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DESIGNING A HYBRID SINGLE SAMPLING PLAN FOR LIFE-TIME ASSESSMENT USING THE EXPONENTIAL-RAYLEIGH DISTRIBUTION

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Abstract

The approach of statistical quality control known as "product control" deals with the steps involved in making judgments on one or more batches of completed goods produced by production processes. One of the main categories of product control is sampling inspection by variables, which includes processes for selecting numerous individual units based on sample measurements for a quality characteristic under investigation. These approaches are predicated on the knowledge of the functional form of the probability distribution and the presumption that the quality feature is measured on a continuous scale. The literature on product control contains inspection techniques that were created with the implicit presumption that the quality characteristic is distributed normally with the associated attributes. In this study, a single variable sampling plan is developed and assessed under the assumption that the quality characteristic will be distributed using an Exponential-Rayleigh distribution. This article discusses the development of reliability sampling plans for intermittent test batches using type-I and type-II censoring data. To build a sampling strategy using the Exponential-Rayleigh distribution, this work offers a two-parameter continuous probability distribution. One of the main categories of acceptance sampling is sampling inspection by variables, which involves processes for making decisions regarding the disposition of numerous individual units based on sample measurements of those units for a quality feature under investigation. Assume that the sample inspection's number of defective items follows the Poisson distribution. The suggested SSP's ideal parameters are determined using a multi-objective genetic algorithm, which is concerned with concurrently minimizing the average number of samples and inspection costs a maximizing the likelihood of the acceptance sampling plan. The Rayleigh distribution is an appropriate model for life-testing studies, and the Exponential Rayleigh Distribution is studied as a model for a lifetime random variable. The paper also analyses the effectiveness of reliable single sampling plans designed using the median lifetime of products. The efficiency of these sampling plans is evaluated in terms of sample size and sampling risks. Poisson probabilities are used to determine the parameters of the sampling plans, to protect both producers and consumers from risks. For manufacturing enterprises to analyze the viability of the sample plan, necessary tables and procedures are constructed with acceptable examples.

Keywords: Reliability Sampling, Exponential Rayleigh Distribution, Median life-time, Reliable Single Sampling, Single Sampling Plan.

I. Introduction

Statistical quality control (SQC) is a valuable technique that can help improve a company's production process. One important aspect of SQC is sampling for acceptance or rejection of a lot. Acceptance single sampling is a commonly used method for determining whether a lot should be accepted or rejected based on classical attribute quality characteristics. Acceptance sampling is a widely used technique in Quality Control. The primary objective of the plan is to determine optimal plan specifications, including the sample size and acceptance number, to save time and cost during the experiment. The study focuses on a group acceptance sampling plan for items with MOKw-E distribution. Key design parameters are extracted and operating characteristic function is determined for different quality levels. The results will guide future research on Nano quality-level topics with different probability distributions [1]. This is particularly important if the product's quality is defined by its lifetime.

Many authors have created Reliability Sampling Plans that rely on the sample size and acceptance constant but do not provide a guarantee of product reliability for intermittent testing lots or batches. A Modified group chain sampling plan is developed for a truncated life test when the lifetime of an item follows Rayleigh distribution. An Optimal number of groups and operating characteristic values are obtained by obeying the specified consumer risk, test termination time, and mean ratio [2]. The duration of a successful product's operation is measured in lifetime data, which is gathered during life tests, in hours, miles, cycles before failure, or any other pertinent parameter. This is referred to as 'Life Data'. These reliability sampling plans are designed to be more reliable in terms of accepting products or batches. A new acceptance sampling plan based on truncated life tests and Quasi Shanker distribution was developed for quality control. The suggested plan provides smaller sample sizes and a substantial sampling economy compared to other competitors. It can be used in industry and for further research [3]. Procedures for designing and simulating necessary tables are provided to simplify product selection and testing.

