. The comparative study of the present economic reliability sampling plans with that of the existing acceptance sampling plans is presented in Section 5.

2. THE ECONOMIC RELIABILITY TEST PLANS

The probability density function (p.d.f), cumulative distribution function (c.d.f) and hazard function of exponential Pareto distribution (EPD) are respectively given by

$$f(t) = \left[(\lambda\theta/\sigma)(t/\sigma)^{\theta-1} e^{-\lambda (t/\sigma)^{\theta}} \right], \ \text{t} > 0; \lambda, \sigma, \theta > 0 \quad (1)$$

$$F(t) = 1 - \left[e^{-\lambda (t/\sigma)^{\theta}} \right], \ \text{t} > 0; \lambda, \sigma, \theta > 0 \quad (2)$$

$$\text{and } h(t) = \frac{\lambda\theta}{\sigma}\left(\frac{t}{\sigma}\right)^{\theta-1}, t > 0; \ \lambda, \sigma, \theta > 0 \quad (3)$$

EPD is decreasing failure rate (DFR) for $0 < \theta < 1$, increasing failure rate (IFR) for $\theta > 1$ and a constant failure rate (CFR) for $\theta = 1$. Hence in reliability studies the EPD can be used as CFR, IFR, DFR model.

Amulya[15] has determined the minimum sample sizes required to make a decision about the lot for a given waiting time in terms of σ_0 (*i.e.*, t/σ_0) and the acceptance number *c*, some risk probability, say *α*, with a specified σ_0 of σ, the probability of detecting *c* or less failures (the probability of accepting the lot) in a sample of size *n* is given by

$$P_a(p) = \sum_{i=0}^{c} \binom{n}{i} p^i (1-p)^{n-i} \quad (4)$$

where $p = F(t; \sigma, \lambda, \theta)$. For $\sigma_0 > \sigma$, the above probability of acceptance should increase. Therefore, if *α* is a prefixed risk probability, this means

$$\sum_{i=0}^{c} \binom{n}{i} p^i (1-p)^{n-i} \geq 1 - \alpha \quad (5)$$

For a given σ_0 and hence t/σ_0, this is a single inequality in two unknowns *n* and *c* assuming that the parameters λ and θ are known. Because, *c* is always less than *n*, inequality

(4) can be solved for *n* with successive values of *c* from zero onwards. The earliest value of *n* that satisfies the inequality (4) are obtained for $\lambda = 1.5,\ \theta = 1.5, 2.0$; $1-\alpha = 0.75,\ 0.90, 0.95, 0.99$; $t/\sigma_0 = 0.628, 0.942, 1.257, 1.571, 2.356, 3.141, 3.927, 4.712$ and $c = 0(1)10$ by Amulya[15] along with the associated performance characteristics like operating characteristic, producer's risk. A typical portion of the tables of Amulya[15] for exponential Pareto distribution (EPD) is reproduced in Table 1 for $\lambda = 1.5,\ \theta = 2.0$.

In the present investigation, inequality (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. The probability of such a rejection should be as small as possible. That is

$$\sum_{i=r}^{n} \binom{n}{i} p^i (1-p)^{n-i} < \alpha \tag{6}$$

Assuming that *n* as a multiple of *r* say *kr* (*k* = 1, 2, …, 10), inequality (5) can be regarded as an inequality in a single unknown in terms of t/σ_0 with known λ, θ. With the choice of *r, k, α,* inequality (5) can be solved for the earliest *p* say p_0 from which the value of t/σ_0 can be obtained by inverting $F\ t;\sigma_0,\lambda,\theta$ given by (2). The specified population average in terms σ_0 can be used here to get the value of *t* called the termination time. These are presented in Table 2 for the values of *n=kr (k=1,2, …, 10),* $\lambda = 1.5,\ \theta = 2.0$.

