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# A Group Acceptance Sampling Plans for Lifetimes Following a Marshall-Olkin Extended Exponential Distribution

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## Abstract

In this paper, a group acceptance sampling plan is developed for a truncated life test when the lifetime of an item follows the Marshall-Olkin extended exponential distribution. The minimum number of groups required for a given group size and the acceptance number is determined when the consumer's risk and the test termination time are specified. The operating characteristic values, according to various quality levels, are found and the minimum ratios of the true average life to the specified life at the specified producer's risk are obtained. The results are explained with examples.

**Keywords:** Marshall-Olkin extended exponential distribution, Group acceptance sampling; Consumer's risk; Operating characteristics; Producer's risk; Truncated life test

**MSC 2010 No.:** 62N05; 62P30

## 1. Introduction

The quality of the product has become one of the most important factors that distinguish different commodities in a global business market. Two important techniques for ensuring quality are the statistical process control and statistical product control in the form of acceptance sampling. The acceptance sampling plan is concerned with accepting or rejecting a submitted lot of products on the basis of the quality of the products inspected in a sample taken from the lot. An acceptance sampling plan is a specified plan that establishes the minimum sample size to be used for testing. This becomes particularly important if the quality of product is defined by its lifetime. Often, it is implicitly assumed when designing a sampling plan that only a single item is put in a tester. However, in practice testers accommodating a multiple number of items at a time are used because testing time and cost can be saved by testing items simultaneously. The items in a tester are regarded as a group and the number of items in a group is called the group size. An acceptance sampling plan based on such groups of items is called a group acceptance sampling plan (GASP). If the GASP is used in conjunction with truncated life tests, it is called a GASP based on truncated life test assuming that the lifetime of product follows a certain probability distribution. For such a test, the determination of the sample size is equivalent to determine the number of groups.

These types of testers are frequently used in the case of so-called sudden death testing that is discussed by Pascual and Meeker (1998) and Vleek *et al.* (2003). Recently, Jun *et al.* (2006) proposed the sudden death test under the assumption that the lifetime of items follows the Weibull distribution with known shape parameter. They developed single and double group acceptance sampling plans in sudden death testing. More recently, Aslam and Jun (2009) considered the inverse Rayleigh and log-logistic distributions, Rao (2009) generalized exponential distribution and Rao (2010) the Marshall-Olkin extended Lomax distribution for a group acceptance sampling plan based on truncated life test.

Acceptance sampling based on truncated life tests having single-item group for a variety of distributions were discussed by Epstein (1954), Sobel and Tischendrof (1959), Goode and Kao (1961), Gupta and Groll (1961), Gupta (1962), Fertig and Mann (1980), Kantam and Rosaiah (1998), Kantam *et al.* (2001), Baklizi (2003), Baklizi and El Masri (2004), Rosaiah and Kantam (2005), Rosaiah *et al.* (2006, 2007 & 2007), Tsai and Wu (2006), Balakrishnan *et al.* (2007), Aslam (2007), Aslam and Shahbaz (2007), Aslam and Kantam (2008) and Rao *et al.* (2008, 2009a & 2009b).

The purpose of this paper is to propose a GASP based on truncated life tests when the lifetime of a product follows the Marshall-Olkin extended Exponential distribution introduced by Ghitany *et al.* (2007) with known index parameter. The probability density function (p.d.f.) and cumulative distribution function (c.d.f) of the Marshall-Olkin extended exponential distribution respectively, are given by

$$g(t;\nu,\sigma)=\frac{\nu \mathrm{e}^{-t/\sigma}}{\sigma\left[1-\bar{\nu}\mathrm{e}^{-t/\sigma}\right]^{2}};\ t>0,\nu,\sigma>0,\bar{\nu}=1-\nu \tag{1.1}$$

$$G(t;\nu,\sigma)=\frac{1-e^{-t/\sigma}}{1-\bar{\nu}e^{-t/\sigma}};t>0,\nu,\sigma>0\ , \tag{1.2}$$

where $\sigma$ is scale parameter and $\nu$ is index parameter of the distribution. The mean of this distribution is given by $\mu = 1.3863\,\sigma$ when $\nu = 2$ (to save the space, tables are displayed for $\nu = 2$, other values of index parameters are available with authors moreover we have chosen $\nu = 2$ to compare existing plans). Rao *et al.* (2009b) studied single acceptance sampling plans based on the Marshall-Olkin extended exponential distribution. In Section 2, we describe the proposed GASP. The operating characteristics values in Section 3. The results are explained with some examples in Section 4 and finally conclusions are given in Section 5.

