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Evaluation of Average Outgoing Quality (AOQ) for Reliability Acceptance Sampling Plan Based on the Exponentiated Rayleigh Distribution

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***Abstract*—** Quality of the product plays vital role in acceptance sampling plan and the quality of the lot is determined by using average outgoing quality (AOQ) which is the expected quality of lots after the application of sampling inspecting. This paper introduces the designing of Average Outgoing Quality (AOQ) and Average Outgoing Quality Limit (AOQL) in Reliability acceptance sampling plan for life test is follows Exponentiated Rayleigh distribution. The procedure for designing a single sampling plan indexed through the Average Outgoing Quality (AOQ) is stated. A statistical software(R) is used to simulate the procedure developed and graphs are constructed for the selection of AOQ values for a sampling plan under the Exponentiated Rayleigh model.

Keywords— Acceptance sampling, Life test, Exponentiated Rayleigh distribution, Probability of acceptance, Average Outgoing quality (AOQ), Average Outgoing Quality Limit (AOQL).

I. INTRODUCTION

Acceptance sampling plans are commonly used to determine the acceptability of a product. Life time is an important quality characteristic of a product. Sampling plans used to determine the acceptability of a product with respect to its lifetime are known as reliability or life test sampling plans. When life- test shows that the mean (average) or percentile life of the product or items is above the desired standard, the submitted lot is accepted; otherwise the same is rejected.

A reliability sampling plan is a course of action that establishes the minimum sample size to be used for testing. This becomes particularly valuable if the quality of product is defined by its lifetime. A specific reliability sampling plan, in the case that the sample observation are lifetime of products are put to test, aim at proving that the actual population average exceeds the required minimum. The population average stands for the average life of the product, say θ. If θ_0 is a specified minimum value, one would like to verify that $\theta \geq \theta_0$, which means that the true mean life of the products exceeds the specified value. On the basis of a random sample of size *n*, the lot is accepted, if by means of suitable decision criterion, the acceptance sampling plan decides in favor of $\theta \geq \theta_0$; 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 θ_0 and the hypothesis $\theta \geq \theta_0$ is not verified. Hence, the lot cannot be accepted. Such a sampling plan is termed as reliability sampling plan or life test sampling plan.

II. RELATED WORK

In Literature various studies regarding truncated life tests based on the mean life time can be found in Epstein (1954)[1],Sobel and Tischendrof (1959)[2] for the exponential model. An extension of this work was carried out by Goode and Kao (1961)[3] by considering the Weibull model which includes the exponential distribution as a particular case, Groll (1961) and Gupta (1962)[4] considered the gamma and log-normal distributions respectively. More recently, Kantam et al (2001)[5], Baklizi (2003)[6], Baklizi and El Masri (2004)[6]. In contrast,. Srinivasa Rao and Kantam (2010)[7] developed similar plans for the percentiles of log-logistic distribution. Rao and Katam[8] , Rosaiah and Pratapa Reddy (2012)[9] developed the Acceptance Sampling Plans For Percentiles Based On The Inverse Rayleigh Distribution. K. Pradeepa Veerakuari & P. Ponneeswari(2006)[10] developed the acceptance samplieng plan for life test based on Exponentiated Rayleigh Distribution. Percentiles are taken into account because lesser percentiles provide more information than mean life regarding the life distribution. The 50th percentile is the median which is equivalent to the mean life. So, literatures prove this as the generalization of acceptance sampling plans based on the mean life of products.

According to ANSI / ASQC Standard A2 (1987) defines AOQ as "the expected quality" of outgoing product following the use of an acceptance sampling plan for a given value of incoming product quality and The maximum AOQ over all possible levels of incoming quality is termed as AOQL. Dodge and Romig (1959) have proposed a procedure for selection of a single sampling plan (SSP) indexed through the AOQL by minimizing the average total inspection. Soundararajan (1981)[11] has suggested a procedure for the selection of an SSP in terms of the acceptable quality level (AQL) and AOQL.
This paper we develop average outgoing quality (AOQ) and average outgoing quality limit (AOQL) for time-truncated life test based on Exponentiated Rayleigh distribution when the quality characteristics follow Poisson condition.