3. OPERATING CHARACTERISTIC

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 life from the true average life. This function is called operating characteristic (O.C.) function of the sampling plan. Specifically, if $F\ t;\sigma_0,\lambda,\theta$ is the cumulative distribution function of the life time random variable of the product and corresponds to specified average life, then we can write

$$F(t/\sigma) = [F(t/\sigma_0)(\sigma_0/\sigma)] \tag{6}$$

Here, σ corresponds to true but unknown average life. The ratio σ_0/σ in the R.H.S. of above equation can be taken as a measure of changes between true and specified average lifes. For instance σ_0/σ < 1 implies true mean life is more than the specified mean life leading to more acceptance probability. Similarly, σ_0/σ is more than 1 implies that less acceptance probability or more failure risk. Hence given a set of hypothetical values say, σ_0/σ =0.1(0.1)1.9, we can have the corresponding acceptance probabilities for the given sampling plan. The graph between σ_0/σ and probabilities of acceptance given by equation (6) for a sampling plan forms the O.C. curve of that plan. Here, we have selected some plans and the corresponding O.C. values of these plans are given in Table 5. The corresponding O.C. curves are also drawn.

4. ILLUSTRATION

Consider the following ordered failure times (in hours) 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[3]. This data can be regarded as an ordered sample of size $n=8$ with observations. $t_i = 519, 968, 1430, 1893, 2490, 3058, 3625, 4422$. The confidence level of the decision process is assured by the present plan only if the lifetime follows EPD, we have verified this for the above ordered sample data by Q-Q plot with $\lambda = 1.5, \theta = 2.0$.

Case (i):-Let the specified lifetime σ_0 be 1000 hours and the testing time be t = 942 hours, i.e., t/σ_0 = 0.942 with a corresponding sample size $n=8$ and an acceptance number c=2, which are obtained from Table 1 for $1-\alpha = 0.99$. Therefore, the sampling plan for the above sample data is (n = 8; c = 2; t/σ_0 = 0.942). Based on the observations, we have to decide whether to accept the lot or reject it. From the given ordered sample, we observe that the number of failures of the software product before 942 hours are only one i.e., 519. Therefore, we accept the lot on the basis of the sampling plans developed by Amulay[15].

Case (ii):- on the basis of present economic reliability test plan for the above ordered sample of size 8 and test termination number $r=1$ at risk probability of 0.01 the value of t/σ_0 from Table 2 is $t/\sigma_0 = 0.0289$. That is, the termination time is 28.9 hours. Hence the number of failures earlier than 28.9 hours of the experiment should not be more than 1. From the given ordered sample data, we observe that no failure is occurred earlier than the termination time of 28.9 hours. Therefore, we accept the lot on the basis of the economic reliability test plan.

Hence, in both of these sampling plans the sample size, acceptance number (termination number), the risk probability and the final decision about the lot are same. But the decision on the sampling plans can be reached at 942 hours and that in the economic reliability test plan at the 28.9 hours, thus the economic reliability test plan requiring a less waiting time and minimum experimental cost. Finally, we concludes that the present economic reliability test plan can be preferred.

5. COMPARATIVE STUDY

In order to compare the present sampling plan with that of Amulya[15], the entries common for both the sampling plans are presented in Tables 3 and 4. The entries given in the first row are corresponding to the present economic reliability test plan and those given in the second row are obtained by Amulya[15]. All the entries in Tables 3 and 4 show that for a given *n, r* (*r = c+1*), the values of the t/σ_0 - the scale termination time are uniformly smaller for the present economic reliability test plan than those of Amulya[15], which shows the reduction in the experimental time and cost.

Table 1: Minimum sample sizes necessary to assert the average life to exceed specified average life σ_0, with probability $1-\alpha$ and the corresponding acceptance number *c*, using Binomial probabilities for $\lambda = 1.5$, $\theta = 2.0$ Amulya, 15 .

