DESIGNING OF ACCEPTANCE SAMPLING PLAN BASED ON PERCENTILES FOR TOPP-LEONE GOMPERTZ DISTRIBUTION

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Abstract

Acceptance sampling is a statistical technique used to inspect the quality of a batch of products. An acceptance sampling plan under which sampling inspection is performed by conducting life test upon the sampled products is termed as reliability sampling plan. In this paper, a single acceptance sampling plan based on percentile is presented for Topp-Leone Gompertz (TL-G) distribution when the life test is truncated at a pre-specified time. The minimum sample size necessary to ensure the specified life percentile is obtained under a given consumer's risk. The operating characteristic values (and curves) of the sampling plans as well as the producer's risk are presented.

Keywords: Acceptance sampling plan, Percentiles, Topp-Leone Gompertz (TL-G) distribution, Operating characteristic values, Producer's risk, Minimum sample size

1. Introduction

In statistical quality control, acceptance sampling for products is one aspect of quality assurance. If the quality characteristic is regarding the lifetime of the product, the acceptance sampling problem becomes a life test. Quality personnel would like to know whether the lifetimes of products reach the consumer's minimum standard or not. Traditionally, when the life test indicates that the mean life of products exceeds the specified one, the lot of products is accepted, otherwise it is rejected. For the purpose of reducing the test time and cost, a truncated life test may be conducted to determine the smallest sample size to ensure a certain mean life of products when the life test is terminated at a preassigned time t, and the number of failures observed does not exceed a given acceptance number 'c'.

Nzei et al. [13] developed the Topp-Leone Gompertz (TL-G) distribution. Studies regarding truncated life tests can be found in Epstein [4], Sobel and Tischendrof [20], Goode and Kao [6], Gupta and Groll [7], Gupta [8], Fertig and Mann [5], Kantam and Rosaiah [10], Baklizi [2], Wu and Tsai [22], Rosaiah et al. [19], Tsai and Wu [21], Balakrishnan et al. [3], Rao et al. [15], Aslam et al. [1], Rao et al. [17], . Mahmood et al. [12]. All these authors designed acceptance sampling plans based on the mean life time under a truncated life test using different distributions.

In contrast, Lio et al. [11] considered acceptance sampling plans for percentiles using Birnbaum-Saunders distribution. Srinivasa Rao et al. [16] studied acceptance sampling plans for percentiles based on the inverse Rayleigh distribution. Rao et al. [18] considered acceptance sampling plans for percentiles using Half Normal distribution. Pradeepa Veerakumari and Ponneeswari [14] designed acceptance sampling plan based on percentiles of exponentiated Rayleigh distribution Jayalakshmi and Vijilamery [9] studied Special Type Double Sampling Plan for truncate life test using Gompertz Frechet distribution.

2. Topp-Leone Gompertz (TL-G) Distribution

The TL-G distribution was developed by Nzei et al. in 2020. The CDF and PDF of the TL-G distribution are given by

$$F(t;\alpha,\delta,\gamma) = [1 - e^{(\dfrac{-2\delta(e^{\gamma t-1})}{\gamma})}]^{\alpha} \tag{1}$$

$$f(t;\alpha,\delta,\gamma) = 2\alpha\delta e^{\gamma t} e^{(\dfrac{-2\delta(e^{\gamma t-1})}{\gamma})}[1 - e^{(\dfrac{-2\delta(e^{\gamma t-1})}{\gamma})}]^{(\alpha-1)}; t > 0 \tag{2}$$

For given 0 < q < 1 the $100q^{t^{`}}$ actual percentile of the TL-G distribution can be given by

$$t_q = \frac{1}{\gamma} ln(1 - \frac{\gamma}{2\delta} ln(1 - q^{\frac{1}{\alpha}})) \tag{3}$$

The t_q increase as q increases Let

$$\eta = ln(1 - \frac{\gamma}{2\delta} ln(1 - q^{\frac{1}{\alpha}})) \tag{4}$$

Then from (3), $\gamma = \eta / t_q$
By letting $a = t/t_q$, F(t) becomes

$$F(t;\alpha,\delta,\gamma) = [1 - e^{(\dfrac{-2\delta(e^{a\eta-1})}{\gamma})}]^{\alpha} \tag{5}$$

Equation (5) gives the modified cdf and by partially differentiating the equation (4) w.r.t a we will get the modified pdf for percentiles of TL-G distribution where t_q is the 25^{th} percentile of the given distribution.

