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An Acceptance Sampling Plan under Frechet Distribution Assuring Median Life

[1]S. Balamurali, [2]Muhammad Aslam and [3]Mohammad Saber Fallah Nezhad
[1]Department of Mathematics, Kalasalingam University, Krishnankoil 626190, TN, India
[2]Department of Statistics, Forman Christian College University, Lahore 54000, Pakistan
[3]Department of Industrial Engineering, Yazd University, Iran

Abstract: Reliability sampling plans are used to determine the acceptability of a product at some future point in its effective life. Whenever the life test is performed based on the non-measurement characteristics, attributes sampling plans can be utilized. In this study, we propose an attribute reliability sampling plan for assuring median life time under failure censored life testing when the life time of the product follows a Frechet distribution. The optimal parameters of the proposed plan are determined by using two points on the operating characteristic curve approach. To determine the optimal parameters, an optimization problem is formulated so as to minimize the average number of failures to be observed.

Keywords: Acceptance sampling plans, Frechet distribution, life test, producer's risk and consumer's risk

INTRODUCTION

Acceptance sampling is one of the major areas of statistical quality control. Acceptance sampling is the methodology that deals with procedures by which decision to accept or reject the lot based on the results of the inspection of samples. Acceptance sampling prescribes a procedure that, if applied to a series of lots, will give a specified risk of accepting lots of given quality. In other words, acceptance sampling yields quality assurance. It is also to be pointed out that the acceptance sampling plans are also used to reduce the cost of inspection. The acceptance sampling could be classified in to sampling plans by attributes and sampling plans by variables. In attributes sampling, several sampling plans are available. For example, single sampling plan, double sampling plan, multiple sampling plan, continuous sampling plan, skip-lot sampling plan etc.

If the quality characteristic is regarding the life time of the products, then the acceptance sampling procedure is called a life test. Quality personnel would like to know whether the life time of the products reach the consumer's standard or not. Generally, when the life test assures that the mean or median life of the products exceeds some specified life time, then the lot of products is accepted otherwise the lot is rejected. In order to save the test time and testing cost, a truncated life test may be conducted to find the smallest sample size to ensure a certain mean or median life time of products when the life test is terminated at the pre-determined time t_0 and the number of failures observed does not exceed a given acceptance number c. The decision is to accept the lot if a pre-determined mean or median life can be reached with a pre-determined high probability which provides protection to the consumers. Hence the life test is ended when (c+1) st failure is observed or at the pre-assigned time t_0. Sampling plans based on truncated life tests have been developed and investigated by many authors. Sampling plans based on truncated life tests for exponential distribution was first discussed by Epstein (1954). The results were extended by Goode and Kao (1961) for Weibull distribution, by Gupta and Groll (1961) for gamma distribution, by Kantam and Rosaiah (1998) for half logistic distribution, by Kantam *et al*. (2001) for log-logistic distribution, by Baklizi and El Masri (2004) for Birnbaum-Saunders distribution, by Rosaiah and Kantam (2005) for inverse Rayleigh distribution, by Tsai and Wu (2006) for generalized Rayleigh distribution and by Balakrishnan *et al*. (2007) for generalized Birnbaum-Saunders distribution. Rosaiah *et al*. (2006) developed sampling plans exponentiated log-logistic distribution. Tsai and Wu (2006) developed sampling plans for generalized Rayleigh distribution; Rao *et al*. (2009) developed sampling plans for Marshell-Olkin extended exponential distribution. Lio *et al*. (2010) studied the sampling plans under Birnbaum-Saunders distribution for percentiles. Aslam *et al*. (2010) developed the time truncated life test sampling plan for the generalized exponential distribution.

In this study, we develop an acceptance sampling plan for sentencing lots when the life time of a product follows Frechet distribution. Tables are also constructed for the selection of optimal parameters for given two

Corresponding Author: S. Balamurali, Department of Mathematics, Kalasalingam University, Krishnankoil 626190, TN, India

points on the Operating Characteristic (OC) curve approach along with respective probability of risks. The rest of the study is organized as follows.