III. METHEDOLOGY

3.1. Exponentiated Rayleigh distribution

If the lifetime of the product follows Exponentiated Rayleigh distribution if it's cumulative distribution function (CDF) and the probability density function (PDF) of ERD are respectively given by,

$$F(t,\tau) = \left[1 - e^{-\frac{1}{2}(\frac{t}{\tau})^2}\right]^{\theta} \qquad t > 0; 1/\tau > 0 \qquad (1)$$

Where τ and θ are the scale and shape parameter respectively.

$$f(t,\tau) = \theta\left[1 - e^{-\frac{1}{2}(\frac{t}{\tau})^2}\right]^{\theta-1}\left[\frac{t}{\tau^2}e^{-\frac{1}{2}(\frac{t}{\tau})^2}\right] \qquad t > 0; 1/\tau > 0, \theta > 0$$

The 100qth percentile of Exponentiated Rayleigh Distribution (ERD) is determined by,

$$P_r(T \le t_q) = q$$

$$\Rightarrow t_q = \tau\sqrt{-2\ln(1-q^{\frac{1}{\theta}})}$$

Where t_q and q are directly proportional.

$$\text{Let, } \eta = \sqrt{-2\ln(1-q^{\frac{1}{\theta}})} \qquad (2)$$

$$\Rightarrow \tau = t_q/\eta \qquad (3)$$

replacing the scale parameter (τ) by (3.9), we get the cumulative distribution function of ERD as,

$$F(t) = \left[1 - e^{-\frac{1}{2}\eta^2(t/t_q)^2}\right]^{\theta}; \qquad t > 0, \theta > 0$$

Letting $\delta = t/t_q$

$$F(t:\tau,\theta) = \left(1 - e^{-\frac{1}{2}(\eta\delta)^2}\right)^{\theta} \qquad (4)$$

3.2. Designing of sampling plans using Exponentiated Rayleigh distribution

ASSP is an inspection procedure used to determine whether to accept or reject a specific lot. While construction of ASP through ERD percentiles we make the following assumptions are,

(1) Let the proposed single sampling plan procedure is said to follow the Poisson distribution with parameter $\lambda = nF(t;\delta_0)$.

(2) Let p be the failure probability observed during specified time t is obtained through, $p = F(t;\delta_0)$

(3) Let c be the acceptance number that is, if the number of failures is less than c for the specified time t we accept the lot and also we have,

$$F(t;\delta) \le F(t;\delta_0) \Leftrightarrow t_q \ge t_{q_0}$$

SSP is the basic for all acceptance sampling. For an SSP, one sample of items is selected at random from a lot and the disposition of the lot is determined from the resulting information. These plans are also denoted as (n, c) plans, where n is the number of observation and c is the acceptance number. Acceptance single sampling plan for percentiles situated on the truncated life test is to bring out the minimum sample size n for the specified acceptance number c such that the probability of accepting the bad lot that is the consumer's risk does not exceed $1-P^*$. Hence the probability P^* is a confidence level in the sense that the assurance of rejecting a bad lot with $t_q < t_q^0$ is at least equal to P^*.the proposed acceptance sampling plan can be characterized by the triplet $(n, c, t/t_q^0)$. If $p = F(t;\delta_0)$ is small and n is large then the binomial probability is approximated by Poisson probability with parameter $\lambda = np$ so that the problem is to determine the smallest positive integer n for given values of c and t/t_q^0 such that:

$$L(p) = \sum_{r=0}^{c} \frac{\exp(-\lambda)(\lambda)^r}{r!} \le 1 - p^* \qquad (4)$$

Where $\lambda = nF(t;\delta_0)$ and $F(t;\delta_0)$ depends on δ_0. It sufficient to specify δ_0. Thus the least sample size n simulated using the search procedure for various P^*, t_q^0, c and t/t_q^0 are tabulated in table 1

3.3 Operating characteristics function

The operating characteristic of the sampling plan gives the probability of accepting the lot. This probability is given by

$$L(p) = \sum_{r=0}^{c} \frac{\exp(-\lambda)(\lambda)^r}{r!} \qquad (5)$$

The producer's risk (α) is the probability of rejecting a lot when $t_q > t_{q_0}$ and the for the given producer's risk (α), p as a function of d_q should be evaluated from the condition given by

$$L(p) = \sum_{r=0}^{c} \frac{\exp(-\lambda)(\lambda)^r}{r!} \ge 1 - \alpha \qquad (6)$$

Where $\lambda = nF(t;\delta_0)$ and $F(t;\delta_0)$ is depends on δ_0.