3. Reliability Acceptance Sampling Plan

A sampling plan in which a decision about the acceptance or rejection of a lot is based on a single sample that has been inspected is known as a Single Sampling Plan. For a single sampling plan, one sample of items is selected at random from a lot and the disposition of the lot is determined from the resulting information. Single Sampling Plans are the most common and easiest plans to use.

Reliability Single Sampling Plans are part of an inspection procedure used to determine whether to accept or reject a specific lot based on lifetime. The Reliability Single Sampling Plan can be represented as $(n, c, t/t_q^0)$. Here n and c are the sample size and acceptance number for the sampling plan. Assume that a life test is conducted and will be terminated at time t_q^0.

3.1. Operating Procedure

The acceptance sampling plan based on truncated life tests consists of the following:

1. Take a random sample of size n from the lot and inspect them.
2. The maximum test duration time is t.
3. Count the number of defectives d in the sample of size n.
4. The benchmark of defective (d) units is c, where if $d \leq c$ defectives out of n occur at the end of the test period t_q^0, the lot is accepted. Otherwise reject the lot.

3.2. Minimum sample size

For a fixed P^* our sampling plan is characterized by $(n, c, t/t_q^0)$. Here we consider sufficiently large sized lots so that the binomial distribution can be applied. The problem is to determine for given values of P^* $(0 < P^* < 1)$, t_q^0 and c, the smallest positive integer, n required to assert that $t_q > t_q^0$ must satisfy

$$\sum_{i=0}^{c} p^i (1-p)^{(n-i)} \leq (1-P^*) \tag{6}$$

where p=F(t,a_q), it is the probability of failure time during time t given a specified percentile of a lifetime t_q^0 and it depends on the $a = t/(t_q^0)$ since t_q^0 increases as q increases. Accordingly, we have

$$F(t,a) < F(t,\delta_0) \iff a \leq a_0$$

Or, equivalently

$$F(t;t_q) < F(t;t_q^0) \iff t_q \geq t_q^0$$

The smallest sample size n satisfying eq. (6) can be obtained for any given sampling plan $(n, c, t/t_q^0)$ is given in Table 1.

3.3. Operating Characteristic (OC) Function

The OC function L(p) of the acceptance sampling plan (n,c,t/t_q^0) is the probability of accepting a lot. It is given as

$$L(p) = \sum_{i=0}^{c} p^i (1-p)^{(n-i)} \tag{7}$$

where $p = F(t, a_q)$. It should be noticed that $F(t, a_q)$ can be represented as a function of $a_q = t/t_q$. Therefore, we have

$$p = F(t,a) = F(\frac{t}{t_q}, \frac{1}{d_q})$$

where d_q=t_q/t_q^0
Using eq. (7) the OC values can be obtained for any sampling plan $(n, c, t/t_q^0)$. The OC values for the proposed sampling plan is presented in Table 3.

3.4. Producer's Risk (λ)

The producer's risk is defined as the probability of rejecting the lot when $t_q > t_q^0$. For a given value of the producer's risk, say λ , we are interested in knowing the value of d_q to ensure the producer's risk is less than or equal to λ if a sampling plan $(n, c, t/t_q^0)$ is developed at a specified confidence level P^*. Thus, one needs to find the smallest value d_q according to eq. (7).

$$L(p) \geq 1 - \lambda$$

Based on the sampling plans (n,c,$t/t_q{}^0$) given in Table 2 the minimum ratios of $d_{0.25}$ at the producer's risk of $\lambda = 0.05$ are presented in Table 4.

4. Illustration

Assume that the life distribution is TL-G distribution, and the experimenter is interested in showing that the true unknown 25^{th} percentile life $t_{0.25}$ is at least 1000 hrs. Let $\alpha = 1.9$,$\delta = 0.125$, $\gamma = 1.7$and $\lambda = 0.05$. It is desire to stop the experiment at time t=3500 hrs. For the acceptance number c=1 from the Table 1 one can obtain the Single Sampling Plan $(n, c, t/t_q^0)$ = (5,1,3.5). The optimum sample sizes needed for the given requirement is found to be as n=5.
The respective OC values for the proposed acceptance sampling plan $(n, c, t/t_q^0)$ with $P^* = 0.95$

Table 1

$t_q/(t_q^0)$	0.75	1	1.25	1.5	1.75	2	2.25	2.5
L(p)	0.000012	0.05241	0.37108	0.67370	0.83596	0.9137	0.95184	0.97148

for TL-G distribution from the Table 2 are given in above Table 1.