FRECHET DISTRIBUTION

Frechet (1927) had developed one possible limit distribution for the largest order statistic called the Fréchet distribution. Kotz and Nadarajah (2000) discussed the applications of this distribution in over fifty fields ranging from accelerated life testing through to earthquakes, foods, horse racing, rainfall, queues in supermarkets, sea currents, wind speeds and track race records. This distribution is also known as the Extreme Value Type II distribution. Suppose that the product lifetime follows a Frechet distribution which has the following Probability Density Function (PDF) and the Cumulative Distribution Function (CDF) respectively:

$$f(t) = \left(\frac{\gamma}{s}\right)\left(\frac{t}{s}\right)^{-1-\gamma} e^{-\left(\frac{t}{s}\right)^{-\gamma}}, \ t > 0 \tag{1}$$

$$F(t) = e^{-\left(\frac{t}{s}\right)^{-\gamma}}, \ t > 0 \tag{2}$$

where,
γ = The shape parameter
s = The scale parameter of the Frechet distribution

The mean of the distribution is given by:

$$\mu = s\sqrt{\left(1 - \frac{1}{\gamma}\right)} \tag{3}$$

where, $\sqrt{(.)}$ is a gamma function. The probability of the failure of an item before experiment time t_0 using the mean as the life time is given by:

$$p = e^{-\left(\frac{aw}{\mu/\mu_0}\right)^{-\gamma}} \tag{4}$$

where, μ/μ_0 is the ratio of true mean life to the specified mean life, a is the termination ratio and $w = \sqrt{\left(1 - \frac{1}{\gamma}\right)}$.
The median of the distribution is given by:

$$m = \frac{s}{\sqrt[\gamma]{\log_e(2)}} \tag{5}$$

The probability of the failure of an item before experiment time using the median as the life of the product is given by:

$$p = e^{-\left(\frac{a}{b}\frac{1}{m/m_0}\right)^{-\gamma}} \tag{6}$$

where,
m/m_0 = The ratio of true median life to the specified median
a = The termination ratio
b = $\sqrt[\gamma]{\log_e(2)}$

ACCEPTANCE SAMPLING PLANS

Assume that a truncated life test is conducted for life time of products that have a Frechet distribution defined in (1). The main objective of the test is to set a lower confidence limit on the median life and to test whether the median life of the products is equal to or larger than the specified expected median. Let m represent the true median life time of a product and m_0 denote the specified median life time. A product is considered as a good and can be accepted for the consumer's use if the sample information should satisfy the null hypothesis H_0: $m \geq m_0$, otherwise the lot of the products rejected. That is, a lot is said to be a good lot if the true median life of the products in the lot should be at least m_0 and a lot is classified as a bad one if the true median life of the products is below m_0. In the concept of acceptance sampling, this hypothesis is tested based on the number of failures observed from the sample in a pre-determined time. We will accept the lot if there is sufficient evidence that $m > m_0$ otherwise the lot is rejected. Based on this, the operation of sampling plan is as follows:

- Select a random sample of size n and put on the tests. An experimenter runs this experiment for a pre-decided experiment time t_0. The acceptance number (action number) c is fixed for an experiment.
- The experiment is truncated if more than c failures are recorded before the end of experiment time or the time of experiment is ended, whichever is earlier. A lot is accepted and released for consumer's use if no more than c failures are observed during this time and we accept $m \geq m_0$, otherwise we reject it.

As mentioned already, an acceptance sampling plan based on truncated life test consists of the minimum number of units on the test n, the acceptance number c and the ration m/m_0, where m_0 is the specified median life time of the Frechet distribution. The proposed sampling plan based on the Frechet distribution is denoted by the triplet (n, c and m/m_0).

