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Economic Reliability Group Acceptance Sampling Plan for Truncated Life Test Having Weibull Distribution

Abdur Razzaque Mughal[1], Amina Shahzadi[2], Muhammad Hanif[3] and Usman Ali[4]

Abstract

In this paper, economic reliability test plan (ERTP) is developed for a Truncated Life test when the lifetime of a product follows Weibull Distribution. Two point approach was adopted to find the design parameters such as the minimum termination time and the probability of lot acceptance by satisfying the producer's and the consumer's risks, while the sample size and acceptance number are specified. Comparison of proposed plan has been made with the existing plan developed by Aslam and Jun (2009). The results are illustrated by tables and examples.

Keywords

Weibull distribution, Producer's risk, Truncated life test, Operating characteristics, Reliability sampling plan

1. Introduction

Economic reliability test plan (ERTP) based on Truncated Life test when the lifetime of a product follows Weibull Distribution are considered essential and pre-requisite to assess the trustworthiness of a product with regard to its lifetime. The main object of such a test is to determine an estimated life of a product. When we are able to establish the estimated (mean) life of an article, it would help

[1] Department of Statistics, Pak Shama College, Doha, Qatar.
Email: abdur_razzaque@live.com
[2] Department of Statistics, Government College University, Lahore, Pakistan
[3] Department of Mathematics, Lahore University of Management Sciences, Lahore, Pakistan
[4] Department of Statistics, Government Degree College, Narang, Pakistan

us to reach at a definite conclusion as to whether the submitted lot may be accepted or rejected. In case, it is observed that the mean life of a product is above the required standard, the submitted lot is accepted otherwise the same is rejected. Hence, there is a need of the time to introduce (ERTP) for a life test using inspection of a multiple number of products at a time on the basis of the facility available to the experimenter for conducting such tests. For instance, if the experimenter has the facility of testers which can inspect a group 10 product at one time, then he would need 10 similar testers to carry out inspection of 100 products at a time. The main advantage of the group acceptance sampling plan is that it provides the strict inspection before it is sent to the consumer for use. The other benefit is that it is more economical than an ordinary sampling plan because sufficient time, cost, energy and labor are saved in group sampling plan. Being economical, it is proposed to introduce (ERTP) for life tests using group acceptance sampling plan. The object of this paper is to reduce and save the experimental time in view of the given design parameters and satisfying both the consumer's as well as the producer's risks. The design of the (ERTP) is given in section 2 with illustration given in section 3. In section 4, we have made an effort to compare the proposed plan with existing one.

2. Design of ERTP

We are concerned to develop an Economic Reliability Test Plan (ERTP) to assure that the mean life of product in a lot μ is higher than the specified life μ_0 .We will reject the lot if $\mu < \mu_0$ at certain quality levels, otherwise accept the lot. The group acceptance sampling plan based on Truncated Life tests proposed by Aslam et al. (2010 a & b) is:

- Determine the group size g . Sample gr products from a lot randomly and allocate r items to each group for the life test.
- The required sample size in the life test is $(n = g \times r)$. Determine the acceptance number c for every group and specify the termination time of the life test t_0
- Implement the life test based on the g groups of products, simultaneously. Accept the lot if at most c failed products are found in every group by the termination time. Truncate the life test and reject the lot if more than c failures are found in any group.

If $r = 1$, the proposed Economic Reliability Test Plan (ERTP) reduces to the Ordinary Acceptance Sampling Plan. We are interested in determining the minimum termination time which satisfies both the risks, whereas the sample size and acceptance number are pre-assumed. Consider that the life time of a product follows Weibull Distribution, then its Distribution function is

$$F(t:\lambda,m) = 1-\exp\left(-\left(\frac{t}{\lambda}\right)^{m}\right) \quad t \geq 0 \tag{2.1}$$

where λ and m are the scale and shape parameters respectively. The mean of this distribution is:

$$\mu = \left(\frac{\lambda}{m}\right)\Gamma\left(\frac{1}{m}\right) \tag{2.2}$$

Suppose, that the lot size is large, so Binomial Distribution could be applied (see, Stephens (2001) for more justification). The submitted lot is accepted, if c or less failure occurs in every group. The probability of accepting the submitted lot will be:

$$L(p) = \left[\sum_{i=0}^{c}\binom{r}{i}p^{i}(1-p)^{r-i}\right]^{g} \tag{2.3}$$

where p denotes the probability that a product fails before the termination time. For simplification, we will assume that the test termination time as a multiple of the pre-specified value of μ_0 which is written as $t_0 = a\mu_0$. So,

$$p = 1-\exp\left(-\left(\frac{t_0}{\lambda}\right)^{m}\right) = 1-\exp\left(-a^{m}\left(\frac{\mu}{\mu_0}\right)^{-m}\left(\frac{\Gamma(1/m)}{m}\right)^{m}\right) \tag{2.4}$$

The quality standard of a product can be representing the ratio of its expected lifetime to the specified life (μ/μ_0). The probability of rejecting a good lot is the producer's risk and the probability of accepting a bad lot is the consumer's risk denoted by (β) and (α) respectively. The objective of this research article is to increase the lot acceptance probability and reduce the experimental time in view of the given designed parameters. No attention from the researchers has been paid to propose an Economic Reliability Group Acceptance Sampling Plan for

Truncated Life test having Weibull Distribution assuming that the lifetime of a product basis this distribution with known shape parameters.

Now, we used two-point approach to determine the minimum termination time and lot acceptance probability that satisfies the following two inequalities:

$$\left[\sum_{i=0}^{c}\binom{r}{i}p^{i}(1-p)^{r-i}\right]^{g} \leq \beta \tag{2.5}$$

$$\left[\sum_{i=0}^{c}\binom{r}{i}p^{i}(1-p)^{r-i}\right]^{g} \geq 1-\alpha \tag{2.6}$$

Tables 1-6 show the minimum termination time and the acceptance number for the proposed (ERTP) according to different values of the consumer's and producer's risks when the true mean $((\mu/\mu_0)=2,4,6,8,10)$ times the specified life and two levels of the testers $(r=5,10)$ are also considered. The lot acceptance probability when the true mean is (μ/μ_0) times the specified life is included in these Tables, which is higher than 0.95. It is observed that the minimum termination time tends to decrease as m increases and r increases. The upper entries of the cells denoting the proposed (ERTP) and the lower entries of the cells represent the existing plan developed by Aslam and Jun (2009).

Since c =1, r =10, g =20, $\alpha=0.05, \beta=0.01$, m =3, (μ/μ_0) =4, the minimum termination time and the probability of lot acceptance can be found as a =0.1200 and $L(p_2)$=1.0000 from Table 6. If the specified mean life is 5000 hours then the termination time is t/μ_0 =0.1200, so that t =0.1200$\times$5000=600 hours. It means that select 200 products from the submitted lot and 20 products will be allocated to the 10 testers, we will reject this lot if more than 1 failure occurs during the 600 hours in each of the 20 groups otherwise accept it and the probability of lot acceptance is 100% when the true mean is 20000 hours.

3. Comparative Study

Let us consider that the lifetime of a product follows a Weibull Distribution with the shape parameter is 3. Suppose, we proposed (ERTP) to assure that the mean life is higher than 1000 hours, the consumer's and producer's risk are 5% when the true mean is 1000 hours and 4000 hours respectively. Since, m =3, (α, β) =0.05, r =5, g =7, c =0 and (μ/μ_0)=4 from Table 5 the minimum termination time and the probability of lot acceptance are a =116 hours and $L(p_2)$=0.9994 respectively for the proposed (ERTP). We will choose a sample of 35 products and allocate 5 products to the 7 groups; we accept the lot and conclude that the mean life is higher than 1000 hours if no failure occurs during the 116 hours. For the same design parameters, the existing plan developed by Aslam and Jun (2009) require 500 hours to reach the same decision and the probability of lot acceptance is $L(p_2)$=0.9525 which is also less than the proposed (ERTP). Now we may conclude that the proposed plan is more efficient and economical in the sense of saving cost, time, energy and labor.