This shows that if the actual 25^{th} percentile is equal to the required 25^{th} percentile $(t_{0.25}/t_{0.25^0} = 3.5)$, the producer's risk is approximately 0.94759 $(1 - 0.05241)$. The producer's risk almost equal to 0.03 or less when the actual 25^{th} percentile is greater than or equal to 2.5 times the specified 25^{th} percentile.

Table 4 gives the $d_{0.25}$ values for c=1 and $t/t^0_{0.25} = 3.5$ to assure that the producer's risk is less than or equal to 0.05.

In this example, the value of $d_{0.25}$ is 2.229656 for c=1, $t/t^0_{0.25} = 3.5$ and λ =0.05. This means the product can have a 25^{th} percentile life of 2.229656 times the required 25^{th} percentile lifetime. That is under the above Single Sampling Plan the product is accepted with probability of at least 0.95.

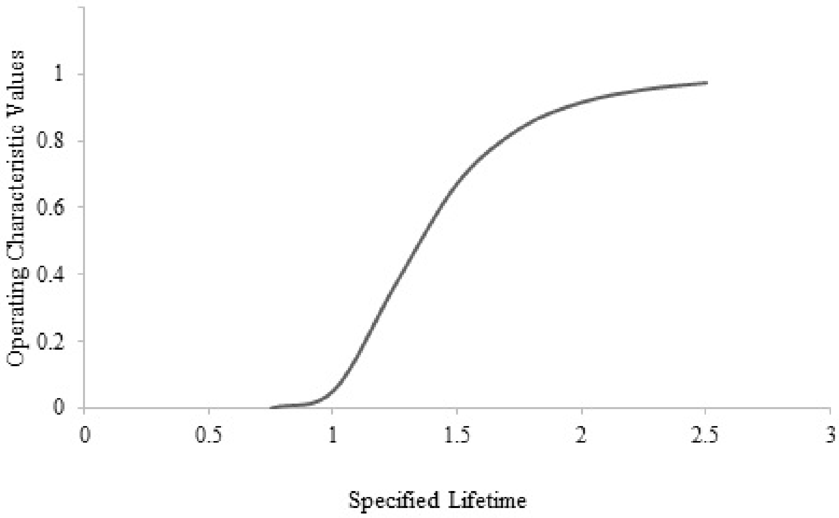

Figure 1: *OC curve for the sampling plan* $(n = 5, c = 1, t/t^0_{0.25} = 3.5)$

5. Construction of the Table

Step 1: Find the value of η for the fixed values of $\alpha = 1.9, \delta = 0.125, \gamma = 1.7$ and q=0.25

Step 2: Set the value of $t/t_q{}^0$ =0.7, 0.9, 0.9, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5

Step 3: Find the sample size n by satisfying $L(p) \leq 1 - P^*$ when $P^* = 0.99, 0.95, 0.90$ and 0.75. Here P^* is the probability of rejecting a bad lot and

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

Step 4: for the n value obtained find the $d_{0.25}$ value such that $L(p) \geq 1 - \lambda$ where $\lambda = 0.05$ and $p = F(t/t^0_q, 1/d_q)$; $d_q = t_q/t^0_q$

Table 2: *Minimum Sample Size values necessary to assure 25^{th} percentile for TL-G distribution*

p^*	c	$t/(t_q^0)$							
		0.7	0.9	1.0	1.5	2.0	2.5	3	3.5
0.75	1	261	144	112	39	18	8	6	3
	2	379	210	162	58	26	14	8	5
	3	495	274	211	75	33	18	10	7
	4	608	336	260	92	41	21	12	8
	5	719	398	309	109	48	25	15	11
0.90	1	377	208	160	57	25	13	7	5
	2	514	284	221	77	34	18	10	6
	3	647	357	276	97	43	21	13	9
	4	74	429	331	116	52	27	15	10
	5	897	498	384	135	60	31	19	12
0.95	1	458	253	196	69	29	15	10	5
	2	609	337	260	90	41	20	12	7
	3	749	414	320	112	50	26	15	9
	4	884	489	379	132	58	31	18	11
	5	1017	562	435	152	68	35	21	13
0.99	1	637	353	271	94	42	21	12	7
	2	803	446	343	121	53	27	15	9
	3	970	534	414	144	64	32	19	12
	4	1118	615	477	166	74	38	22	13
	5	1263	695	539	187	83	43	25	16