There are two kinds of risks always involved in any acceptance sampling plan. The probability of rejecting a good lot is called the producer's risk (α) whereas the probability of accepting a bad quality lot is known as the consumer's risk (β). The OC function of the proposed plan is given by:

$$L(p) = \sum_{i=1}^{c} \binom{n}{i} p^i (1-p)^{n-i} \tag{7}$$

where, p is the function of cdf of underlying lifetime distribution and is obtained from Eq. (2). We need to find the values of plan parameters mentioned above. It is only possible, if both producer's risk and consumer's risk are used in simulation process. This approach to simulate the optimal plan parameters is known as the two points on the OC curve approach. In acceptance sampling schemes, producer and consumer are more conscious about the rejection of a good lot and acceptance of a bad lot respectively. So, the producer wants that the probability of acceptance should be larger than his confidence level $(1-\alpha)$ and consumer desires that the lot acceptance probability should be less than his risk β. The main advantage of the simulation process using this approach is that we get the plan parameters that are according to the producer's and consumer's risk desire. Other than two conditions stated above, we need to impose some other constraints to reduce the space to reach on appropriate combinations of the plan parameters. Let p_1 (Acceptable Quality Level (AQL)) be the probability of failure corresponding to producer's risk and p_2 (Limiting Quality Level (LQL)) is the probability of failure of the product corresponding to consumer's risk. We are interested to find four values of the plan parameters such that the following two inequalities should be satisfied:

$$L(p_1) = \sum_{i=1}^{c} \binom{n}{i} p_1^{\,i} (1-p_1)^{n-i} \geq 1-\alpha$$

$$L(p_2) = \sum_{i=1}^{c} \binom{n}{i} p_2^{\,i} (1-p_2)^{n-i} \leq \beta \tag{8}$$

Under the Frechet distribution p_1 and p_2 obtained from producer's risk at m/m_0 by considering median ratios larger than 1 and consumer's risk at m/m_0 = 1. These probabilities under the Frechet distribution can be obtained from Eq. (6). We obtained the plan parameters of the proposed plan by minimizing the sample size at consumer's risk. These optimal parameters of the proposed plan under the Frechet distribution are placed in Table 1 to 3. We considered three values of shape parameters of the Frechet distribution (γ = 1, 2, 3), experiment termination ratios (a = 0.5, 1.0), producer risk $(\alpha = 0.05)$, consumer's risk $(\beta = 0.25, 0.10, 0.05, 0.01)$ and various values of percentile ratios m/m_0 = 1.2, 1.4, 1.6, 1.8, 2., 2.2. Table 1 is constructed for shape parameter 1, Table 2 is

Table 1: Optimal parameters for the SSP under the Frechet distribution with shape parameter γ = 1

