New two-sided group chain acceptance sampling plan for Marshall-Olkin extended exponential distribution

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Abstract. Acceptance sampling remains as a popular method of quality assurance in many industries. The primary goal is to reach an accurate decision whether to accept or reject a lot based on the results from sample inspection at a minimal cost. In this study, a new two-sided group chain acceptance sampling plan (NTSGChSP) using the Marshall-Olkin Extended Exponential (MOEE) distribution is introduced. This plan emphasizes customer’s protection by considering the consumer’s risk in its development. The findings suggest that the NTSGChSP could potentially offer minimal inspection cost by selecting a small sample size for lot inspection. Such advantage should render it as a preferred sampling plan for products with lifetime that follows MOEE distribution.

Keywords: Marshall-Olkin Extended Exponential distribution, Acceptance Sampling, New Two-Sided Group Chain Acceptance Sampling Plan (NTSGChSP)

1. Introduction
Acceptance sampling can be interpreted as the inspection and classification of a sample of units chosen randomly from a batch or lot [1]. The lots that fulfill the requirements are proceeded into production, while the lots that fail to fulfill the requirements may be reworked or scrapped. The inspection is usually done on raw materials, semi-finished products, or finished products. Acceptance sampling is one of the main elements in statistical quality control. This method was applied for the first time during World War II when the United States (US) military tested the bullets before sending it to the army [2]. Acceptance sampling plays a critical role in ensuring that the final products fulfill all the specified requirements.

There are two main parties involved in acceptance sampling, which are the producer or supplier, and the consumer or buyer. The producer’s risk, $\alpha$, is defined as the chances to reject a good lot (a type I error) while the consumer’s risk, $\beta$, can be defined as the chances to accept a bad lot or a lot with a lot tolerance proportion defective (LTPD) quality (a type II error). The $\alpha$ is usually set at 0.05 (5%) and the usual value for the $\beta$ is 0.10 (10%) [1-3].

Generally, there are several types of sampling plans, but the most fundamental plan is single. A single sampling plan (SSP) [3] comprises of a sample of size, $n$ and an acceptance number, $c$. The defective items must not be more than $c$ or else the lot is rejected. Another type of acceptance sampling is the chain sampling plan (ChSP-1) [4]. ChSP-1 is considered as not only the inspection result from the current production lot, but also the previous lot. However, to reduce the cost and time consumption, practitioners nowadays conduct a group acceptance sampling plan (GASP) which can inspect multiple products at the same time.
The GASP with zero or one as c is used when the inspection is costly or destructive. However, the GASP has one disadvantage; when the c is set to zero or one, the probability of lot acceptance, \( L(p) \) rapidly declines.

To solve the issue of both the ChSP-1 and GASP, the group chain sampling plan (GChSP) was proposed by Mughal et al. [6] and further developed by The et. al. [7]. The purpose of the GChSP is to cut the cost and inspection time while keeping the \( L(p) \) as low as possible. The studies showed that the GChSP has better discriminating power compared to the ChSP-1 and GASP. To improve the protection towards the consumer by demanding a continuously high-quality background from the producer while maintaining the protection towards the producer, the two-sided complete chain sampling plan (TSCoChSP) was proposed [8]. Although the TSCoChSP demands a continuously high-quality background from the producer, the problem of multiple inspections repeated. Thus, the new two-sided complete group chain sampling plan (NTSCoGChSP) was proposed [9]. The NTSCoGChSP is quite similar to the ChSP-1, but it considers the information from the preceding and succeeding lots while conducting multiple inspections simultaneously. It is to be noted that the NTSCoGChSP also provides a higher \( L(p) \).

The NTSCoGChSP has five acceptance criteria that result in lot sentencing, but, a type-II error may happen in the process. Mughal then proposed a new plan, two-sided group chain sampling plan (TSGChSP) which has three acceptance criteria [10]. This plan is more cost-effective than the NTSCoGChSP as it only needs a small sample size. Recently, Farouk et. al. [11] proposed the new two-sided group chain sampling plan (NTSGChSP) which operated on four acceptance criteria instead of five. The plan had been tested with the Pareto distribution of the 2nd kind and Log-logistic distribution [12] and, up until now, no authors have applied the Marshall-Olkin Extended Exponential (MOEE) distribution for the NTSGChSP. Thus, this paper intends to study the NTSGChSP with the MOEE distribution.