Table 3: *Operating characteristic values of the sampling plan $(n, c = 1, t/(t_q^0))$ for a given P^* under TL-G distribution*

p^*	$t/(t_q{}^0)$	n	$t_q/(t_q{}^0)$							
			0.75	1	1.25	1.5	1.75	2	2.25	2.5
0.75	0.7	261	0.0303	0.2489	0.5162	0.7027	0.8152	0.8815	0.9214	0.9462
	0.9	144	0.0255	0.2497	0.5292	0.7188	0.8293	0.8927	0.9299	0.9526
	1	112	0.0225	0.2466	0.5320	0.7238	0.8342	0.8967	0.9330	0.9550
	1.5	39	0.9497	0.9845	0.9938	0.9970	0.9984	0.9990	0.9994	0.9996
	2	18	0.0066	0.2254	0.5666	0.7751	0.8794	0.9315	0.9588	0.9739
	2.5	8	0.0104	0.2979	0.6584	0.8414	0.9216	0.9581	0.9675	0.9805
	3	6	0.0008	0.1566	0.5351	0.7774	0.8905	0.9424	0.9675	0.9805
	3.5	3	0.0046	0.2777	0.6755	0.8650	0.9395	0.9702	0.9840	0.9907
0.90	0.7	377	0.0038	0.0991	0.3191	0.5330	0.6879	0.7900	0.8559	0.8988
	0.9	208	0.0029	0.0995	0.3321	0.5536	0.7087	0.8079	0.8704	0.9103
	1	160	0.0026	0.1009	0.3407	0.5656	0.7202	0.8175	0.8779	0.9161
	1.5	57	0.0010	0.0934	0.3585	0.6009	0.7568	0.8487	0.9027	0.9352
	2	25	0.0005	0.0939	0.3889	0.6446	0.7963	0.8795	0.9256	0.9521
	2.5	13	0.0002	0.0851	0.3998	0.6692	0.8202	0.8983	0.9395	0.9622
	3	7	0.0001	0.0971	0.4461	0.7177	0.8563	0.9229	0.9560	0.9734
	3.5	5	0.00001	0.0524	0.3710	0.6737	0.8359	0.9137	0.9518	0.9714
0.95	0.7	458	0.00087	0.0502	0.2214	0.4298	0.6009	0.7227	0.8054	0.8611
	0.9	253	0.00062	0.0501	0.2324	0.4508	0.6246	0.7444	0.8237	0.8760
	1	196	0.0005	0.0495	0.2367	0.4598	0.6348	0.7538	0.8316	0.8823
	1.5	69	0.00018	0.0470	0.2583	0.5040	0.6833	0.7969	0.8172	0.9988
	2	29	0.00011	0.0555	0.3082	0.5732	0.7464	0.8466	0.8667	0.9375
	2.5	15	0.00003	0.0498	0.3201	0.6018	0.7757	0.8704	0.9039	0.9507
	3	10	0.00001	0.0213	0.2451	0.5458	0.7456	0.8555	0.8172	0.9471
	3.5	5	0.00001	0.0524	0.3710	0.6737	0.8359	0.9137	0.9518	0.9714
0.99	0.7	637	0.00003	0.0104	0.0933	0.2555	0.4306	0.5780	0.6896	0.7706
	0.9	353	0.00001	0.0101	0.0993	0.2733	0.4558	0.6047	0.7143	0.7920
	1	271	0.00001	0.0105	0.1049	0.2863	0.4725	0.6213	0.7290	0.8044
	1.5	94	0.000004	0.0105	0.1243	0.3370	0.5379	0.6855	0.7850	0.8505
	2	42	0	0.0092	0.1362	0.3750	0.5870	0.7324	0.8245	0.8822
	2.5	21	0	0.0093	0.1562	0.4226	0.6409	0.7793	0.8614	0.9103
	3	12	0	0.0074	0.1593	0.4450	0.6703	0.8059	0.8825	0.9262
	3.5	7	0	0.0085	0.1852	0.4945	0.7177	0.8422	0.9085	0.9444