## 2. The Group Acceptance Sampling Plan (GASP)

Let $\mu$ represent the true average life of a product and $\mu_0$ denote the specified life of an item, under the assumption that the lifetime of an item follows Marshall-Olkin extended exponential distribution. A production lot is accepted for consumer's use if the sample statistics supports the hypothesis $H_0 : \mu \geq \mu_0$. On the other hand, the production lot is rejected. In acceptance sampling schemes, this hypothesis is tested based on the number of failures from a sample in a pre-fixed time. If the number of failures exceeds the action limit $c$ we reject the lot. We will accept the lot if there is enough evidence that $\mu \geq \mu_0$ at certain level of consumer's risk. Otherwise, we reject the lot. Let us propose the following GASP based on the truncated life test:

1) Select the number of groups $g$ and allocate predefined $r$ items to each group so that the sample size for a lot will be $n = g.r$.
2) Select the acceptance number (or action limit) $c$ for a group and the experiment time $t_0$.
3) Perform the experiment for the $g$ groups simultaneously and record the number of failures for each group.
4) Accept the lot if at most $c$ failures occur in each of all groups.
5) Terminate the experiment if more than $c$ failures occur in any group and reject the lot.

The proposed sampling plan is an extension of the ordinary sampling plan available in literature such as in Rao *et al*. (2009b), for r=1 when n=g. We are interested in determining the number of groups $g$ required for Marshall-Olkin extended exponential distribution and various values of acceptance number c, whereas the group size $r$ and the termination time $t_0$ are assumed to be specified. Since it is convenient to set the termination time as a multiple of the specified life $\mu_0$, we will consider $t_0 = a\mu_0$ for a specified constant $a$ (termination ratio).

The probability ($\alpha$) of rejecting a good lot is called the producer's risk, whereas the probability ($\beta$) of accepting a bad lot is known as the consumer's risk. The parameter value $g$ of the proposed sampling plan is determined for ensuring the consumer's risk $\beta$. Often, the consumer's risk is expressed by the consumer's confidence level. If the confidence level is $p^*$, then the consumer's risk will be $\beta = 1 - p^*$. We will determine the number of groups $g$ in the proposed sampling plan so that the consumer's risk does not exceed $\beta$. If the lot size is large enough, we can use the binomial distribution to develop GASP. According to GASP the lot of products is accepted only if there were at most $c$ failures occurred in each of g groups. So, the lot acceptance probability is given by:

$$L(p) = \left[ \sum_{i=0}^{c} \binom{r}{i} p^{i}(1-p)^{r-i} \right]^{g}, \tag{2.1}$$

where $p$ is the probability that an item in a group fails before the termination time $t_0 = a\mu_0$. The probability $p$ for the Marshall-Olkin extended exponential distribution with $\nu = 2$ is given by

$$p = G_T(t_0) = \frac{1 - e^{\{-1.3863a/(\mu/\mu_0)\}}}{1 - \bar{\nu} e^{\{-1.3863a/(\mu/\mu_0)\}}}. \tag{2.2}$$

The minimum number of groups required can be determined by considering the consumer's risk when the true mean life equals the specified mean life ($\mu = \mu_0$) through the following inequality:

$$L(p_0) \le \beta, \tag{2.3}$$

where $p_0$ is the failure probability at $\mu = \mu_0$, and it is given by:

$$p_0 = \frac{1 - e^{\{-1.3863a\}}}{1 - \bar{\nu} e^{\{-1.3863a\}}}. \tag{2.4}$$

Particularly for c=0 (so-called zero failure test), g can be determined by the minimum integer satisfying the following inequality:

$$g \ge \frac{\ln \beta}{r \ln(1 - p_0)}. \tag{2.5}$$

Table 1 shows the minimum number of groups required for the proposed sampling plan for the Marshall-Olkin extended exponential distribution with $\nu = 2$ according to various values of consumer's risk ($\beta$ = 0.25, 0.10, 0.05, 0.01), group size ($r$), acceptance number ($c$) and the test termination time multiplier ($a$ = 0.7, 0.8, 1.0, 1.2, 1.5,2.0). It can be seen from this table that the number of groups required for the Marshall-Olkin extended exponential distribution are smaller than the groups required for generalized exponential distribution proposed by Rao (2009) whereas larger than the groups required for inverse Rayleigh distribution and log-logistic distribution proposed by Aslam and Jun (2009) and for Marshall-Olkin extended Lomax distribution proposed by Rao (2010).

**Table 1:** Minimum number of groups ($g$) and acceptance number (c) for the proposed plan for the Marshall-Olkin extended exponential distribution with $\nu = 2$.

| | | | a | | | | | |
|---|---|---|---|---|---|---|---|---|
| β | r | c | 0.7 | 0.8 | 1.0 | 1.2 | 1.5 | 2.0 |
| 0.25 | 2 | 0 | 2 | 1 | 1 | 1 | 1 | 1 |
| 0.25 | 3 | 1 | 3 | 2 | 2 | 1 | 1 | 1 |
| 0.25 | 4 | 2 | 6 | 4 | 3 | 2 | 1 | 1 |
| 0.25 | 5 | 3 | 10 | 7 | 4 | 3 | 2 | 1 |
| 0.25 | 6 | 4 | 20 | 12 | 6 | 3 | 2 | 1 |
| 0.25 | 7 | 5 | 38 | 21 | 9 | 5 | 2 | 1 |
| 0.10 | 4 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0.10 | 5 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| 0.10 | 6 | 2 | 3 | 3 | 2 | 1 | 1 | 1 |
| 0.10 | 7 | 3 | 5 | 4 | 2 | 2 | 1 | 1 |
| 0.10 | 8 | 4 | 8 | 5 | 3 | 2 | 1 | 1 |
| 0.10 | 9 | 5 | 13 | 8 | 4 | 2 | 2 | 1 |
| 0.05 | 5 | 0 | 2 | 1 | 1 | 1 | 1 | 1 |
| 0.05 | 6 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| 0.05 | 7 | 2 | 3 | 2 | 2 | 1 | 1 | 1 |
| 0.05 | 8 | 3 | 5 | 3 | 2 | 2 | 1 | 1 |
| 0.05 | 9 | 4 | 7 | 5 | 3 | 2 | 1 | 1 |
| 0.05 | 10 | 5 | 10 | 7 | 3 | 2 | 1 | 1 |
| 0.01 | 7 | 0 | 2 | 1 | 1 | 1 | 1 | 1 |
| 0.01 | 8 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| 0.01 | 9 | 2 | 3 | 2 | 2 | 1 | 1 | 1 |
| 0.01 | 10 | 3 | 4 | 3 | 2 | 2 | 1 | 1 |
| 0.01 | 11 | 4 | 5 | 4 | 2 | 2 | 1 | 1 |
| 0.01 | 12 | 5 | 8 | 5 | 3 | 2 | 1 | 1 |

## 3. Operating Characteristics

The probability of acceptance can be regarded as a function of the deviation of the specified value $\mu_0$ of the mean from its true value $\mu$. This function is called operating characteristic (OC) function of the sampling plan. Once the minimum number of groups $g$ is obtained, one may be interested to find the probability of acceptance of a lot when the quality (or reliability) of the product is sufficiently good. As mentioned earlier, the product is considered to be good if $\mu > \mu_0$ or $\mu / \mu_0 > 1$. The probabilities of acceptance based on (2.1) for various mean lifetimes ($\mu / \mu_0 =$2, 4, 6, 8, 10, 12) under the plan parameters $\beta$ = 0.25, 0.10, 0.05, 0.01; $a$=0.7, 0.8, 1.0, 1.2, 1.5, 2.0; $c$ = 2 and different chosen values of r and g are reported in Table 2 for the Marshall-Olkin extended exponential distribution with $\nu = 2$.