2. Literature

Dodge is the first person to propose the chain sampling plan (ChSP-1) in an acceptance sampling plan [13]. Dodge [4] developed the ChSP-1 as a plan that could be implemented on products that involve destructive or costly inspection. It was then developed into a new plan which is the GChSP in order to cut the cost and time of operation.

Farouk et. al. [11] proposed a new plan which was the NTSGChSP since errors may occur during the inspection of the NTSCoGChSP. The Pareto distribution of the 2nd kind was used in this study. The number of minimum groups was decided by observing three parameters, which were consumers’ risk, time of test termination and mean ratio. The parameter values were predetermined, where the number of products, \( r = (2, 3, 4, 5) \), specified constant, \( a = \{0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0\} \), number of preceding lots, \( i = \{1, 2, 3, 4\} \), consumer’s risk, \( \beta = \{0.01, 0.05, 0.1\} \) and mean ratio, \( \frac{\sigma}{\mu_0} = \{1, 2, 4, 6, 8, 10, 12\} \). The result showed that the NTSGChSP yielded a lower \( L(p) \) than NTSCoGChSP and the effectiveness of both plans in terms of the number of samples to be drawn from the lot was at the same level. Hence, the NTSGChSP provided better protection to the consumer than the NTSCoGChSP. Later, Farouk et. al. [12] extended the sampling plan by applying it for the Log-logistic distribution using the same parameter values from the previous study. The study showed that operating with four acceptance criteria was a more balanced approach rather than the two-sided group chain sampling plan (TSGChSP) and NTSCoGChSP. The NTSGChSP also used fewer minimum groups than the NTSCoGChSP, which means that the operational cost would be lesser. It has been proven that the NTSGChSP is a good option to apply in the industry.

The exponential distribution is a widely used distribution for lifetime data analysis and reliability theory. However, the implementation of this distribution is restricted as the hazard function is constant [14]. Hence, many researchers have developed generalisations based on this distribution to address the monotone failure rate behaviour [15]. Marshall and Olkin introduced a new generalisation of exponential distribution in 1997 which was known as the Marshall-Olkin Extended Exponential (MOEE). Previous studies have demonstrated the implementation of the MOEE on the endurance of deep groove ball bearings [15] and the airborne communication transceiver [16].

Ramswamy and Jayasri [17] applied the MOEE distribution in their research. The main objective of their research is to find the \( L(p) \) for ChSP-1 by applying the MOEE distribution and assuming that the study is truncated at a preassigned time. The result showed that the \( L(p) \) increases with the ratio \( \frac{\sigma}{\sigma_0} \). The \( L(p) \) also
hit the maximum value which is 1 when \( \frac{\sigma}{\mu} \) is more than 8. Meanwhile, Rao [18] proposed the GASP for the MOEE distribution with known index parameter, \( v = 2 \). In this study, Rao has predetermined the parameter values where \( \beta = \{0.25, 0.10, 0.05, 0.01\} \), \( a = \{0.7, 0.8, 1.0, 1.2, 1.5, 2.0\} \) and \( \frac{\sigma}{\mu_0} = \{2, 4, 6, 8, 10, 12\} \). He concluded that the MOEE distribution required a smaller number of groups than the generalised exponential distribution. The plan would be advantageous to use as it is less costly. The study was the extension work for the plan by Rao et al. [19] where they developed a reliability test plan of single acceptance sampling plans for the MOEE Distribution for number of products, \( r = 1 \) when \( n = g \).

3. Methodology

The six phases involved when developing the NTSGChSP are summarized in figure 1.