Table 4: *Minimum ratio of true $d_{0.25}$ for the acceptability of a lot for the TL-G distribution and producer's risk of* $\lambda = 0.05$

p^*	$t/(t_q^0)$	n	$t_q/(t_q^0)$							
0.75	0.7	261	2.5451	2.5464	2.5454	2.5462	2.5467	2.5470	2.5499	2.5496
	0.9	144	2.4588	2.4600	2.4599	2.4611	2.4614	2.4622	2.4578	2.4750
	1	112	2.4264	2.4276	2.4277	2.4290	2.4293	2.4301	2.4273	2.4281
	1.5	39	2.2498	2.2507	2.2517	2.2433	2.2472	2.2521	2.2500	2.2600
	2	18	2.1487	2.1495	2.1506	2.1457	2.1494	2.1478	2.1416	2.1542
	2.5	8	1.9254	1.9191	1.9240	1.9192	1.9183	1.9201	1.9305	1.9229
	3	6	2.0570	2.0575	2.0514	2.0556	2.0526	2.0559	2.0600	2.0635
	3.5	3	1.8133	1.8095	1.8127	1.8122	1.8089	1.8143	1.8122	1.8124
0.90	0.7	377	3.0392	3.0515	3.0508	3.0483	3.0461	3.0442	3.0389	3.0529
	0.9	208	2.9272	2.9362	2.9356	2.934	2.9337	2.9324	2.9304	2.9324
	1	160	2.8693	2.8768	2.8763	2.8754	2.8753	2.8742	2.8734	2.8761
	1.5	57	2.6634	2.6585	2.6691	2.6692	2.6573	2.6571	2.6620	2.6675
	2	25	2.4689	2.4683	2.4662	2.4693	2.4698	2.4717	2.4658	2.4750
	2.5	13	2.3440	2.3433	2.3431	2.3452	2.3463	2.3419	2.3398	2.3515
	3	7	2.1876	2.1875	2.1887	2.1896	2.1861	2.1826	2.1875	2.1911
	3.5	5	2.2309	2.2296	2.2298	2.2313	2.2249	2.2319	2.2275	2.2250
0.95	0.7	458	3.3592	3.3560	3.3529	3.3445	3.3597	3.3578	3.3548	3.3483
	0.9	253	3.2281	3.2253	3.2241	3.2174	3.2289	3.2283	3.2264	3.2238
	1	196	3.1704	3.1678	3.1667	3.1612	3.1563	3.1710	3.1695	3.1681
	1.5	69	2.9000	2.9104	2.9096	2.9082	2.9081	2.9065	2.9054	2.9086
	2	29	2.6336	2.6372	2.6368	2.6370	2.6371	2.6260	2.6323	2.6365
	2.5	15	2.4881	2.4836	2.4807	2.4846	2.4853	2.4879	2.4804	2.5
	3	10	2.5268	2.5294	2.5290	2.5197	2.5206	2.5241	2.5288	2.5250
	3.5	5	2.2309	2.2296	2.2298	2.2313	2.2249	2.2319	2.2275	2.2250
0.99	0.7	637	3.9519	3.9484	3.9580	3.9540	3.9405	3.9577	3.9512	3.9411
	0.9	353	3.7928	3.7890	3.7985	3.7958	3.7860	3.7990	3.7958	3.7899
	1	271	3.7035	3.6996	3.7089	3.7065	3.6989	3.7096	3.7076	3.7032
	1.5	94	3.3554	3.3517	3.3462	3.3578	3.3558	3.3537	3.3496	3.3429
	2	42	3.1019	3.0989	3.0974	3.0906	3.1031	3.1027	3.1017	3.1013
	2.5	21	2.8693	2.8672	2.8660	2.8642	2.8648	2.8632	2.8635	2.8679
	3	12	2.7162	2.7239	2.7230	2.7227	2.7231	2.7232	2.7245	2.7183
	3.5	7	2.5509	2.5545	2.5539	2.5544	2.5546	2.5469	2.5534	2.5537

6. CONCLUSION

In this paper we have derived the acceptance sampling plans based on percentiles for the Topp-Leone Gompertz (TL-G) distribution when the life test is truncated at a pre-fixed time. The minimum sample size required to decide upon accepting or rejecting a lot based on its specified 25^{th} percentile, the operating characteristic function values and corresponding producer's risk are obtained. Tables provided are helpful for the industrial use to save the cost and time of the experiment.

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