1-α	c	$t/\sigma_0 = 0.628$	0.942	1.257	1.571	2.356	3.141	3.927	4.712
0.75	0	3	2	1	1	1	1	1	1
	1	6	3	2	2	2	2	2	2
	2	8	5	4	3	3	3	3	3
	3	11	6	5	4	4	4	4	4
	4	13	8	6	5	5	5	5	5
	5	16	9	7	6	6	6	6	6
	6	18	11	8	7	7	7	7	7
	7	21	12	9	8	8	8	8	8
	8	23	13	10	9	9	9	9	9
	9	26	15	12	10	10	10	10	10
	10	28	16	13	11	11	11	11	11
0.90	0	4	2	1	1	1	1	1	1
	1	8	4	3	2	2	2	2	2
	2	11	6	4	3	3	3	3	3
	3	13	7	5	4	4	4	4	4
	4	16	9	7	6	5	5	5	5
	5	19	10	8	7	6	6	6	6
	6	22	12	9	8	7	7	7	7
	7	24	14	10	9	8	8	8	8
	8	27	15	11	10	9	9	9	9
	9	29	17	12	11	10	10	10	10
	10	32	18	14	12	11	11	11	11
0.95	0	6	3	2	1	1	1	1	1
	1	9	5	3	2	2	2	2	2
	2	12	6	4	4	3	3	3	3
	3	15	8	6	5	4	4	4	4
	4	18	10	7	6	5	5	5	5
	5	21	11	8	7	6	6	6	6
	6	24	13	9	8	7	7	7	7
	7	27	15	11	9	8	8	8	8
	8	29	16	12	10	9	9	9	9
	9	32	18	13	11	10	10	10	10
	10	35	19	14	12	11	11	11	11
0.99	0	8	4	2	2	1	1	1	1
	1	12	6	4	3	2	2	2	2
	2	16	8	5	4	3	3	3	3
	3	19	10	7	5	4	4	4	4
	4	22	12	8	6	5	5	5	5
	5	25	13	9	8	6	6	6	6
	6	28	15	11	9	7	7	7	7
	7	31	17	12	10	8	8	8	8
	8	34	18	13	11	9	9	9	9
	9	37	20	14	12	10	10	10	10
	10	40	21	15	13	11	11	11	11

Table 2: Life test termination time in units of scale parameter t/σ_0 in exponential Pareto distribution for $\lambda = 1.5$, $\theta = 2$.