3.4. Average Outgoing Quality (AOQ)

The average outgoing quality (AOQ) is the expected average quality level of the outgoing component for a given value of incoming component quality. The equation for calculation of the average outgoing quality is as follows.

$$AOQ = p.\frac{P_a(p)(N-n)}{N} = p.P_a(p)(1 - \frac{n}{N})$$

If all lots come with a defect (failure) is exactly p. Where $p = F(t;\delta_0)$ is the failure probability is depends on δ_0. The OC curve for the Reliability acceptance sampling plan for $(n, c, t/t_q^0)$ indicates a probability $Pa(p)$ of accepting a lot, in the long run. Assuming the quality characteristic follows Poisson condition it becomes

$$AOQ = pP_a(p) = p\sum_{r=0}^{c} \frac{\exp(-\lambda)(\lambda)^r}{r!} \qquad (7)$$

A plot of the life time against the AOQ is called the AOQ curve in reliability acceptance sampling plan. The maximal ordinate on the AOQ curve is called AOQL which is an important characteristic of the acceptance sampling plan because it represent the worst possible long term AOQ.

$$AOQL = Max(AOQ) \qquad (8)$$

The values average outgoing quality (AOQ) and average outgoing quality limit (AOQL) of the sampling plan $(n, c, t/t_q^0)$ for a given P^* under Exponentiated Rayleigh distribution are given in Table 2 and Table 3 for $\theta = 2$ and $q = 0.1$.

3.4.1 Construction of table

Step 1: Find the value of η for $\theta = 2$ and $q = 0.1$.

Step 2: Set the value at $c = 0,1,\ldots,10$ and

$t/t_q^0 = 0.7, 0.9, 1, 1.5, 2, 2.5, 3, 3.5, 4$ $\eta = 0.871929$

Step3: Find the smallest value of n satisfying

$$L(p) = \sum_{r=0}^{c} \frac{\exp(-\lambda)(\lambda)^r}{r!} \le 1 - P^*$$

Where $P^* = 0.75, 0.90, 0.95, 0.99$ is the probability of rejecting the bad lot.

Step 4: For the evaluated n find $L(p) = \sum_{r=0}^{c} \frac{\exp(-\lambda)(\lambda)^r}{r!}$

such that $p = F(t/t_{q_0}.1/d_q)$, $d_q = t_{q_0}/t_q$ and $\alpha = 0.05$.

Step 5: Using p and $L(p)$ find $p.L(p)$ which gives the AOQ values which are given in Table 3.

Step 6: Use Max (AOQ) which gives AOQL given in Table 4.

IV. RESULTS AND DISCUSSION

Suppose $\theta = 2$, $t = 40\,hrs$, $t_{0.1} = 20\,hrs$, $c = 2$, $\alpha = 0.05$, $\beta = 0.10$ then $\eta = 0.871929$ is calculated from the equation derived under percentile estimator and the ratio, $t/t_{0.1} = 2.00$ and from table 1 the minimum sample size suitable for the given information is found to be as $n = 9$. And the respective operating characteristic values $L(p)$ for the single sampling plan $(n, c, t/t_{0.1}) = (9,2,2)$ with $P^* = 0.90$ and the corresponding average outgoing quality values under ERD is given in Table 2 and Table 3 are,

$t/t_{0.1}$	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3
$P_a(p)$	0.200	0.491	0.760	0.9059	0.9658	0.987	0.9954	0.9982	1
AOQ	0.122	0.190	0.183	0.1388	0.09666	0.066	0.0464	0.0331	0.0

This shows that if the actual 10th percentile is equal to the required 10th percentile $(t_{0.1}/t_{0.1}^{0}=1)$ the producer's risk is approximately 0.7994. The producer's risk is about zero when the true 10th percentile is 3 or more times the specified 10th percentile.