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Table 1: Minimum Termination Time and the Probability of Lot Acceptance (m =1)

β	r =5									
	μ/μ_0	g	c	$L(p_2)$	a	μ/μ_0	g	c	$L(p_2)$	a
0.25	2	-	-	-	-	2	-	-	-	-
	4	17	3	0.9863 0.9854	0.4920 0.5000	4	3	3	0.9741 0.9707	0.9640 1.0000
	6	4	2	0.9833 0.9820	0.4870 0.5000	6	3	3	0.9936 0.9927	0.9636 1.0000
	8	4	2	0.9925 0.9919	0.4870 0.5000	8	2	2	0.9900 0.9732	0.6930 1.0000
	10	2	1	0.9746 0.9574	0.3780 0.5000	10	2	2	0.9946 0.9852	0.6930 1.0000
0.10	2	-	-	-	-	2	-	-	-	-
	4	27	3	0.9771 0.9769	0.4988 0.5000	4	5	3	0.9575 0.9517	0.9619 1.0000
	6	7	2	0.9730 0.9688	0.4744 0.5000	6	5	3	0.9894 0.9879	0.9620 1.0000
	8	7	2	0.9878 0.9859	0.4745 0.5000	8	2	2	0.9787 0.9732	0.9170 1.0000
	10	7	2	0.9935 0.9925	0.4750 0.5000	10	2	2	0.9883 0.9852	0.9170 1.0000
0.05	2	-	-	-	-	2	-	-	-	-
	4	35	3	0.9704 0.9702	0.4993 0.5000	4	29	4	0.9854 0.9848	0.9895 1.0000
	6	9	2	0.9649 0.9601	0.4770 0.5000	6	6	3	0.9856 0.9855	0.9970 1.0000
	8	9	2	0.9841 0.9819	0.4770 0.5000	8	3	2	0.9743 0.9600	0.8460 1.0000
	10	9	2	0.9916 0.9904	0.4770 0.5000	10	3	2	0.9859 0.9779	0.8460 1.0000
0.01	2	-	-	-	-	2	-	-	-	-
	4	54	3	0.9551 0.9544	0.4980 0.5000	4	44	4	0.9778 0.9770	0.9920 1.0000
	6	54	3	0.9899 0.9897	0.4980 0.5000	6	10	3	0.9792 0.9759	0.9590 1.0000
	8	13	2	0.9754 0.9740	0.4899 0.5000	8	10	3	0.9926 0.9914	0.9590 1.0000
	10	13	2	0.9869 0.9861	0.4899 0.5000	10	4	2	0.9770 0.9706	0.9130 1.0000

Table 2: Minimum Termination Time and the Probability of Lot Acceptance (m =1)

β	r =10									
	μ/μ_0	g	c	$L(p_2)$	a	μ/μ_0	g	c	$L(p_2)$	a
0.25	2	27	6	0.9569 0.9568	0.4998 0.5000	2	20	8	0.9728 0.9712	0.9920 1.0000
	4	2	3	0.9709 0.9559	0.4390 0.5000	4	1	4	0.9769 0.9511	0.8111 1.0000
	6	1	2	0.9711 0.9600	0.4390 0.5000	6	1	4	0.9953 0.9891	0.8111 1.0000
	8	1	2	0.9862 0.9807	0.4390 0.5000	8	1	3	0.9892 0.9777	0.8020 1.0000
	10	1	2	0.9924 0.9893	0.4390 0.5000	10	1	3	0.9949 0.9892	0.8020 1.0000
0.10	2	209	7	0.9659 0.9658	0.4997 0.5000	2	32	8	0.9545 0.9843	0.9990 1.0000
	4	6	4	0.9832 0.9799	0.4997 0.5000	4	2	5	0.9815 0.9787	0.9690 1.0000
	6	3	3	0.9871 0.9827	0.4591 0.5000	6	2	4	0.9934 0.9783	0.7450 1.0000
	8	2	2	0.9793 0.9617	0.3950 0.5000	8	1	3	0.9892 0.9777	0.8020 1.0000
	10	2	2	0.9887 0.9786	0.3950 0.5000	10	1	3	0.9949 0.9892	0.8020 1.0000
0.05	2	272	7	0.9559 0.9557	0.4990 0.5000	2	22	9	0.9802 0.9802	0.9990 1.0000
	4	7	4	0.9769 0.9766	0.4980 0.5000	4	3	5	0.9788 0.9683	0.9140 1.0000
	6	4	3	0.9835 0.9770	0.4540 0.5000	6	2	4	0.9892 0.9777	0.8390 1.0000
	8	2	2	0.9693 0.9617	0.4590 0.5000	8	1	3	0.9822 0.9777	0.9320 1.0000
	10	2	2	0.9830 0.9786	0.4590 0.5000	10	1	3	0.9915 0.9892	0.9320 1.0000
0.01	2	315	8	0.9689 0.9685	0.4991 0.5000	2	45	9	0.9613 0.9607	0.9970 1.0000
	4	11	4	0.9655 0.9634	0.4930 0.5000	4	4	5	0.9641 0.9579	0.9650 1.0000
	6	6	3	0.9747 0.9658	0.4580 0.5000	6	3	4	0.9833 0.9676	0.8470 1.0000
	8	6	3	0.9908 0.9874	0.4580 0.5000	8	2	3	0.9788 0.9559	0.7980 1.0000
	10	3	2	0.9740 0.9681	0.4640 0.5000	10	2	3	0.9901 0.9786	0.7980 1.0000