The Exponential and Rayleigh distribution are two of the most important distributions in the field of life testing and reliability theory. They possess significant structural properties and offer great mathematical flexibility. The concept of truncated single acceptance sampling plan at a pre-assigned time. Different acceptance numbers and values for the ratio of the specified test duration to the specified mean life are achieved with the given probability levels. It is also discovered that the minimal sample sizes guaranteed the specified mean lifetime [4]. The problem of acceptance sampling when the life test is truncated at a pre-assigned time is discussed with known shape and scale parameters. For different acceptance ratios, different levels of confidence, and different proportions of the fixed experimental period to the given median lifetime [5]. However, it's important to note that all of these works were carried out assuming that the life testing was done under a hybrid censoring scheme. They also only consider the consumer's risk while ignoring the risk for the producer in rejecting lots of good products. The paper proposes a fuzzy Poisson-based single sampling plan with varying OC curve widths and compares it to the binomial-based plan [6].

This paper aims to establish the dependability of sampling plans based on exponential Rayleigh distribution while considering the levels of producer and consumer risk. Briefly describe the theoretical view of Rayleigh distribution in section II. The OC function of the reliability single sampling plan is derived in section III, and the procedures for determining and operating the sampling plans are explained in section IV. Section V covers the construction of tables for optimal sampling plans in specific cases, and an example is provided to illustrate the selection of the sampling plan. Finally, the results are summarized in section VI. Two acceptance sampling plans based on Weibull Exponential and Weibull Lomax distributions, using the maximum likelihood method to estimate model parameters. The proposed plans are compared with existing plans based on inspected items [7].

II. Theoretical View of Rayleigh Distribution

The Rayleigh distribution is a continuous probability distribution within the domain of probability theory and statistics, applicable to random variables featuring non-negative values. It exhibits a correlation with the chi distribution, specifically when endowed with two degrees of freedom, although this connection involves rescaling. The eponym for this distribution stems from Lord Rayleigh [18]. When the overall magnitude of a vector in the plane is correlated with its directional components, a Rayleigh distribution is frequently seen. The Rayleigh distribution might naturally appear, for instance, when the two-dimensional analysis of wind velocity is performed. The overall wind speed (vector magnitude) will be represented by a Rayleigh distribution if each component has zero mean, equal variance, and is normally distributed. The situation of random complex numbers with real and imaginary components that are independently and identically distributed Gaussian with equal variance and zero mean provides a second illustration of the distribution. In that situation, the complex number's absolute value has a Rayleigh distribution.

Magnetic Resonance Imaging (MRI) is a field in which the estimation is applied. The background data is Rayleigh distributed because MRI pictures are typically interpreted as magnitude images even though they are recorded as complex images. As a result, the noise variance in an MRI image can be calculated from background data using the technique above [19] [20]. The application of the Rayleigh distribution extended to the field of nutrition, where it was employed to establish a link between dietary nutrient levels and the physiological responses of both humans and animals. This technique represents one approach to compute the nutritional response relationship through utilization of the parameter [21].

III. Operating Characteristic Function of RSSPs under the conditions of Exponential Rayleigh distribution

A reliability single sampling plan is a process used to make decisions about submitted lots by conducting a life test on randomly selected items. A single sampling plan by variables assumes a non-normal Inverse Gaussian distribution for the quality characteristic and develops a procedure for determining plan parameters based on specified quality levels [8]. It is characterized by four parameters (N, n, c, t): lot size (N), sample size (n), acceptance number (c), and test termination time (t). A new sampling plan based on the Generalized Poisson Distribution is proposed and studied for its performance measures in lot acceptance [9]. The plan can be implemented by selecting items from the lot according to these parameters. Economic Reliability Test Plan (ERTP) is developed considering that the lifetime of the submitted items follows a generalized exponential distribution. Test termination time is calculated for a given group size, defined acceptance number, and producer's risk [10].

(1) Choose a random selection of n products from the submitted lot of size N.
(2) Conduct the life test for the selected items considering t as the test terminated time. Observe the number of failed items X=x.
(3) Terminate the life test, if either at time of t or X>c before reaching time t, whichever is earlier.
(4) Accept the lot, if x ≤ c at time t; reject the lot if x>c either at time t or earlier.