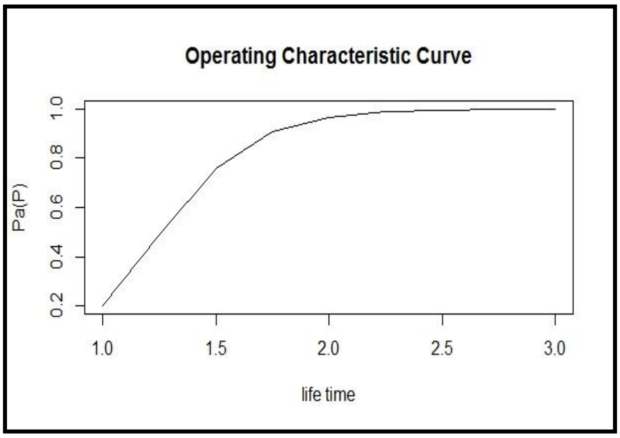

Figure 1: Shows the OC curve for the sampling plan $(n,c,t/t_{0.1})=(9,2,2)$ with $P^*=0.90$ under ERD when $\theta=2$.

Figure 2: Shows the AOQ curve for the sampling plan $(n,c,t/t_{0.1})=(9,2,2)$ with $P^*=0.90$ under ERD when $\theta=2$.

From the above the AOQL is 0.1902

Table 1. Minimum sample size for the 10th percentile of ERD to exceed the given value $t_{0.1}$

		0.7	**0.9**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**
0.75	0	48	20	14	5	3	2	2	2
0.75	1	93	38	27	8	5	4	3	3
0.75	2	135	55	39	11	6	5	5	4
0.75	3	176	72	51	16	9	7	6	6
0.75	4	217	89	62	19	11	8	7	7
0.75	5	256	105	74	23	13	9	8	8
0.75	6	296	121	85	26	14	11	10	9
0.75	7	334	137	96	30	16	12	11	10
0.75	8	373	153	107	33	18	14	12	11
0.75	9	412	169	119	36	20	15	13	13
0.75	10	450	184	130	40	22	16	14	14
0.9	0	79	32	23	7	4	3	3	3
0.9	1	134	54	38	12	7	5	5	4
0.9	2	183	75	52	16	9	7	6	6
0.9	3	230	94	66	20	11	8	7	7
0.9	4	275	112	79	24	13	10	9	8
0.9	5	319	130	91	28	15	12	10	10
0.9	6	364	148	107	32	17	13	12	11
0.9	7	408	166	116	36	19	15	13	12
0.9	8	449	183	128	40	21	16	14	14
0.9	9	490	200	140	43	23	18	15	15
0.9	10	532	217	152	46	25	19	17	16
0.95	0	103	42	29	9	5	4	4	3
0.95	1	164	66	46	14	8	6	5	5
0.95	2	216	88	61	19	10	8	7	7
0.95	3	267	108	76	23	13	10	8	8
0.95	4	315	128	89	27	15	11	10	10
0.95	5	362	147	104	31	17	13	11	11
0.95	6	408	166	116	35	19	14	13	12
0.95	7	453	185	129	39	21	16	14	14
0.95	8	498	203	142	43	24	18	16	15
0.95	9	541	221	154	47	26	19	17	16
0.95	10	584	238	167	51	28	21	18	17
0.99	0	158	64	44	12	7	5	5	4
0.99	1	228	92	64	18	10	8	7	6
0.99	2	288	117	81	23	13	10	9	8
0.99	3	349	140	97	29	16	12	10	10
0.99	4	398	162	113	35	19	14	12	11
0.99	5	450	183	127	39	21	15	14	13
0.99	6	501	204	142	42	23	17	15	14
0.99	7	550	224	156	45	25	19	17	16
0.99	8	598	244	170	50	27	20	18	17
0.99	9	646	263	183	54	29	22	19	18
0.99	10	693	282	197	58	31	24	21	20

Table 2. Gives the OC values for Sampling Plan $(n,c=2,t/t_{0.1})$ for a given P^* under ERD when $\theta=2$.