r	n=2r	3r	4r	5r	6r	7r	8r	9r	10r
					$\alpha = 0.25$				
1	0.3097	0.2528	0.2190	0.1958	0.1788	0.1655	0.1548	0.1460	0.1385
2	0.4308	0.3423	0.2927	0.2600	0.2362	0.2180	0.2034	0.1914	0.1813
3	0.4846	0.3808	0.3242	0.2871	0.2605	0.2401	0.2239	0.2105	0.1993
4	0.5158	0.4029	0.3422	0.3027	0.2743	0.2527	0.2355	0.2214	0.2096
5	0.5366	0.4176	0.3541	0.3129	0.2835	0.2611	0.2432	0.2286	0.2164
6	0.5515	0.4281	0.3626	0.3203	0.2901	0.2670	0.2488	0.2338	0.2212
7	0.5629	0.4361	0.3691	0.3259	0.2951	0.2716	0.2530	0.2377	0.2250
8	0.5718	0.4424	0.3743	0.3304	0.2990	0.2752	0.2563	0.2409	0.2279
9	0.5792	0.4476	0.3785	0.3340	0.3023	0.2782	0.2591	0.2434	0.2303
10	0.5853	0.4519	0.3820	0.3370	0.3050	0.2806	0.2613	0.2455	0.2323
					$\alpha = 0.10$				
1	0.1874	0.1530	0.1325	0.1185	0.1082	0.1001	0.0937	0.0883	0.0838
2	0.3202	0.2545	0.2177	0.1933	0.1757	0.1621	0.1513	0.1424	0.1349
3	0.3867	0.3041	0.2589	0.2293	0.2080	0.1918	0.1788	0.1681	0.1592
4	0.4274	0.3341	0.2838	0.2511	0.2276	0.2096	0.1954	0.1837	0.1739
5	0.4554	0.3547	0.3008	0.2659	0.2409	0.2218	0.2067	0.1943	0.1839
6	0.4760	0.3698	0.3133	0.2768	0.2507	0.2308	0.2150	0.2021	0.1912
7	0.4921	0.3816	0.3230	0.2853	0.2583	0.2377	0.2215	0.2081	0.1969
8	0.5049	0.3910	0.3308	0.2921	0.2644	0.2433	0.2266	0.2130	0.2015
9	0.5156	0.3988	0.3373	0.2977	0.2694	0.2479	0.2309	0.2170	0.2053
10	0.5246	0.4053	0.3427	0.3024	0.2737	0.2518	0.2345	0.2203	0.2085
					$\alpha = 0.05$				
1	0.1308	0.1068	0.0925	0.0827	0.0755	0.0699	0.0654	0.0616	0.0584
2	0.2617	0.2080	0.1779	0.1580	0.1436	0.1325	0.1236	0.1164	0.1102
3	0.3329	0.2619	0.2230	0.1975	0.1792	0.1652	0.1540	0.1448	0.1371
4	0.3780	0.2956	0.2511	0.2221	0.2013	0.1855	0.1729	0.1625	0.1538
5	0.4095	0.3191	0.2707	0.2393	0.2168	0.1996	0.1860	0.1748	0.1655
6	0.4331	0.3367	0.2853	0.2520	0.2282	0.2101	0.1958	0.1840	0.1741
7	0.4516	0.3504	0.2966	0.2620	0.2372	0.2183	0.2034	0.1911	0.1809
8	0.4666	0.3614	0.3059	0.2700	0.2444	0.2250	0.2095	0.1969	0.1863
9	0.4790	0.3706	0.3135	0.2767	0.2504	0.2305	0.2147	0.2017	0.1908
10	0.4895	0.3784	0.3200	0.2824	0.2555	0.2352	0.2190	0.2058	0.1947
					$\alpha = 0.01$				
1	0.0579	0.0472	0.0409	0.0365	0.0334	0.0309	0.0289	0.0272	0.0258
2	0.1691	0.1345	0.1150	0.1021	0.0928	0.0857	0.0799	0.0752	0.0713
3	0.2429	0.1912	0.1628	0.1442	0.1308	0.1206	0.1125	0.1058	0.1001
4	0.2932	0.2294	0.1949	0.1724	0.1563	0.1440	0.1342	0.1262	0.1194
5	0.3297	0.2570	0.2181	0.1928	0.1746	0.1608	0.1498	0.1409	0.1333
6	0.3577	0.2782	0.2357	0.2083	0.1886	0.1737	0.1618	0.1521	0.1439
7	0.3800	0.2950	0.2498	0.2206	0.1997	0.1839	0.1713	0.1609	0.1523
8	0.3982	0.3087	0.2613	0.2307	0.2088	0.1922	0.1790	0.1682	0.1592
9	0.4136	0.3202	0.2709	0.2391	0.2164	0.1992	0.1855	0.1743	0.1649
10	0.4267	0.3301	0.2791	0.2463	0.2229	0.2052	0.1911	0.1795	0.1698

Table 3: **Comparison of Life test termination time for sampling plans of Amulya[15] and the present sampling plans with producer's risk $\alpha = 0.05$ for $\lambda = 1.5, \theta = 2.0$**

