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# The Optimal Acceptance Sampling Plan: Goal Programing Models

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**Abstract:** Acceptance sampling is the statistical method used to accept or reject product based on a random sample of the products. When done correctly, accepting sampling is effective for quality control. The acceptance number (c) and the sample size (n) are the basic objectives of any sampling plan. This study aims to construct two goal programing models for the determination of (n) and (c) with regard to four conflicting criteria. It applies non-linear integer goal programing techniques. The first model is assumed, a known and constant lot fraction defective, whereas the other model expected that it is a random variable having a Gamma prior distribution. The resulting two models were non-linear integer goal programing models. Consequently, these models could be worked out using any non-linear integer goal programing package.

***Keywords**: Lexico-graphic goal programing; Acceptance sampling plan; Producer's risk Consumer's risk; Average lot inspection cost (ALIC); Average outgoing quality (AOQ).*

## 1. Introduction

In today's global business environment, quality cannot be belittled or condoned by any firm, regardless of its volume or assets. Business leaders cite quality as one of the most strategic factors in the long-term profitability and considered it as success of their firms. One of the important issues in quality control (QC) is the determination of the optimal acceptance sampling plan in a single, double, multiple, and sequential inspections with minimal cost and high quality. In acceptance sampling, a drawn random sample of units produced are inspected, and the quality of this sample is accepted to reflect the overall quality of all items, or a particular group of items called a lot.

Acceptance sampling is a classical approach to quality control based on the preference that some acceptable number of defective items will result from the production process. The producers and customers agree on the number of acceptable defects, normally measured in percentage. However, the idea of a producer or consumer concurring to any defects at all is an imprecation to the disciples of Total Quality Management (TQM). The objective of companies that have embraced TQM is to attain zero defects. Acceptance sampling identifies defective items after the product is already finished, while TQM preaches the prevention of defects altogether. To adherents of TQM, acceptance sampling is simply a mean of recognizing products to discard or rework. It does nothing to prevent poor quality and to guarantee a good quality in the future.

TQM companies do not even report the number of defective parts in terms of percentage for the expected fraction of the defective items which is so small that a percentage is meaningless. The international measure for reporting defects has turned into defective parts per million (PPM). For example, a defective rate of 1%, utilized in acceptance sampling, was once considered a high – quality standard. 10000 parts per million! This is completely unacceptable level of quality for TQM companies persistently attempting to achieve zero defects. Three or four defects per million would be more acceptable level of quality for such companies. Nevertheless, acceptance sampling is still exercised as a statistical quality control method by numerous companies that have not yet adopted TQM or are demanded by customers or government regulations to use acceptance sampling. Since this method as yet has wide application, it is substantial for it to be studied.

**Sampling Plan:**

When a sample is drawn and inspected for quality, the items in the samples are being checked to see whether they conform to some predetermined specification. A sampling plan sets the guidelines for taking a sample and the criteria for making a decision with respect to the quality of the lot from which the sample is drawn. The simplest form of sampling plan is a single sampling attribute plan which requires the drawing of only one sample. A single sampling plan has as its premise an attribute that can be assessed with a simple, discrete decision, such as defective or non-defective, or good or bad. The plan incorporates the following elements:

N: the lot size
n: the sample size, (selected at random)
c: the acceptable number of defective items in a sample
d: the actual number of the defective items in a sample

Sampling plans are expressed in terms of the sample size (n), and the acceptance number (c). The issue is complicated since there are numerous characteristics to be taken into consideration. Most of the desired objectives are conflicted. For example, minimizing the average lot inspection cost (ALIC) requires decreasing the sample size, whereas minimizing the average outgoing quality requires increasing it. The same conflict occurs between the producer's risk (PR) and the consumer's risk (CR). For a given sample size, decreasing producer's risk causes an increase in consumer's risk. Conversely, decreasing consumer's risk results in an increase in producer's risk. Thus, it is not conceivable to fulfill such objectives all together. The conflicting objectives can be defined as a *multi-objectives programing model*.