Table 3: Minimum Termination Time and the Probability of Lot Acceptance (m =2)

β	r =5									
	μ/μ_0	g	c	$L(p_2)$	a	μ/μ_0	g	c	$L(p_2)$	a
0.25	2	32	2	0.9994 0.9670	0.2480 0.5000	2	5	3	0.9805 0.9785	0.9820 1.0000
	4	6	1	0.9995 0.9913	0.2380 0.5000	4	1	1	0.9923 0.9792	0.7640 1.0000
	6	6	1	0.9999 0.9982	0.2380 0.5000	6	1	1	0.9984 0.9955	0.7640 1.0000
	8	2	0	0.9962 0.9698	0.1750 0.5000	8	1	1	0.9995 0.9985	0.7640 1.0000
	10	2	0	0.9976 0.9866	0.1750 0.5000	10	1	1	0.9998 0.9994	0.7640 1.0000
0.10	2	531	3	0.9999 0.9866	0.2480 0.5000	2	9	3	0.9724 0.9617	0.9495 1.0000
	4	10	1	0.9992 0.9856	0.2380 0.5000	4	2	1	0.9908 0.9588	0.6698 1.0000
	6	10	1	0.9998 0.9971	0.2380 0.5000	6	2	1	0.9981 0.9911	0.6698 1.0000
	8	3	0	0.9930 0.9550	0.1940 0.5000	8	2	1	0.9994 0.9971	0.6698 1.0000
	10	3	0	0.9955 0.9710	0.1940 0.5000	10	1	0	0.9867 0.9615	0.5810 1.0000
0.05	2	591	3	0.9999 0.9851	0.2590 0.5000	2	11	3	0.9599 0.9534	0.9740 1.0000
	4	13	1	0.9990 0.9813	0.2380 0.5000	4	2	1	0.9813 0.9588	0.8060 1.0000
	6	13	1	0.9998 0.9962	0.2380 0.5000	6	2	1	0.9961 0.9911	0.8060 1.0000
	8	13	1	0.9999 0.9988	0.2380 0.5000	8	2	1	0.9987 0.9971	0.8060 1.0000
	10	4	0	0.9944 0.9615	0.1890 0.5000	10	1	0	0.9777 0.9615	0.7540 1.0000
0.01	2	1063	3	0.9999 0.9734	0.2480 0.5000	2	95	4	0.9843 0.9830	0.9870 1.0000
	4	19	1	0.9984 0.9728	0.2440 0.5000	4	6	2	0.9961 0.9939	0.9191 1.0000
	6	19	1	0.9997 0.9945	0.2440 0.5000	6	3	1	0.9938 0.9867	0.8160 1.0000
	8	19	1	0.9999 0.9982	0.2440 0.5000	8	3	1	0.9980 0.9957	0.8160 1.0000
	10	5	0	0.9895 0.9521	0.2310 0.5000	10	3	1	0.9992 0.9982	0.8160 1.0000

Table 4: Minimum Termination Time and the Probability of Lot Acceptance (m =2)