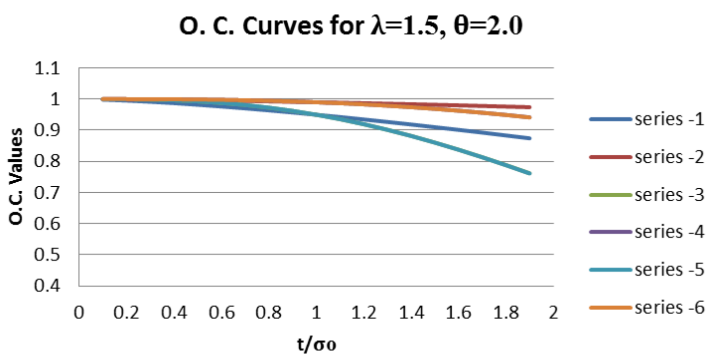
r \ n	2r	3r	4r	5r	6r	7r	8r	9r	10r
1	0.1308 **(1.257)**	0.1068 **(0.942)**			0.0755 **(0.628)**				
2									
3	0.3329 **(0.942)**		0.2230 **(0.628)**						
4	0.3780 **(0.942)**								
5	0.4095 **(0.942)**								
6									
7									
8									
9									
10									

Table 4: **Comparison of Life test termination time for sampling plans of Amulya[15] and the present sampling plans with producer's risk $\alpha = 0.01$ for $\lambda = 1.5, \theta = 2.0$**

r \ n	2r	3r	4r	5r	6r	7r	8r	9r	10r
1	0.0579 **(1.257)**		0.0409 **(0.942)**				0.0289 **(0.628)**		
2	0.1691 **(1.257)**	0.1345 **(0.942)**			0.0928 **(0.628)**				
3									
4									
5									
6									
7			0.2498 **(0.628)**						
8									
9	0.4136 **(0.942)**								
10	0.4267 **(0.942)**								

Table 5: **Operating characteristic (O.C) values of sampling plans** $n, r, t/\sigma_0$ **for** $\lambda = 1.5, \theta = 2.0$

	n=2, r=1		**n=4, r=2**		**n=8, r=2**	
	t/σ_0		t/σ_0		t/σ_0	
	0.0664	**0.0224**	**0.1674**	**0.0935**	**0.1001**	**0.0560**
σ_0/σ	$1-\alpha=0.95$ Series -1	$1-\alpha=0.99$ Series -2	$1-\alpha=0.95$ Series -3	$1-\alpha=0.99$ Series -4	$1-\alpha=0.95$ Series -5	$1-\alpha=0.99$ Series -6
0.1	0.9984	0.9997	0.9999	1.0000	0.9999	1.0000
0.2	0.9954	0.9991	0.9995	0.9999	0.9995	0.9999
0.3	0.9916	0.9983	0.9984	0.9997	0.9984	0.9997
0.4	0.9871	0.9975	0.9962	0.9993	0.9962	0.9993
0.5	0.9820	0.9965	0.9927	0.9987	0.9927	0.9987
0.6	0.9764	0.9953	0.9878	0.9977	0.9878	0.9977
0.7	0.9704	0.9941	0.9811	0.9964	0.9811	0.9964
0.8	0.9639	0.9928	0.9726	0.9947	0.9727	0.9947
0.9	0.9571	0.9914	0.9623	0.9926	0.9623	0.9926
1.0	0.9500	0.9900	0.9500	0.9900	0.9500	0.9900
1.1	0.9425	0.9885	0.9357	0.9869	0.9357	0.9869
1.2	0.9348	0.9869	0.9196	0.9833	0.9196	0.9832
1.3	0.9267	0.9852	0.9016	0.9791	0.9016	0.9790
1.4	0.9185	0.9835	0.8819	0.9743	0.8818	0.9742
1.5	0.9100	0.9817	0.8606	0.9689	0.8604	0.9688
1.6	0.9013	0.9799	0.8377	0.9630	0.8375	0.9628
1.7	0.8925	0.9780	0.8136	0.9564	0.8133	0.9563
1.8	0.8834	0.9760	0.7882	0.9493	0.7878	0.9491
1.9	0.8742	0.9740	0.7618	0.9415	0.7613	0.9412



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