A wide variety of sampling plans have been evolved in acceptance sampling. One set of plans, referred to as Military Standard 105 D, develop sampling plans for varying lot sizes and sample sizes indexed by the accepted quality level (AQL) (Duncan, 1986). Single acceptance plans with cost-based model can be found in (Deming, 1986) and (Gitlow, et. al., 1989). The case of multiple attributes was discussed in (Wadsworth, et. al., 1986). A few other models employ Bayesian approach (Montgomery, 1996). In this study, goal programing (GP) technique will be applied to address the acceptance sampling problems using goal programing formulation both when the lot fraction defective (D) is assumed constant, and when it is a random variable having certain probability distribution; specifically, when it follows Gamma distribution. The resulting models are both nonlinear integer goal programing models.

## 2. Goal Programing (GP)

Regarding goal programing, points of interest and wide variety of its models and methodologies could be found in (Ignizio, 1985). Lexcio-graphic goal programing (LGP), i.e., goal programing with preemptive priority structure that is one of the important versions of goal programing, where optimal values of the decision variables, vector X are decided as follows:

$$\text{Lexcio-graphically min } \underline{a} = \{a_1, \ldots, a_k\}$$

Such that:

$$f_i(x) + d_i^- - d_i^+ = b_i \qquad i = 1, \ldots, m$$
$$h_j(x) \le 0 \qquad j = 1, \ldots, J$$

where:

$\underline{a}$: a vector of the achievement function $a_k$, $k = 1, \ldots, k$.
$a_k$: a function of the goal deviation variables ($d_i$) that is to be minimized at priority level k, i.e, $a_k = g_k(d_i^-, d_i^+)$.
$\underline{X}$: a vector of the decision variables, i.e, $\underline{X} = \{x_1, \ldots, x_n\}$.
$d_i^-$: the negative deviation variable corresponding to goal, i
$i = 1, \ldots, m$.
$d_i^+$: the positive deviation variable corresponding to goal i
$i = 1, \ldots, m$.
$h_j(x)$: the $j^{th}$ constraint which may be linear or nonlinear
$j = 1, \ldots, J$.
$f_i(x)$: the $i^{th}$ constraint which may be linear or nonlinear,
$i = 1, \ldots, m$.

When $f_i(x)$ and $h_j(x)$ are both linear functions, the problem is managed as a linear goal programing model through the linear goal programing methodologies, and when they are both nonlinear, the problem is treated through nonlinear methodologies (Land & Powell, 2007).

### 2.1. A Goal Programing Model When the Lot Fraction Defective (D) is Known:

A single sample scheme implies drawing random sample of n items from the batch and observing the number of defectives in the sample. When the decided number of defectives does not exceed some predetermined level c, then the lot will be accepted, apart from that it will be rejected. Expecting that the lot fraction defective D is known, a goal programing model can be constructed for a single acceptance sampling plan using the below notations:

N : the size of the lot
n : the sample size
c : the acceptance number
D : the lot fraction defective
P : the probability of accepting the lot
α : the producer's risk
β : the consumer's risk
$C_r$ : the cost of repair (replace) of the defective items per unit;
$C_s$ : the sampling cost per unit
$C_I$ : the cost per unit of inspection, where:

$$C_I = C_s + D\,C_r \qquad \textbf{(i)}$$

Thus, the main conflicting objectives of a single acceptance sampling plan may be expressed as follows:

- **Goal Ⅰ: The Producer's Risk (α)**

The producer's risk represents the rejection of a lot that should have been accepted. It is usually stated in terms of a probability (α) that a lot will be considered as a bad lot by the consumer even though it is at or exceeds a certain acceptable quality level called (AQL).