β	r =10									
	μ/μ_0	g	c	$L(p_2)$	a	μ/μ_0	g	c	$L(p_2)$	a
0.25	2	16	3	0.9999 0.9913	0.2450 0.5000	2	2	4	0.9954 0.9594	0.7590 1.0000
	4	2	1	0.9995 0.9875	0.2240 0.5000	4	1	2	0.9996 0.9898	0.5555 1.0000
	6	2	1	0.9999 0.9974	0.2240 0.5000	6	1	1	0.9996 0.9813	0.3590 1.0000
	8	1	0	0.9962 0.9698	0.1750 0.5000	8	1	1	0.9999 0.9937	0.3590 1.0000
	10	1	0	0.9976 0.9806	0.1750 0.5000	10	1	1	1.0000 0.9974	0.3590 1.0000
0.10	2	26	3	0.9999 0.9775	0.2467 0.5000	2	2	4	0.9736 0.9594	0.9410 1.0000
	4	3	1	0.9989 0.9813	0.2390 0.5000	4	1	2	0.9978 0.9898	0.7530 1.0000
	6	3	1	0.9998 0.9961	0.2390 0.5000	6	1	1	0.9985 0.9813	0.5180 1.0000
	8	3	1	0.9999 0.9988	0.2390 0.5000	8	1	1	0.9995 0.9937	0.5180 1.0000
	10	2	0	0.9967 0.9615	0.1451 0.5000	10	1	1	0.9998 0.9974	0.5180 1.0000
0.05	2	34	3	0.9999 0.9707	0.2470 0.5000	2	5	5	0.9889 0.9827	0.9510 1.0000
	4	4	1	0.9987 0.9751	0.2350 0.5000	4	1	2	0.9944 0.9898	0.8910 1.0000
	6	4	1	0.9997 0.9948	0.2350 0.5000	6	1	1	0.9967 0.9813	0.6320 1.0000
	8	4	1	0.9999 0.9983	0.2350 0.5000	8	1	1	0.9989 0.9937	0.6320 1.0000
	10	2	0	0.9944 0.9615	0.1890 0.5000	10	1	1	0.9996 0.9974	0.6320 1.0000
0.01	2	52	3	0.9998 0.9555	0.2460 0.5000	2	7	5	0.9790 0.9758	0.9810 1.0000
	4	6	1	0.9979 0.9629	0.2380 0.5000	4	2	2	0.9957 0.9796	0.7490 1.0000
	6	6	1	0.9996 0.9923	0.2380 0.5000	6	1	1	0.9883 0.9813	0.8790 1.0000
	8	6	1	0.9999 0.9995	0.2380 0.5000	8	1	1	0.9961 0.9937	0.8790 1.0000
	10	6	1	0.9999 0.9990	0.2380 0.5000	10	1	1	0.9984 0.9974	0.8790 1.0000

Table 5: Minimum Termination Time and the Probability of Lot Acceptance (m =3)

β	r =5									
	μ/μ_0	g	c	$L(p_2)$	a	μ/μ_0	g	c	$L(p_2)$	a
0.25	2	23	1	1.0000 0.9728	0.1180 0.5000	2	2	2	0.9929 0.9892	0.9397 1.0000
	4	4	0	0.9998 0.9726	0.0940 0.5000	4	1	1	0.9996 0.9988	0.8206 1.0000
	6	4	0	0.9999 0.9918	0.0940 0.5000	6	1	1	1.0000 0.9999	0.8206 1.0000
	8	4	0	1.0000 0.9965	0.0940 0.5000	8	1	1	1.0000 1.0000	0.8206 1.0000
	10	4	0	1.0000 0.9982	0.0940 0.5000	10	1	1	1.0000 1.0000	0.8206 1.0000
0.10	2	37	1	1.0000 0.9566	0.1200 0.5000	2	4	2	0.9993 0.9785	0.6610 1.0000
	4	6	0	0.9996 0.9591	0.1040 0.5000	4	2	1	0.9999 0.9976	0.5200 1.0000
	6	6	0	0.9999 0.9877	0.1040 0.5000	6	1	0	0.9959 0.9837	0.6240 1.0000
	8	6	0	1.0000 0.9848	0.1040 0.5000	8	1	0	0.9983 0.9931	0.6240 1.0000
	10	6	0	1.0000 0.9973	0.1040 0.5000	10	1	0	0.9991 0.9964	0.6240 1.0000
0.05	2	48	1	1.0000 0.9441	0.1201 0.5000	2	5	2	0.9907 0.9732	0.8700 1.0000
	4	7	0	0.9994 0.9525	0.1160 0.5000	4	2	1	0.9989 0.9976	0.8700 1.0000
	6	7	0	0.9998 0.9857	0.1160 0.5000	6	1	0	0.9909 0.9837	0.8110 1.0000
	8	7	0	0.9999 0.9939	0.1160 0.5000	8	1	0	0.9962 0.9931	0.8110 1.0000
	10	7	0	1.0000 0.9969	0.1160 0.5000	10	1	0	0.9980 0.9964	0.8110 1.0000
0.01	2	256	2	1.0000 0.9966	0.1880 0.5000	2	7	2	0.9811 0.9627	0.9100 1.0000
	4	74	1	1.0000 0.9986	0.1194 0.5000	4	3	1	0.9982 0.9964	0.8800 1.0000
	6	11	0	0.9997 0.9776	0.1124 0.5000	6	2	0	0.9919 0.9676	0.6190 1.0000
	8	11	0	0.9999 0.9905	0.1124 0.5000	8	2	0	0.9966 0.9862	0.6190 1.0000
	10	11	0	0.9999 0.9951	0.1124 0.5000	10	2	0	0.9983 0.9929	0.6190 1.0000