Let T be the lifetime of the product, which is distributed according to an exponential Rayleigh distribution having the probability density function (PDF)

$$f(x) = \lambda\beta x e^{\frac{\beta}{2}x^2} . e^{-\lambda(e^{\frac{\beta}{2}x^2-1)}} \qquad x\varepsilon R;\ \lambda,\beta > 0 \tag{1}$$

Here λ and β are the shape and scale parameters respectively. The cumulative distribution function of the exponential Rayleigh distribution is given by,

$$F\ (x) = 1 - \lambda e^{-\lambda(e^{\frac{\beta}{2}x^2-1)}} \qquad x\varepsilon R;\ \lambda, \beta > 0 \tag{2}$$

Estimate to a parameter β respectively

$$\beta = \frac{2}{m^2} log\ (\frac{1 - log\ (\frac{1}{2})}{\lambda})$$

The lot fraction nonconforming, n, p, can be calculated corresponding to each value of 1/m from

$$F(X) = F\left(\frac{1}{m}\right) = p$$

The performance of a sampling plan may be analyzed using their OC functions. The OC function of a sampling plan is given by

$$P_a = P\ (x \leq c) = \sum_{x=0}^{c} P\ (X = x)$$

The probability distribution of X can be assumed appropriately as hyper-geometric distribution. When n/N ≤0.10, n is large and p is small such that np<5, the sampling distribution of X can be approximated by the Poisson (np) distribution [11]. In light of these facts, it is suggested here

$$P_a(\text{p}) = \sum_{x=0}^{c} \frac{e^{-np}(np)^x}{x!}$$

IV. Determination of Plan Parameters under the conditions of Exponential Rayleigh Distribution

The most reliable single sampling plans are established for ER (λ, θ) distribution by using the Binomial probability distribution's OC function. A Special Type of Double Sampling (STDS) plan has been proposed to emphasize the importance of acceptance sampling plans in ensuring product quality. This plan uses the Generalized Poisson Distribution to achieve the same level of acceptance with fewer samples than a single sampling plan [12]. A sampling plan is designed to protect both the producer and consumer simultaneously. To ensure protection, two points are specified on the OC curve: (p_1, 1-α) and (p_2, β). Here, p_1 represents acceptable quality, α represents the producer's risk, p_2 represents limiting quality, and β represents the consumer's risk. Derivation of the Operating Characteristic (OC) function of the sampling plan, which describes its performance in terms of the probability of accepting or rejecting a batch based on the observed number of defects. The plan parameters are determined for specific sets of values for (p_1, α, p_2, β), which are parameters of the ZIP distribution [13]. An optimal RSSP can be found based on the points that meet the following requirements.

$$P_a(p_1) \geq 1 - \alpha$$

and

$$P_a(p_2) \leq \beta$$

These conditions may be written as

$$\sum_{x=0}^{c} \frac{e^{-np_1}(np_1)^x}{x!} \geq 1-\alpha \quad (3)$$

and

$$\sum_{x=0}^{c} \frac{e^{-np_1}(np_1)^x}{x!} \leq \beta \quad (4)$$

There are various ways to figure out the best values for n and c while adhering to conditions (3) and (4). Economic Reliability Test Plans (ERTP) is proposed considering that the lifetime of the submitted items follows the Pareto distribution of the second kind [14]. To determine the plan parameters, an iterative process is used as outlined below. In summary, when given λ, t, m_1, m_2, α, and β, the most effective values for n and c can be found using the following steps.

(1) For specified values of m_1 and m_2 with $m_1>m_2$, calculate $\beta_1 = \frac{2}{m_1^2} \log \left(\frac{1-\log\left(\frac{1}{2}\right)}{\lambda}\right)$ and $\beta_2 = \frac{2}{m_2^2} \log \left(\frac{1-\log\left(\frac{1}{2}\right)}{\lambda}\right)$
(2) Corresponding to t, β_1 and β_2, determine $p_1=F_T(1/m_1)$ and $p_2=F_T(1/m_2)$
(3) Set c=0
(4) Find the largest n, say n_L, such that $P_a(p_1) \geq 1-\alpha$
(5) Find the smallest n, say n_S, such that $P_a(p_2) \leq \beta$
(6) If $n_S \leq n_L$, then the optimum plan is (n_S, c); otherwise increase c by 1.
(7) Till the optimum values of n and c are attained, repeat steps 4 through 6.