![Figure 1. The algorithmic steps for developing the NTSGChSP.](image)

3.1. Phase 1: Determining the design parameters

Design parameters are the constant values which are usually identified before the inspection is run. Table 1 shows the predetermined values for the design parameters.

| Design Parameters                  | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 |
|-----------------------------------|------|------|------|------|------|------|------|------|
| Specified constant, \( a \)       |      |      |      |      |      |      |      |      |
| Consumer’s risk (CR), \( \beta \) | 0.01 | 0.05 | 0.1  | 0.25 |      |      |      |      |
| Number of preceding lots, \( i \) | 1    | 2    | 3    | 4    |      |      |      |      |
| Number succeeding lots, \( j \)   |      |      |      |      |      |      |      |      |
| Number of products, \( r \)       | 2    | 3    | 4    | 5    |      |      |      |      |

3.2. Phase 2: Applying the operating procedure

The operating procedure is a step by step taken in designing any sampling plan. Every sampling plan has a different operating procedure. Table 2 lists the operating procedure for the NTSGChSP [11].

| Operating Procedure                  |
|--------------------------------------|
| Step 1: Draw a sample of size \( n \) from the lot under inspection. Divide the sample into \( g \) groups, with \( r \) testers (units) in a group before starting the life test. |
| Step 2: Stop the test at \( t = t_0 \). Inspect all units in each group simultaneously. |
| Step 3: If the number of defectives, \( d > 1 \), reject the lot. |
| Step 4: If \( d = 0 \), accept the lot given that the preceding and succeeding lots have at most 1 defective unit, \( d_i + d_j \leq 1 \). |
3. Phase 3: Computing the probability of lot acceptance

Denote the probabilities of finding zero and one defectives in the current sample as \( P_0 \) and \( P_1 \), respectively. The \( P_0^i \) , \( P_1^i \), \( P_0^j \) and \( P_1^j \) are the probabilities of finding zero and one defectives in the preceding, \( i \) and succeeding, \( j \) samples. There are four acceptance criteria for the NTSGChSP, and we assume that the number of preceding and succeeding lots is the same, as illustrated in figure 2.

| Lot 1 | Lot 2 | Lot 3 | Probability | Decision |
|-------|-------|-------|-------------|----------|
| \( P_0 \) | \( P_0 \) | \( P_0 \) | \( P_0 P_0 P_0 \) | Accept |
| \( P_0 \) | \( P_1 \) | \( P_0 \) | \( P_0 P_0 P_1 \) | Accept |
| \( P_0 \) | \( P_1 \) | \( P_0 \) | \( P_0 P_1 P_0 \) | Accept |
| \( P_0 \) | \( P_1 \) | \( P_0 \) | \( P_0 P_1 P_1 \) | Reject |
| \( P_1 \) | \( P_0 \) | \( P_0 \) | \( P_1 P_0 P_0 \) | Accept |
| \( P_0 \) | \( P_1 \) | \( P_0 \) | \( P_1 P_0 P_1 \) | Reject |
| \( P_1 \) | \( P_0 \) | \( P_0 \) | \( P_1 P_1 P_0 \) | Reject |
| \( P_1 \) | \( P_1 \) | \( P_1 \) | \( P_1 P_1 P_1 \) | Reject |

**Figure 2.** The tree diagrams showing all the probability and their corresponding decision.

Notes: \( P_0 \) = non-defective; \( P_1 \) = defective

Refraining to the tree diagrams in figure 2, lot 2 is considered as the current lot and \((i = j)\). Based on the operating procedure from Phase II, the probability of lot acceptance for the NTSGChSP is calculated as shown below [11].

\[
L(p) = P_0^i P_0^j P_0 + P_0^i P_0^j P_1 + P_0^i P_1^j P_0 + P_0^i P_1^j P_1 P_0 P_0^i
\]

\[
= P_0^i [P_0^j P_0 + P_0^j P_1 + P_1^j P_0 + P_1^j P_1 P_0 P_0]
\]

\[
= P_0^2 [(2i + 1) P_1 + P_0]
\]

The probability of lot acceptance can be written as [11]:

\[
L(p) = P_0^2 [(2i + 1) P_1 + P_0]
\]

3.4. Phase 4: Computing the probability of zero or one defective

The probability of zero defectives, \( P_0 \), is the likelihood that no defectives are found while the probability of one defective, \( P_1 \), is the chance of finding one defective in the lot.