P^*	n	$t_{0.1}/t_{0.1}^{0}$					
		$t/t_{0.1}^{0}$	**1**	**1.5**	**2**	**2.5**	**3**
0.75	135	0.7	0.253	0.9447	0.9970	1	1
0.75	55	0.9	0.2589	0.9371	0.9963	1	1
0.75	39	1	0.2531	0.9299	0.9956	1	1
0.75	11	1.5	0.2966	0.9004	0.9916	1	1
0.75	6	2	0.2916	0.8218	0.9768	0.9970	1
0.75	4	2.5	0.3612	0.7569	0.9522	0.9920	1
0.75	3	3	0.4677	0.7221	0.9212	0.9829	1
0.75	3	3.5	0.4360	0.598	0.8288	0.9484	0.9863
0.75	3	4	0.4262	0.5155	0.7221	0.8878	0.9628
0.9	183	0.7	0.1025	0.8890	0.9931	1	1
0.9	75	0.9	0.1038	0.8736	0.9914	1	1
0.9	52	1	0.1087	0.8670	0.9905	1	1

0.9	15	1.5	0.1283	0.8088	0.9810	0.9979	1
0.9	7	2	0.2006	0.7600	0.9658	0.9954	1
0.9	5	2.5	0.2218	0.6425	0.9191	0.9856	0.9973
0.9	4	3	0.2782	0.5586	0.852	0.9645	0.9920
0.9	3	3.5	0.4360	0.5985	0.8288	0.9484	0.9863
0.9	3	4	0.4262	0.5155	0.7221	0.8878	0.9628
0.95	216	0.7	0.0521	0.8422	0.9893	1	1
0.95	88	0.9	0.0543	0.8238	0.9868	0.9987	1
0.95	61	1	0.0576	0.8153	0.9855	0.9986	1
0.95	17	1.5	0.0813	0.7572	0.9738	0.9970	1
0.95	8	2	0.1347	0.6954	0.9525	0.993	1
0.95	5	2.5	0.2218	0.6425	0.9191	0.9856	0.9973
0.95	4	3	0.2782	0.5586	0.8520	0.9645	0.9920
0.95	4	3.5	0.2493	0.4112	0.7057	0.8996	0.9713
0.95	3	4	0.4262	0.5155	0.7221	0.8878	0.9628
0.99	288	0.7	0.010	0.7258	0.9772	1	1
0.99	117	0.9	0.0116	0.6999	0.9725	1	1
0.99	81	1	0.0127	0.6882	0.9698	1	1
0.99	23	1.5	0.0187	0.596	0.9447	0.9932	1
0.99	11	2	0.0366	0.5048	0.9004	0.9846	0.9974
0.99	7	2.5	0.0736	0.4283	0.8325	0.9658	0.993
0.99	5	3	0.1544	0.4114	0.7697	0.9390	0.9856
0.99	4	3.5	0.2493	0.4112	0.7057	0.8996	0.9713
0.99	3	4	0.4262	0.5155	0.7221	0.8878	0.9628

Table 3. Gives the AOQ values for Sampling Plan $(n, c=2, t/t_{0.1})$ for a given $P*$ under ERD when $\theta = 2$.