		a = 0.5			a = 1.0			a = 2.0			a = 4.0		
β	m/m_0	n, c	ASN at p_2	$P_a(p_1)$	n, c	ASN at p_2	$P_a(p_1)$	n, c	ASN at p_2	$P_a(p_1)$	n, c	ASN at p_2	$P_a(p_1)$
0.25	1.2	253, 58	253	0.9523	129, 65	129	0.9511	73, 55	73	0.9679	49, 44	49	0.9659
	1.4	77, 16	77	0.9558	94, 43	94	0.9517	73, 52	73	0.9676	49, 43	49	0.9679
	1.6	38, 7	38	0.9511	46, 20	46	0.9501	73, 49	73	0.9649	49, 42	49	0.9696
	1.8	39, 22	39	0.9622	29, 12	29	0.9526	48, 31	48	0.9739	49, 41	49	0.9708
	2.0	26, 14	26	0.9517	23, 9	23	0.9591	30, 19	30	0.9506	49, 40	49	0.9717
	2.2	15, 2	15	0.9685	16, 6	16	0.9591	24, 15	24	0.9611	43, 34	43	0.9582
0.10	1.2	309, 70	309	0.9562	129, 65	129	0.9511	73, 55	73	0.9679	49, 44	49	0.9659
	1.4	118, 23	118	0.9526	129, 58	129	0.9585	73, 52	73	0.9676	49, 43	49	0.9679
	1.6	64, 11	64	0.9582	72, 30	72	0.9526	73, 49	73	0.9649	49, 42	49	0.9696
	1.8	40, 6	40	0.9567	46, 18	46	0.9543	70, 44	70	0.9539	49, 41	49	0.9708
	2.0	30, 4	30	0.9633	33, 12	33	0.9516	49, 30	49	0.9573	49, 40	49	0.9717
	2.2	25, 3	25	0.9713	26, 9	26	0.9600	37, 22	37	0.9579	49, 39	49	0.9582
0.05	1.2	309, 70	309	0.9562	129, 65	129	0.9511	73, 55	73	0.9679	49, 44	49	0.9659
	1.4	118, 23	118	0.9526	129, 58	129	0.9585	73, 52	73	0.9676	49, 43	49	0.9679
	1.6	64, 11	64	0.9582	72, 30	72	0.9526	73, 49	73	0.9649	49, 42	49	0.9696
	1.8	40, 6	40	0.9567	46, 18	46	0.9543	70, 44	70	0.9539	49, 41	49	0.9708
	2.0	30, 4	30	0.9633	33, 12	33	0.9516	49, 30	49	0.9573	49, 40	49	0.9717
	2.2	25, 3	25	0.9713	26, 9	26	0.9600	37, 22	37	0.9579	49, 39	49	0.9582
0.01	1.2	309, 70	309	0.9562	129, 65	129	0.9511	73, 55	73	0.9679	49, 44	49	0.9659
	1.4	221, 40	221	0.9501	129, 58	129	0.9585	73, 52	73	0.9676	49, 43	49	0.9679
	1.6	116, 18	116	0.9543	129, 51	129	0.9514	73, 49	73	0.9649	49, 42	49	0.9696
	1.8	76, 10	76	0.9530	82, 30	82	0.9525	70, 46	70	0.9592	49, 41	49	0.9708
	2.0	60, 7	60	0.9673	59, 20	59	0.9544	73, 44	73	0.9698	49, 40	49	0.9717
	2.2	49, 5	49	0.9724	45, 14	45	0.9505	64, 36	64	0.9519	49, 39	49	0.9582

Table 2: Optimal parameters for the SSP under the Frechet distribution with shape parameter γ = 2