**Table 2:** Operating characteristics values of the group sampling plan with $c$ =2 for Marshall-Olkin extended exponential distribution with $\nu = 2$ .

| $\beta$ | r | g | a | $\mu / \mu_0$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 2 | 4 | 6 | 8 | 10 | 12 |
| 0.25 | 4 | 6 | 0.7 | 0.7621 | 0.9622 | 0.9882 | 0.9949 | 0.9974 | 0.9985 |
| 0.25 | 4 | 4 | 0.8 | 0.7708 | 0.9630 | 0.9884 | 0.9950 | 0.9974 | 0.9985 |
| 0.25 | 4 | 3 | 1.0 | 0.7023 | 0.9481 | 0.9834 | 0.9928 | 0.9962 | 0.9978 |
| 0.25 | 4 | 2 | 1.2 | 0.6860 | 0.9425 | 0.9813 | 0.9918 | 0.9957 | 0.9975 |
| 0.25 | 4 | 1 | 1.5 | 0.7203 | 0.9468 | 0.9824 | 0.9922 | 0.9959 | 0.9976 |
| 0.25 | 4 | 1 | 2.0 | 0.5248 | 0.8889 | 0.9612 | 0.9824 | 0.9906 | 0.9944 |
| 0.10 | 6 | 3 | 0.7 | 0.6123 | 0.9225 | 0.9741 | 0.9884 | 0.9939 | 0.9964 |
| 0.10 | 6 | 3 | 0.8 | 0.5064 | 0.8909 | 0.9626 | 0.9831 | 0.9910 | 0.9947 |
| 0.10 | 6 | 2 | 1.0 | 0.4629 | 0.8703 | 0.9540 | 0.9790 | 0.9887 | 0.9933 |
| 0.10 | 6 | 1 | 1.2 | 0.5579 | 0.8949 | 0.9622 | 0.9825 | 0.9906 | 0.9943 |
| 0.10 | 6 | 1 | 1.5 | 0.3866 | 0.8238 | 0.9329 | 0.9681 | 0.9825 | 0.9894 |
| 0.10 | 6 | 1 | 2.0 | 0.1792 | 0.6804 | 0.8652 | 0.9329 | 0.9622 | 0.9767 |
| 0.05 | 7 | 3 | 0.7 | 0.4764 | 0.8784 | 0.9576 | 0.9807 | 0.9897 | 0.9939 |
| 0.05 | 7 | 2 | 0.8 | 0.5085 | 0.8846 | 0.9592 | 0.9813 | 0.9900 | 0.9940 |
| 0.05 | 7 | 2 | 1.0 | 0.3256 | 0.8050 | 0.9269 | 0.9657 | 0.9813 | 0.9888 |
| 0.05 | 7 | 1 | 1.2 | 0.4342 | 0.8433 | 0.9405 | 0.9718 | 0.9845 | 0.9906 |
| 0.05 | 7 | 1 | 1.5 | 0.2649 | 0.7476 | 0.8972 | 0.9495 | 0.9718 | 0.9827 |
| 0.05 | 7 | 1 | 2.0 | 0.0963 | 0.5706 | 0.8025 | 0.8972 | 0.9405 | 0.9627 |
| 0.01 | 9 | 3 | 0.7 | 0.2553 | 0.7674 | 0.9113 | 0.9581 | 0.9771 | 0.9862 |
| 0.01 | 9 | 2 | 0.8 | 0.2957 | 0.7820 | 0.9158 | 0.9598 | 0.9779 | 0.9866 |
| 0.01 | 9 | 2 | 1.0 | 0.1423 | 0.6563 | 0.8555 | 0.9284 | 0.9598 | 0.9754 |
| 0.01 | 9 | 1 | 1.2 | 0.2443 | 0.7249 | 0.8843 | 0.9421 | 0.9672 | 0.9797 |
| 0.01 | 9 | 1 | 1.5 | 0.1139 | 0.5888 | 0.8101 | 0.9005 | 0.9421 | 0.9635 |
| 0.01 | 9 | 1 | 2.0 | 0.0250 | 0.3772 | 0.6648 | 0.8101 | 0.8843 | 0.9249 |

From this table we see that OC values increase more quickly as the quality increases. For example, when $\beta$=0.25, $r$ = 4, $c$ = 2 and $a$ = 0.7, the number of groups required is $g$ = 6. However, if the true mean lifetime is twice the specified mean lifetime ( $\mu / \mu_0$ = 2) the producer's risk is approximately $\alpha$ = 0.2379, while $\alpha$ =0.0378 when the true mean life is 4 times the specified mean life.