A submitted lot may undergo the sampling examination after n and c have been established using the hybrid censoring procedures outlined in section 2.

V. Construction of Tables

The values of n and c of the optimum reliability sampling plans are determined using Poisson probabilities for the combination of λ, t, m_1, m_2, α, and β. The producer's risk and consumer's risk are considered at two different levels such as α=0.05, 0.05 and β=0.05, 0.10. The producer's estimated range of mean product lifetime is taken as m_1=4000, 4500, 5000, 5500, 6000, 6500, 7000, and 7500 hours respectively. Two different levels of test termination time and one value for shape parameter λ as assumed as t=200, 350, 500, and 650 hours and λ=1 respectively. The consumer's projected mean product lifespan is taken as m_2 = 750, 1000, 1250, 1500, 1750, 2000, 2250 hours respectively. The optimum reliability sampling plans' n and c values are shown in Tables 1 through Table 4. Each cell entry (n, c) in every table reflects the ideal value of the pair (n, c) that corresponds to the given values of λ, t, m_1, m_2, α, and β. The Selection of plans from these for the given requirements is described in the following illustration.

Illustration

Let the lifetime of the products submitted for inspection be distributed according to ER (1, β). The mean lifetime of the products meeting the expectation of the producer and consumer are respectively m_1=4000 hours and m_2=2250 hours. Suppose that the quality inspector prescribes to censor the life test at t=500 hours. Then, the values of acceptable quality level and limiting quality level can be computed as p_1=0.0082 and p_2=0.0260. If the producer's risk and the consumer's risk as α=0.05 and β=0.05, then the plan parameters may be obtained using Poisson probabilities from Table 3 as n=556 and c=8.

Now, the life-test-based lot-by-lot sampling inspection can be carried out as follows: A sample of 556 products may be selected randomly from the submitted lot. Life tests may be conducted on all the sampled products. The life test may be stopped after 500 hours if there have been no more than 8 failures. The lot might be approved. On the other hand, if the ninth failure occurs before t=500 hours, terminate the life test. The lot may be rejected.

Table 1: *Parameters of RSSPs under the conditions of ER (β, λ=1) Distribution with α=0.05, λ=1 and t=200 hours.*

		m1	4000	4500	5000	5500	6000	6500	7000	7500
t=200, λ=1		t/m1	0.05	0.0444	0.04	0.0363	0.0333	0.0307	0.0285	0.0266
		P1	0.0013	0.0010	0.0008	0.0006	0.0005	0.0004	0.0004	0.0003
m2	t/m2	P2								
750	0.2666	0.0374	(104,1) (127,1)	(104,1) (127,1)	(104,1) (127,1)	(62,0) (127,1)	(62,0) (81,0)	(62,0) (81,0)	(62,0) (81,0)	(62,0) (81,0)
1000	0.2	0.0210	(185,1) (226,1)	(185,1) (226,1)	(185,1) (226,1)	(185,1) (226,1)	(185,1) (226,1)	(185,1) (226,1)	(110,0) (226,1)	(110,0) (226,1)
1250	0.16	0.0134	(395,2) (468,2)	(289,1) (468,2)	(289,1) (352,1)	(289,1) (352,1)	(289,1) (352,1)	(289,1) (352,1)	(289,1) (352,1)	(289,1) (352,1)
1500	0.1333	0.0093	(569,2) (829,3)	(569,2) (673,2)	(416,1) (673,2)	(416,1) (507,1)	(416,1) (507,1)	(416,1) (507,1)	(416,1) (507,1)	(416,1) (507,1)
1750	0.1142	0.0068	(972,3) (1331,4)	(774,2) (1128,3)	(740,2) (916,2)	(774,2) (916,2)	(566,1) (916,2)	(566,1) (690,1)	(566,1) (690,1)	(566,1) (690,1)
2000	0.1	0.0052	(1762,5) (2249,6)	(1269,3) (1739,4)	(1269,3) (1473,3)	(1011,2) (1473,3)	(1011,2) (1196,2)	(1011,2) (1196,2)	(739,1) (1196,2)	(739,1) (901,1)
2250	0.0888	0.0041	(2830,7) (3470,8)	(2230,5) (2847,6)	(1606,3) (2200,4)	(1606,3) (1864,3)	(1280,2) (1864,3)	(1280,2) (1514,2)	(1280,2) (1514,2)	(935,1) (1514,2)

In each cell, the first pair is the value of (n, c) corresponding to (α=0.05, β=0.10) and the Second pair corresponding to (α=0.05, β=0.05).