		a = 0.5			a = 1.0			a = 2.0			a = 4.0		
β	m/m_0	n, c	ASN at p_2	P_a (p_1)	n, c	ASN at p_2	P_a (p_1)	n, c	ASN at p_2	P_a (p_1)	n, c	ASN at p_2	P_a (p_1)
0.25	1.2	100, 4	100	0.9618	77, 35	77	0.9523	49, 43	49	0.9736	*	*	*
	1.4	43, 1	43	0.9847	23, 9	23	0.9514	49, 40	49	0.9666	*	*	*
	1.6	22, 0	22	0.9820	12, 4	12	0.9611	30, 23	30	0.9514	29, 28	29	0.9599
	1.8	81, 0	81	0.9899	7, 2	7	0.9701	16, 12	16	0.9598	29, 28	29	0.9829
	2.0	659, 0	659	0.9899	5, 1	5	0.9656	11, 8	11	0.9673	29, 27	29	0.9574
	2.2	*	*	*	5, 1	5	0.9886	9, 6	9	0.9605	29, 27	29	0.9822
0.10	1.2	167, 6	167	0.9635	126, 55	126	0.9517	49, 43	49	0.9736	*	*	*
	1.4	61, 1	61	0.9706	35, 13	35	0.9549	49, 40	49	0.9666	*	*	*
	1.6	36, 0	36	0.9707	19, 6	19	0.9694	44, 33	44	0.9545	29, 28	29	0.9599
	1.8	81, 0	81	0.9899	12, 3	12	0.9691	25, 18	25	0.9595	29, 28	29	0.9829
	2.0	659, 0	659	0.9899	9, 2	9	0.9846	16, 11	16	0.9616	29, 27	29	0.9574
	2.2	*	*	*	7, 1	7	0.9772	11, 7	11	0.9523	29, 27	29	0.9822
0.05	1.2	208, 7	208	0.9595	129, 57	129	0.9642	49, 43	49	0.9736	*	*	*
	1.4	75, 1	75	0.9571	44, 16	44	0.9593	49, 40	49	0.9666	*	*	*
	1.6	47, 0	47	0.9619	23, 7	23	0.9697	49, 37	49	0.9676	29, 28	29	0.9599
	1.8	81, 0	81	0.9899	13, 3	13	0.9590	31, 22	31	0.9623	29, 28	29	0.9829
	2.0	659, 0	659	0.9899	11, 2	11	0.9724	21, 14	16	0.9608	29, 27	29	0.9574
	2.2	*	*	*	8, 1	8	0.9703	16, 10	16	0.9644	29, 27	29	0.9822
0.01	1.2	318, 10	318	0.9640	129, 57	129	0.9642	49, 43	49	0.9736	*	*	*
	1.4	132, 2	132	0.9795	64, 22	64	0.9548	49, 40	49	0.9666	*	*	*
	1.6	181, 1	181	0.9899	33, 9	33	0.9580	49, 37	49	0.9676	29, 28	29	0.9599
	1.8	81, 0	81	0.9899	19, 4	19	0.9565	44, 30	44	0.9519	29, 28	29	0.9829
	2.0	659, 0	659	0.9899	17, 3	17	0.9812	28, 18	28	0.9564	29, 27	29	0.9574
	2.2	*	*	*	14, 2	14	0.9884	20, 12	20	0.9585	29, 27	29	0.9822

Plan does not exist

Table 3: Optimal parameters for the SSP under the Frechet distribution with shape parameter γ = 3

		a = 0.5			a = 1.0			a = 2.0			a = 4.0		
β	m/m_0	n, c	ASN at p_2	P_a (p_1)	n, c	ASN at p_2	P_a (p_1)	n, c	ASN at p_2	P_a (p_1)	n, c	ASN at p_2	P_a (p_1)
0.25	1.2	355, 0	355	0.9758	33, 14	33	0.9540	36, 34	36	0.9689	*	*	*
	1.4	*	*	*	10, 3	10	0.9508	36, 32	36	0.9628	*	*	*
	1.6	*	*	*	5, 1	5	0.9696	19, 16	19	0.9527	*	*	*
	1.8	*	*	*	2, 0	2	0.9652	10, 8	10	0.9516	*	*	*
	2.0	*	*	*	3, 0	3	0.9883	8, 6	8	0.9648	35, 34	35	0.9518
	2.2	*	*	*	17, 0	17	0.9895	6, 4	6	0.9602	26, 25	26	0.9501
0.10	1.2	589, 0	589	0.9602	55, 22	55	0.9556	36, 34	36	0.9689	*	*	*
	1.4	*	*	*	14, 4	14	0.9541	36, 32	36	0.9628	*	*	*
	1.6	*	*	*	9, 2	9	0.9871	28, 23	28	0.9512	*	*	*
	1.8	*	*	*	9, 1	9	0.9898	17, 13	17	0.9509	*	*	*
	2.0	*	*	*	4, 0	4	0.9845	11, 8	11	0.9673	35, 34	35	0.9518
	2.2	*	*	*	17, 0	17	0.9895	6, 4	6	0.9602	26, 25	26	0.9501
0.05	1.2	*	*	*	69, 27	69	0.9573	36, 34	36	0.9689	*	*	*
	1.4	*	*	*	18, 5	18	0.9590	36, 32	36	0.9628	*	*	*
	1.6	*	*	*	11, 2	11	0.9769	36, 30	36	0.9776	*	*	*
	1.8	*	*	*	9, 1	9	0.9898	17, 13	17	0.9509	*	*	*
	2.0	*	*	*	5, 0	5	0.9806	13, 9	13	0.9539	35, 34	35	0.9518
	2.2	*	*	*	17, 0	17	0.9895	8, 5	8	0.9517	26, 25	26	0.9501
0.01	1.2	*	*	*	96, 36	96	0.9505	36, 34	36	0.9689	*	*	*
	1.4	*	*	*	27, 7	27	0.9612	36, 32	36	0.9628	*	*	*
	1.6	*	*	*	14, 2	14	0.9552	36, 30	36	0.9776	*	*	*
	1.8	*	*	*	11, 1	11	0.9847	27, 20	27	0.9547	*	*	*
	2.0	*	*	*	7, 0	7	0.9730	16, 11	16	0.9616	35, 34	35	0.9518
	2.2	*	*	*	17, 0	17	0.9895	11, 7	11	0.9719	26, 25	26	0.9501