By using a binomial distribution, the \( P_0 \) and \( P_1 \) are given by:

\[
P_0 = (1-p)^n
\]

\[
P_1 = np (1-p)^{n-1}
\]
Based on (2) and (3), let \( n = gr \) where \( n \) is the sample size, \( g \) is the minimum number of groups, \( r \) is the number of products and \( p \) is the fraction defective. Then, upon substituting (2) and (3) into (1), it can be written as [11]:

\[
L(p) = P_0^{2i} [(2i + 1) P_1 + P_0]
\]

\[
L(p) = [(1 - p)^{gr}]^{2i} * [(2i + 1) * grp (1 - p)^{gr-1} + (1 - p)^{gr}] \tag{4}
\]

3.5. Phase 5: Computing the fraction defective

The Marshall-Olkin extended distribution (MOEE) was introduced in 1997, and it is a method that adds a new parameter to an existing distribution. The cumulative distribution function (CDF) is given by [18]:

\[
G(t; \upsilon, \sigma) = \frac{1 - e^{-\frac{t}{\upsilon}}}{(1 - e^{-\frac{t}{\sigma}})}; \quad t > 0, \quad \upsilon, \sigma > 0, \quad \bar{\upsilon} = 1 - \upsilon,
\]

where \( \upsilon \) and \( \sigma \) are the index and scale parameters, respectively.

The test termination time, denoted as \( t_0 \), is defined as a product of specified constant, \( a \) and specified mean life time, \( \mu_0 \) which can be written as:

\[
t_0 = a\mu_0 \tag{6}
\]

When \( \upsilon = 2 \), the mean of the distribution is given by:

\[
\mu = 1.3863 \sigma. \tag{7}
\]

The required \( g \) can be calculated by considering the \( \beta \) when \( \mu = \mu_0 \) through the following inequality:

\[
L(p) \leq \beta \tag{8}
\]

Therefore, by substituting equations (6) and (7) into Equation (5), the fraction defective, \( p \) can be written as [18]:

\[
p = \frac{1 - e^{-\frac{\sigma_\mu}{1.3863}}} {1 - (-1)e^{-\frac{\sigma_\mu}{1.3863}}} \tag{9}
\]

\[
p = \frac{1 - e^{-\frac{\sigma_\mu}{1.3863}}}{1 + e^{-\frac{\sigma_\mu}{1.3863}}} \tag{10}
\]

\[
p = \frac{1 - \sigma_\mu}{1 + \sigma_\mu} \tag{11}
\]
3.6. Phase 6: Measuring the performance
The implementation of the NTSGChSP for MOEE is measured based on the $g$ at different values of design parameters.

4. Findings
In this research, the values of the parameters are pre-determined as written in table 2 earlier. Table 3 shows the $g$ yielded from the NTSGChSP. It is to be observed that $g$ is inversely proportional to the design parameters as $g$ decreases when $\beta$, $r$, $i$, $j$ and $a$ increase. For example, when $\beta = 0.01$, $r = 2$, $i = j = 1$ and $a = 0.25$, the value of $g$ is 6. When the parameter values increase, $g$ decreases. For instance, when $\beta = 0.25$, $r = 3$, $i = j = 2$ and $a = 0.25$, the value of $g$ is 1. It is shown that the value of $g$ decreases from 6 to 1 when the parameter values are increased. To further elaborate the information from table 3, consider that a bolt manufacturer wants to inspect a production lot. The company operates with $\beta = 0.1$ with two workers for the inspection process for the duration when $a = 0.25$. Thus, $g$ is 4 and the minimum number of samples needed is 8.