The producer may be interested in enhancing the quality level of the product so that the acceptance probability should be greater than a specified level. At the producer's risk $\alpha$ the minimum ratio $\mu / \mu_0$ can be obtained by satisfying the following inequality:

$$\left[ \sum_{i=0}^{c} \binom{r}{i} \; p^i (1-p)^{r-i} \right]^g \geq 1-\alpha \, , \tag{3.1}$$

where $p$ is given by equation (2.2) and g is chosen at the consumer's risk $\beta$ when $\mu / \mu_0$ =1.

Table 3 shows the minimum ratio of $\mu / \mu_0$ for Marshall-Olkin extended exponential distribution with $\nu = 2$ at the producer's risk of $\alpha$ =0.05 under the plan parameters chosen before. For example, when $\beta$ = 0.25, r = 4, $g$ = 6, c = 2 and $a$ = 0.7, the manufacturer requires to increase the true mean 3.62 times the specified life in order for the lot to be accepted with the producer's risk at 5 percent.

**Table 3:** Minimum ratio of true mean life to specified mean life for the producer's risk of $\alpha$ = 0.05 under Marshall-Olkin extended exponential distribution with $\nu = 2$.

| | | | a | | | | | |
|---|---|---|---|---|---|---|---|---|
| β | r | c | 0.7 | 0.8 | 1.0 | 1.2 | 1.5 | 2.0 |
| 0.25 | 2 | 0 | 38.23 | 21.92 | 27.40 | 32.96 | 41.17 | 54.82 |
| 0.25 | 3 | 1 | 6.28 | 5.83 | 7.28 | 6.11 | 7.65 | 10.24 |
| 0.25 | 4 | 2 | 3.62 | 3.60 | 4.06 | 4.21 | 4.10 | 5.48 |
| 0.25 | 5 | 3 | 2.58 | 2.68 | 2.88 | 3.19 | 3.55 | 3.89 |
| 0.25 | 6 | 4 | 2.17 | 2.21 | 2.37 | 2.43 | 2.76 | 3.12 |
| 0.25 | 7 | 5 | 1.90 | 1.95 | 2.08 | 2.22 | 2.31 | 2.66 |
| 0.10 | 4 | 0 | 38.23 | 43.54 | 54.50 | 65.49 | 82.03 | 109.77 |
| 0.10 | 5 | 1 | 9.20 | 10.47 | 9.11 | 10.98 | 13.61 | 18.25 |
| 0.10 | 6 | 2 | 4.74 | 5.42 | 5.83 | 5.42 | 6.74 | 9.02 |
| 0.10 | 7 | 3 | 3.37 | 3.62 | 3.71 | 4.46 | 4.55 | 6.07 |
| 0.10 | 8 | 4 | 2.68 | 2.75 | 3.05 | 3.32 | 3.50 | 4.67 |
| 0.10 | 9 | 5 | 2.29 | 2.37 | 2.58 | 2.69 | 3.37 | 3.86 |
| 0.05 | 5 | 0 | 94.88 | 54.50 | 67.93 | 82.03 | 102.35 | 136.05 |
| 0.05 | 6 | 1 | 11.25 | 12.84 | 11.11 | 13.40 | 16.58 | 22.27 |
| 0.05 | 7 | 2 | 5.65 | 5.58 | 6.95 | 6.46 | 8.06 | 10.72 |
| 0.05 | 8 | 3 | 3.97 | 3.94 | 4.37 | 5.26 | 5.35 | 7.11 |
| 0.05 | 9 | 4 | 3.03 | 3.20 | 3.55 | 3.86 | 4.06 | 5.42 |
| 0.05 | 10 | 5 | 2.51 | 2.67 | 2.81 | 3.09 | 3.32 | 4.44 |
| 0.01 | 7 | 0 | 134.05 | 76.51 | 95.88 | 115.34 | 142.45 | 190.11 |
| 0.01 | 8 | 1 | 15.13 | 17.29 | 14.93 | 17.94 | 22.40 | 29.92 |
| 0.01 | 9 | 2 | 7.52 | 7.40 | 9.20 | 8.51 | 10.72 | 14.25 |
| 0.01 | 10 | 3 | 4.87 | 5.11 | 5.65 | 6.79 | 6.90 | 9.20 |
| 0.01 | 11 | 4 | 3.58 | 3.87 | 4.10 | 4.92 | 5.14 | 6.90 |
| 0.01 | 12 | 5 | 3.01 | 3.14 | 3.53 | 3.89 | 4.15 | 5.55 |