Plan does not exist

constructed for the shape parameter 2 and at the same time, Table 3 is constructed for the shape parameter 3.

ILLUSTRATIVE EXAMPLES

Suppose that manufacturer wants to adopt a single sampling plan for assuring that the median life of the products under inspection is at least 1000 h when β = 0.10 and α = 0.05 at the median ratio = 2. He wants to run this experiment 1000 h. From the past data, it is observed that the lifetime of the product follows a Frechet distribution with shape parameter 1. Table 1 can be used to find the optimal parameters of the single sampling plan. The optimal plan from Table 1 for specified requirements such as $\alpha = 0.05$, $\beta = 0.10$, $\gamma = 1$, $m/m_0 = 2$ and a =1.0 is obtained as: n = 23 and c = 9. It is to be pointed out that most of the life testing sampling plans for various life time distributions like exponential, Weibull etc available in the literature is based on one point on the OC curve approach for assuring mean or percentile life time. But in this study, we have designed sampling plans based on two-points on the OC curve approach for assuring median life time of the products under Frechet distribution. Hence we cannot make any comparative study of the results of the proposed plan with the results of the existing sampling plans.

Real world example: Now we will explain the proposed plan using the failure times of air conditioning system of an air plane (Bain and Engelhardt, 1991). The lifetimes of 11 air conditioning system of an air plane are as: 33, 47, 55, 56, 104, 176, 182, 220, 239, 246 and 320. We found that the failure time data is well fitted to Frechet distribution with $\gamma = 1.19$ (close to 1). Suppose that the specified median life of air conditioning system is 40 and we want to run the test for 80 h (this leads to termination ratio a = 2.0) with $\alpha = 0.05$, $\beta = 0.25$, $\gamma = 1$, $m/m_0 = 2$ and a = 2.0. From Table 1, we have plan parameters n = 30 and c = 19. According to the plan, we will accept the products if no more than 19 failures are noted in air conditioning systems before 80 h. From the ordered lifetime air conditioning data, we note that four failures 33, 47, 55 and 56 are recorded before the termination time 80 h. So, according to the plan, the air conditioning system should be accepted.

CONCLUSION

In this study, we have proposed a single sampling plan for the truncated life test when the life time of the product follows a Frechet distribution since Frechet distribution has been shown to be a useful model in the areas of quality and control and reliability studies. To ensure that the life quality of products exceeds a specific standard, acceptance sampling plans based on median can be used. In this study, a single sampling plan has been developed based on the median of Frechet distribution when the life test is truncated at a pre-determined time. Some useful tables have also been provided selection of optimal parameters. The optimal parameters are determined in such a way that it should satisfy two points on the OC curve.

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