Table 3. The $g$ required for MOEE distribution with $\nu = 2$.  

| $\beta$ | $i=j$ | $r$ | 0.25 | 0.5 | 0.75 | 1 | 1.25 | 1.5 | 1.75 | 2 |
|---------|-------|-----|------|-----|------|---|------|-----|------|---|
| 0.01    | 6     | 3   | 2    | 2   | 2    | 1 | 1    | 1   | 1    | 1 |
| 0.05    | 5     | 3   | 2    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
| 0.1     | 4     | 2   | 2    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
| 0.25    | 3     | 2   | 1    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
| 0.01    | 2     | 2   | 1    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
| 0.05    | 1     | 1   | 1    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
| 0.1     | 1     | 1   | 1    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
| 0.25    | 1     | 1   | 1    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
| 0.01    | 1     | 1   | 1    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
| 0.05    | 1     | 1   | 1    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
| 0.1     | 1     | 1   | 1    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
| 0.25    | 1     | 1   | 1    | 1   | 1    | 1 | 1    | 1   | 1    | 1 |
Table 4 illustrates the value of $L(p)$ when $r = 2$, $i = j = 1$ and $v = 2$. The mean ratios, $\frac{\mu}{\mu_0}$, are also predetermined where $\mu_0 = \{1, 2, 4, 6, 8, 10, 12\}$. $\frac{\mu}{\mu_0}$ indicates the ratio of the true mean lifetime to the specified mean lifetime of a product. The values of $L(p)$ in table 4 have shown that the products can last longer than they are meant to since only positive integers are recorded in the table. It can be observed that the $L(p)$ increases as the $\frac{\mu}{\mu_0}$ increases. For example, when $\beta = 0.01$, $g = 6$, $a = 0.25$, $\frac{\mu}{\mu_0} = 1$, the value of $L(p)$ is 0.0096 and when $\frac{\mu}{\mu_0}$ increases to 12, the value of $L(p)$ is 0.9048. This observation indicates that the quality of the products manufactured from a process with higher $\frac{\mu}{\mu_0}$ is superior to lower $\frac{\mu}{\mu_0}$.

To further illustrate the information in table 4, suppose the company produces 1000 bolts in a production lot and $\mu_0 = 1000$ hours. The design parameters for the inspection are $\beta = 0.1$, $a = 0.25$, $r = 2$, $i = j = 1$, and $g = 4$. Thus, the $L(p)$ will be in the range of between 0.0652 to 0.9534, depending on the $\frac{\mu}{\mu_0}$.

Table 4. The $L(p)$ for the NTSGChSP for MOEE distribution with $r = 2$, $i = j = 1$ and $v = 2$.

| $\beta$ | $g$ | $a$ | 1   | 2   | 4   | 6   | 8   | 10  | 12  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.01    |     |     |     |     |     |     |     |     |     |
| 6       | 0.25| 0.0096 | 0.1701 | 0.5344 | 0.7211 | 0.8170 | 0.8713 | 0.9048 |
| 3       | 0.5 | 0.0068 | 0.1597 | 0.5311 | 0.7212 | 0.8181 | 0.8726 | 0.9060 |
| 2       | 0.75| 0.0049 | 0.1507 | 0.5284 | 0.7217 | 0.8193 | 0.8739 | 0.9072 |
| 2       | 1   | 0.0003 | 0.0540 | 0.3642 | 0.5907 | 0.7217 | 0.8002 | 0.8502 |
| 0.05    |     |     |     |     |     |     |     |     |     |
| 0.05    |     |     |     |     |     |     |     |     |     |
| 6       | 0.25| 0.0255 | 0.2549 | 0.6249 | 0.7856 | 0.8628 | 0.9050 | 0.9305 |
| 3       | 0.5 | 0.0068 | 0.1597 | 0.5311 | 0.7212 | 0.8181 | 0.8726 | 0.9060 |
| 2       | 0.75| 0.0049 | 0.1507 | 0.5284 | 0.7217 | 0.8193 | 0.8739 | 0.9072 |
| 1       | 1   | 0.0410 | 0.3512 | 0.7249 | 0.8550 | 0.9114 | 0.9404 | 0.9573 |
| 1       | 2   | 0.0001 | 0.0410 | 0.3512 | 0.5892 | 0.7249 | 0.8049 | 0.8550 |
| 0.1     |     |     |     |     |     |     |     |     |     |
| 6       | 0.25| 0.0652 | 0.3736 | 0.7211 | 0.8482 | 0.9054 | 0.9356 | 0.9534 |
Table 5 shows the comparison in the minimum number of groups between NTSGChSP and TSGChSP using the MOEE distribution. The difference of \( g \) in both sampling plans are significantly distinctive when the parameters are \( \beta = 0.05, r = 2, \) and \( i = j = 1. \)