Table 2: *Parameters of RSSPs under the conditions of ER (β, λ=1) Distribution with α=0.05, λ=1 and t=350 hours.*

		m1	4000	4500	5000	5500	6000	6500	7000	7500
t=350, λ=1		t/m1	0.0875	0.0777	0.07	0.0636	0.0538	0.0538	0.05	0.0466
		P1	0.0040	0.0031	0.0025	0.0021	0.0017	0.0015	0.0013	0.0011
m2	t/m2	P2								
750	0.4666	0.1144	(34,1) (42,1)	(34,1) (42,1)	(34,1) (42,1)	(21,0) (42,1)	(21,0) (27,0)	(21,0) (27,0)	(21,0) (27,0)	(21,0) (27,0)
1000	0.35	0.0644	(61,1) (74,1)	(61,1) (74,1)	(61,1) (74,1)	(61,1) (74,1)	(61,1) (74,1)	(61,1) (74,1)	(36,0) (74,1)	(36,0) (74,1)
1250	0.28	0.0412	(129,2) (153,2)	(95,1) (153,2)	(95,1) (115,1)	(95,1) (115,1)	(95,1) (115,1)	(95,1) (115,1)	(95,1) (115,1)	(95,1) (115,1)
1500	0.2333	0.0286	(186,2) (271,3)	(186,2) (220,2)	(136,1) (220,2)	(136,1) (166,1)	(136,1) (166,1)	(136,1) (166,1)	(136,1) (166,1)	(136,1) (166,1)
1750	0.2	0.0210	(318,3) (435,4)	(253,2) (369,3)	(253,2) (299,2)	(253,2) (299,2)	(185,1) (299,2)	(185,1) (226,1)	(185,1) (226,1)	(185,1) (226,1)
2000	0.17 5	0.0161	(576,5) (735,6)	(415,3) (568,4)	(415,3) (481,3)	(331,2) (481,3)	(331,2) (391,2)	(331,2) (391,2)	(242,1) (391,2)	(242,1) (295,1)
2250	0.1555	0.0127	(924,7) (1133,8)	(728,5) (930,6)	(525,3) (719,4)	(525,3) (609,3)	(418,2) (609,3)	(418,2) (495,2)	(418,2) (495,2)	(306,1) (495,2)

In each cell, the first pair is the value of (n, c) corresponding to (α=0.05, β=0.10) and the Second pair corresponding to (α=0.05, β=0.05).

Table3: *Parameters of RSSPs under the conditions of ER (β, λ=1) Distribution with α=0.05, λ=1 and t=500 hours.*

		m1	4000	4500	5000	5500	6000	6500	7000	7500
t=500, λ=1		t/m1	0.125	0.1111	0.1	0.0909	0.0833	0.0769	0.0714	0.0666
		P1	0.0082	0.0065	0.0052	0.0043	0.0036	0.0031	0.0026	0.0023
m2	t/m2	P2								
750	0.6666	0.2317	(17,1) (21,1)	(17,1) (21,1)	(17,1) (21,1)	(10,0) (21,1)	(10,0) (13,0)	(10,0) (13,0)	(10,0) (13,0)	(10,0) (13,0)
1000	0.5	0.1312	(30,1) (37,1)	(30,1) (37,1)	(30,1) (37,1)	(30,1) (37,1)	(30,1) (37,1)	(30,1) (37,1)	(18,0) (37,1)	(18,0) (37,1)
1250	0.4	0.0841	(64,2) (75,2)	(47,1) (75,2)	(47,1) (57,1)	(47,1) (57,1)	(47,1) (57,1)	(47,1) (57,1)	(47,1) (57,1)	(47,1) (57,1)
1500	0.3333	0.0584	(92,2) (133,3)	(92,2) (108,2)	(67,1) (108,2)	(67,1) (108,2)	(67,1) (82,1)	(67,1) (82,1)	(67,1) (82,1)	(67,1) (82,1)
1750	0.2857	0.0429	(156,3) (214,4)	(124,2) (181,3)	(124,2) (147,2)	(124,2) (147,2)	(91,1) (147,2)	(91,1) (111,1)	(91,1) (111,1)	(91,1) (111,1)
2000	0.25	0.0329	(282,5) (360,6)	(204,3) (279,4)	(204,3) (236,3)	(162,2) (236,3)	(162,2) (192,2)	(162,2) (192,2)	(119,1) (192,2)	(119,1) (145,1)
2250	0.2222	0.0260	(453,7) (556,8)	(357,5) (456,6)	(257,3) (353,4)	(257,3) (299,3)	(205,2) (299,3)	(205,2) (243,2)	(205,2) (243,2)	(150,1) (243,2)