## 4. Description of Tables and Examples

The design parameters of GASP are found at the various values of the consumer's risk ($\beta$ = 0.25, 0.10, 0.05, 0.01) and the test termination time multiplier $a$ = 0.7, 0.8, 1.0, 1.2, 1.5, 2.0 in Table 1. It should be noted that if one needs the minimum sample size, it can be obtained by $n = r \times g$. In this table, note that, as the test termination time multiplier $a$ increases, the number of groups decrease. We need a smaller number of groups and the acceptance number if the test termination time multiplier increases at a fixed group size. For an example, from Table 1, if $\beta$ = 0.01, $r$ = 9, $c$ = 2 and $a$ changes from 0.7 to 0.8, the required values of design parameters of GASP have been changed from $g$ = 3 to $g$ = 2. However, the trend is not monotonic since it depends on the acceptance number as well. The probability of acceptance for the lot at the mean ratio corresponding to the producer's risk is also given in Table 2. Finally, Table 3 presents the minimum ratios of true mean life to specified mean life for the acceptance of a lot with producer's risk of 5 percent for chosen parameters.

Suppose that the lifetime of a product follows the Marshall-Olkin extended exponential distribution with $\nu = 2$. It is desired to design a GASP to test that the mean life is greater than 1,000 hours and experimenter wants to run an experiment for 700 hours using testers equipped with 4 items each. It is assumed that $c$ = 2 and $\beta$ = 0.25. This leads to the termination multiplier $a$ = 0.700 and from Table 1 the minimum number of groups required is $g$ = 6. Thus, we will draw a random sample of size 24 items and allocate 4 items to each of 6 groups to put on test for 700 hours. This indicates that a total of 24 products are needed and that 4 items are allocated to each of 6 testers. We will accept the lot if no more than 2 failure occurs before 700 hours in each of 6 groups. We truncate the experiment as soon as the 3rd failure occurs before the 700$^{th}$ hours. For this proposed sampling plan the probability of acceptance is $p$ = 0.9622 when the true mean is $\mu$ = 4,000 hours. This shows that, if the true value of mean is 4 times of required mean $\mu_0$ =1000 hours, the producer's risk is $\alpha$ = 0.0378. If we need the ratio to assure a producer's risk of $\alpha$ = 0.05, we can obtain it from Table 3. For example, when $\beta$ = 0.10, $r$ = 6, $g$ = 3, c = 2 and $a$ = 0.700, the required ratios is $\mu / \mu_0$ = 4.74.

## 5. Conclusion

In this paper, a group acceptance sampling plan from the truncated life test was proposed, the number of groups and the acceptance number were determined for the Marshall-Olkin extended exponential distribution with $\nu = 2$ when plan parameters like the consumer's risk ($\beta$), group size ($r$) and termination time multiplier (a) are specified. It can be observed that the minimum number of groups required decreases as the test termination time multiplier increases and also the operating characteristics values increases more rapidly as the quality improves. The proposed group sampling plan is compared with the existing plans in the literature and found that the number of groups required for the Marshall-Olkin extended exponential distribution are smaller than the groups required for generalized exponential distribution whereas larger than the groups required for inverse Rayleigh, log-logistic and Marshall-Olkin extended Lomax distributions. This GASP can be used when a multiple number of items at a time are adopted for a life test and it would be beneficial in terms of test time and cost because a group of items will be tested simultaneously.

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