Table 5. The comparison in the minimum number of groups.

| \( \beta \) | \( a \) | TSGChSP | NTSGChSP |
|---------|-------|--------|----------|
| 0.25    | 6     | 6      |          |
| 0.5     | 3     | 3      |          |
| 0.75    | 2     | 2      |          |
| 0.01    | 1     | 2      |          |
| 1.25    | 1     | 2      |          |
| 1.5     | 1     | 1      |          |
| $\beta$ | $\alpha$ | TSGChSP | NTGChSP |
|--------|--------|---------|---------|
| 1.75   | 1      | 1       |         |
| 2      | 1      | 1       |         |
| 0.25   | 4      | 5       |         |
| 0.5    | 2      | 3       |         |
| 0.75   | 2      | 2       |         |
| 0.05   | 1      | 1       |         |
| 1.25   | 1      | 1       |         |
| 1.5    | 1      | 1       |         |
| 1.75   | 1      | 1       |         |
| 2      | 1      | 1       |         |
| 0.25   | 4      | 4       |         |
| 0.5    | 2      | 2       |         |
| 0.75   | 1      | 2       |         |
| 0.1    | 1      | 1       |         |
| 1.25   | 1      | 1       |         |
| 1.5    | 1      | 1       |         |
| 1.75   | 1      | 1       |         |
| 2      | 1      | 1       |         |
| 0.25   | 3      | 3       |         |
| 0.5    | 2      | 2       |         |
| 0.75   | 1      | 1       |         |
| 0.25   | 1      | 1       |         |
| 1.25   | 1      | 1       |         |
| 1.5    | 1      | 1       |         |
| 1.75   | 1      | 1       |         |
| 2      | 1      | 1       |         |
The TSGChSP has three acceptance criteria while the NTSGChSP has four acceptance criteria. Thus, the $g$ of the TSGChSP is slightly lower than the $g$ of the NTSGChSP, which indicates that the minimum sample size is also lower in the TSGChSP. The operational cost for the TSGChSP is lower as the plan is stricter than the NTSGChSP. Table 6 below shows the comparison of the $L(p)$ between the TSGChSP and NTSGChSP.

**Table 6. The comparison in the probability of lot acceptance.**

| $\beta$ | $i=j$ | $r$ | $a$ | Mean Ratio | TSGChSP | NTSGChSP |
|--------|-------|-----|-----|------------|---------|----------|
|        |       |     |     | $g = 4$    |         | $g = 5$  |
| 0.05   | 1     | 2   | 0.25| 6          | 0.7305  | 0.7856   |
|        | 8     |     |     | 10         | 0.8428  | 0.9050   |
|        | 12    |     |     | 12         | 0.8707  | 0.9305   |
|        | 1     | 2   |     | 0.0471     | 0.0255  |          |
|        | 2     |     |     | 0.2872     | 0.2549  |          |
|        | 4     |     |     | 0.5960     | 0.6249  |          |

From table 6, the $L(p)$ of the NTSGChSP is slightly lower at $\frac{\mu}{\mu_0}$ 1 and 2. This shows that the NTSGChSP can perform better than TSGChSP when it comes to inspecting production lots with lower $\frac{\mu}{\mu_0}$. Table 6 also shows that higher $\frac{\mu}{\mu_0}$ yields higher $L(p)$. Therefore, we can conclude that the NTSGChSP performed slightly better in $L(p)$ than the TSGChSP.

5. **Conclusion**
This paper develops a new type of two-sided group chain sampling plan, and it can be used by industry practitioners. The plan has been implemented for three distributions (see, [11] and [12]) including this paper and has been proven to be one of the sampling plans that enhance the consumer’s protection. The NTSGChSP is also a more balanced approach in contrast to TSGChSP and NTSCoGChSP as it operates on four acceptance criteria.
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