In each cell, the first pair is the value of (n, c) corresponding to (α=0.05, β=0.10) and the second pair corresponding to (α=0.05, β=0.05).

Table 4: *Parameters of RSSPs under the conditions of ER (β, λ=1) Distribution with α=0.05, λ=1 and t=650 hours.*

		m1	4000	4500	5000	5500	6000	6500	7000	7500
t=650, λ=1		t/m1	0.1625	0.1444	0.13	0.1181	0.1083	0.1	0.0928	0.0866
		P1								
m2	t/m2	P2	0.0139	0.0109	0.0088	0.0073	0.0061	0.0052	0.0045	0.0039
750	0.8666	0.3844	(11,1) (13,1)	(11,1) (13,1)	(11,1) (13,1)	(6,0) (13,1)	(6,0) (8,0)	(6,0) (8,0)	(6,0) (8,0)	(6,0) (8,0)
1000	0.65	0.2205	(18,1) (22,1)	(18,1) (22,1)	(18,1) (22,1)	(18,1) (22,1)	(18,1) (22,1)	(18,1) (22,1)	(11,0) (22,1)	(11,0) (22,1)
1250	0.52	0.1418	(38,2) (45,2)	(28,1) (45,2)	(28,1) (34,1)	(28,1) (34,1)	(28,1) (34,1)	(28,1) (34,1)	(28,1) (34,1)	(28,1) (34,1)
1500	0.4333	0.0987	(54,2) (79,3)	(54,2) (64,2)	(54,2) (64,2)	(40,1) (64,2)	(40,1) (49,1)	(40,1) (49,1)	(40,1) (49,1)	(40,1) (49,1)
1750	0.3714	0.0725	(93,3) (127,4)	(74,2) (107,3)	(74,2) (87,2)	(74,2) (87,2)	(54,1) (87,2)	(54,1) (66,1)	(54,1) (66,1)	(54,1) (66,1)
2000	0.325	0.0555	(167,5) (214,6)	(121,3) (165,4)	(121,3) (140,3)	(96,2) (140,3)	(96,2) (114,2)	(96,2) (114,2)	(70,1) (114,2)	(70,1) (86,1)
2250	0.2888	0.0439	(268,7) (329,8)	(212,5) (270,6)	(153,3) (209,4)	(153,3) (177,3)	(122,2) (177,3)	(122,2) (144,2)	(122,2) (144,2)	(89,1) (144,2)

In each cell, the first pair is the value of (n, c) corresponding to (α=0.05, β=0.10) and the second pair corresponding to (α=0.05, β=0.05).

VI. Conclusion

Under the assumption that the lifespan quality feature is modeled by an Exponential-Rayleigh distribution, a method for determining single sampling plans for life tests is derived. The paper introduces a sampling plan for a truncated life test, specifically for the Exponential Rayleigh distribution with parameters λ and β. The number of groups and acceptance number are provided for the special case where λ=1 and the consumer's and producer's risk plan parameters are specified. Tables are also included to aid in selecting the optimal plan parameters for products with Exponential Rayleigh distribution, ultimately reducing test time and cost.

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