P*	n	$t_{0.1}/t_{0.1}^{0}$					
		$t/t_{0.1}^{0}$	**1**	**1.5**	**2**	**2.5**	**3**
0.75	135	0.7	0.253	0.9447	0.9970	1	1
0.75	55	0.9	0.2589	0.9371	0.9963	1	1
0.75	39	1	0.2531	0.9299	0.9956	1	1
0.75	11	1.5	0.2966	0.9004	0.9916	1	1
0.75	6	2	0.2916	0.8218	0.9768	0.9970	1
0.75	4	2.5	0.3612	0.7569	0.9522	0.9920	1
0.75	3	3	0.4677	0.7221	0.9212	0.9829	1
0.75	3	3.5	0.4360	0.598	0.8288	0.9484	0.9863
0.75	3	4	0.4262	0.5155	0.7221	0.8878	0.9628
0.9	183	0.7	0.1025	0.8890	0.9931	1	1
0.9	75	0.9	0.1038	0.8736	0.9914	1	1
0.9	52	1	0.1087	0.8670	0.9905	1	1
0.9	15	1.5	0.1283	0.8088	0.9810	0.9979	1
0.9	7	2	0.2006	0.7600	0.9658	0.9954	1
0.9	5	2.5	0.2218	0.6425	0.9191	0.9856	0.9973
0.9	4	3	0.2782	0.5586	0.852	0.9645	0.9920
0.9	3	3.5	0.4360	0.5985	0.8288	0.9484	0.9863
0.9	3	4	0.4262	0.5155	0.7221	0.8878	0.9628
0.95	216	0.7	0.0521	0.8422	0.9893	1	1
0.95	88	0.9	0.0543	0.8238	0.9868	0.9987	1
0.95	61	1	0.0576	0.8153	0.9855	0.9986	1
0.95	17	1.5	0.0813	0.7572	0.9738	0.9970	1
0.95	8	2	0.1347	0.6954	0.9525	0.993	1
0.95	5	2.5	0.2218	0.6425	0.9191	0.9856	0.9973
0.95	4	3	0.2782	0.5586	0.8520	0.9645	0.9920
0.95	4	3.5	0.2493	0.4112	0.7057	0.8996	0.9713
0.95	3	4	0.4262	0.5155	0.7221	0.8878	0.9628
0.99	288	0.7	0.010	0.7258	0.9772	1	1
0.99	117	0.9	0.0116	0.6999	0.9725	1	1
0.99	81	1	0.0127	0.6882	0.9698	1	1
0.99	23	1.5	0.0187	0.596	0.9447	0.9932	1
0.99	11	2	0.0366	0.5048	0.9004	0.9846	0.9974
0.99	7	2.5	0.0736	0.4283	0.8325	0.9658	0.993
0.99	5	3	0.1544	0.4114	0.7697	0.9390	0.9856
0.99	4	3.5	0.2493	0.4112	0.7057	0.8996	0.9713
0.99	3	4	0.4262	0.5155	0.7221	0.8878	0.9628

Table 4. Gives the AOQL values for Sampling Plan $(n, c=2, t/t_{0.1})$ for a given $P*$ under ERD when $\theta = 2$.

$P*$	n	$t/t_{0.1}$	AOQL
0.75	135	0.7	0.0095
0.75	55	0.9	0.0237
0.75	39	1	0.0338
0.75	11	1.5	0.1224
0.75	6	2	0.2284
0.75	4	2.5	0.3411
0.75	3	3	0.4563
0.75	3	3.5	0.4570
0.75	3	4	0.4569
0.9	183	0.7	0.0074
0.9	75	0.9	0.0182
0.9	52	1	0.0262
0.9	15	1.5	0.0892
0.9	7	2	0.1901
0.9	5	2.5	0.2732
0.9	4	3	0.3411
0.9	3	3.5	0.4570
0.9	3	4	0.4569
0.95	216	0.7	0.0061
0.95	88	0.9	0.0149
0.95	61	1	0.0213
0.95	17	1.5	0.0757
0.95	8	2	0.1678
0.95	5	2.5	0.2732
0.95	4	3	0.3411
0.95	4	3.5	0.3411
0.95	3	4	0.4569
0.99	288	0.7	0.0045
0.99	117	0.9	0.0114
0.99	81	1	0.0166
0.99	23	1.5	0.0596
0.99	11	2	0.1218
0.99	7	2.5	0.1940
0.99	5	3	0.2742
0.99	4	3.5	0.3411
0.99	3	4	0.4569

V. CONCLUSIONS

Quality of the product plays vital role in reliability acceptance sampling plan because in any manufacturing sector, quality is a measure or state of being free from defects (failure) So that average outgoing quality is an important measure to ensure the quality of the products. In this study, we have proposed Average outgoing Quality (AOQ) and AOQL for the truncated life test when the life time of the product follows a Exponentiated Rayleigh distribution since the Exponentiated Rayleigh distribution has been shown to be a useful model to analyze the system reliability studies.

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