Table 6: Minimum Termination Time and the Probability of Lot Acceptance (m =3)

β	r =10									
	μ/μ_0	g	c	$L(p_2)$	a	μ/μ_0	g	c	$L(p_2)$	a
	2	6	1	1.0000 0.9692	0.1204 0.5000	2	1	2	0.9992 0.9530	0.5960 1.0000
	4	2	0	0.9998 0.9726	0.0940 0.5000	4	1	1	1.0000 0.9948	0.3852 1.0000
0.25	6	2	0	0.9999 0.9918	0.0940 0.5000	6	1	0	0.9998 0.9676	0.1880 1.0000
	8	2	0	1.0000 0.9965	0.0940 0.5000	8	1	0	0.9999 0.9862	0.1880 1.0000
	10	2	0	1.0000 0.9982	0.0940 0.5000	10	1	0	1.0000 0.9929	0.1880 1.0000
	2	10	1	1.0000 0.9493	0.1201 0.5000	2	1	2	0.9898 0.9530	0.8100 1.0000
	4	3	0	0.9996 0.9591	0.1040 0.5000	4	1	1	0.9998 0.9948	0.5570 1.0000
0.10	6	3	0	0.9999 0.9877	0.1040 0.5000	6	1	0	0.9990 0.9676	0.3120 1.0000
	8	3	0	1.0000 0.9948	0.1040 0.5000	8	1	0	0.9996 0.9862	0.3120 1.0000
	10	3	0	1.0000 0.9973	0.1040 0.5000	10	1	0	0.9998 0.9929	0.3120 1.0000
	2	63	2	1.0000 0.9904	0.1200 0.5000	2	1	2	0.9627 0.9530	0.9580 1.0000
	4	13	1	1.0000 0.9989	0.1200 0.5000	4	1	1	0.9994 0.9948	0.6800 1.0000
0.05	6	4	0	0.9999 0.9837	0.1013 0.5000	6	1	0	0.9977 0.9676	0.4060 1.0000
	8	4	0	0.9999 0.9931	0.1013 0.5000	8	1	0	0.9990 0.9862	0.4060 1.0000
	10	4	0	1.0000 0.9964	0.1013 0.5000	10	1	0	0.9995 0.9929	0.4060 1.0000
	2	96	2	1.0000 0.9854	0.1210 0.5000	2	3	3	0.9943 0.9784	0.8710 1.0000
	4	20	1	1.0000 0.9983	0.1200 0.5000	4	1	1	0.9960 0.9948	0.9450 1.0000
0.01	6	6	0	0.9998 0.9756	0.1040 0.5000	6	1	0	0.9919 0.9676	0.6200 1.0000
	8	6	0	0.9999 0.9896	0.1040 0.5000	8	1	0	0.9966 0.9862	0.6200 1.0000
	10	6	0	1.0000 0.9947	0.1040 0.5000	10	1	0	0.9982 0.9929	0.6200 1.0000