That is:

$$\propto = 1 - \rho_1 \qquad \textbf{(ii)}$$

**where:**

$$\rho_1 = \sum_{\bar{d}=0}^{c} \frac{e^{-nD_1}(nD_1)^{\bar{d}}}{\bar{d}!} \quad N \geq 10n \qquad \textbf{(iii)}$$

and p1 takes the form of equation (ii) under the assumption that the hypergeometric distribution would be used when the size of the lot (N) is than ten times the sample size(n), i.e, N < 10 n, but if N ≥ 10n both the binomial ad Poisson distributions might be used as an approximation to the hypergeometric distribution.
Hence:

$$\propto = 1 - \sum_{\bar{d}=0}^{c} \frac{e^{-nD_1}(nD_1)^{\bar{d}}}{\bar{d}!} \qquad \textbf{(iv)}$$

where $D_1$ is the nonconforming fraction for a supplier's process, and it is known. The first objective is, thus, to decide (n) – the sample size, and (c) – the acceptance number- such that the producer's risk (α) is minimized, or on the other hand, to maximize (1 - α ), i.e.,

$$\max(1-\propto) = \sum_{\bar{d}=0}^{c} \frac{e^{-nD_1}(nD_1)^{\bar{d}}}{\bar{d}!} \qquad \textbf{(v)}$$

- **Goal II: The Consumer's Risk (β)**

The consumer's risks represent the acceptance of a lot that should have been rejected. It is usually defined in terms of the probability (β) that a lot whose quality is below a certain level, i.e., called the lot tolerance percent defective (LTPD) is accepted.
That is:

$$\beta = \sum_{\bar{d}=0}^{c} \frac{e^{-nD_2}(nD_2)^{\bar{d}}}{\bar{d}!} \qquad \textbf{(vi)}$$

where D2 is the poorest fraction of nonconforming in an individual lot. The second objective in a single sampling plan is to find (n) and (c) that minimize equation (vi) given that D1 and D2 are known.

- **Goal III: The Average Lot Inspection Cost (ALIC)**

The average lot inspection cost (ALIC) could be defined as:

$$ALIC = nC_I + (N-n)(1-\rho)C_I \qquad \textbf{(vii)}$$

That is, ALIC equals the cost of inspection of the sample, and the cost of inspection of the remaining items of the lot when it is rejected.
where:

$$\rho = \sum_{\bar{d}=0}^{c} \frac{e^{-nD_1}(nD_1)^{\bar{d}}}{\bar{d}!} \quad \textbf{(viii)}$$

It is clear that keeping the acceptance number, c fixed, then ALIC will increase as the sample size, n increases, and that ALIC will decrease as c increases when n is kept fixed, since p (the probability of accepting the lot) increases as c increases. The third goal is to minimize the average lot inspection cost (ALIC) in the course of finding the optimal sample size, n and the acceptance number, c.

- **Goal IV: The Average Outgoing Quality (AOQ)**

The average outgoing quality (AOQ) represents the expected average quality level of an outgoing lot for a given value of incoming lot quality. AOQ is defined in terms of the defectives proportion in an outgoing lot. It is given by:

$$AOQ = \begin{cases} \frac{N-n}{N} & \rho D \qquad N\ is\ small, N\ is\ large \\ \rho D & \end{cases} \quad \textbf{(ix)}$$

It is obvious that AOQ will decrease as (n) increases when (c) is kept fixed, and it will increase as c increases for a fixed sample size n. The fourth objective in the acceptance plan is the minimization of the average outgoing quality in the course of determining the optimal n and c.

Thus, the multi-objectives programing (MOP) model for a single acceptance plan may be defined as follows:

Find n, c so that:

$$\textbf{Z1}: \max(1-\propto) = \sum_{\bar{d}=0}^{c} \frac{e^{-nD_1}(nD_1)^{\bar{d}}}{\bar{d}!}$$

$$\textbf{Z2}: \min(\beta) = \sum_{\bar{d}=0}^{c} \frac{e^{-nD_2}(nD_2)^{\bar{d}}}{\bar{d}!}$$

$$\textbf{Z3}: min\ ALIC = nC_I + (N-n)(1-\rho)C_I$$

$$\textbf{Z4}: \min\ AOQ = \frac{N-n}{N}\ \rho D$$

**Model I:**

$$\sum_{\bar{d}=0}^{c} \frac{e^{-nD_1}(nD_1)^{\bar{d}}}{d'!} + \bar{d}_1 - d_1{}^{+} = b_1$$

$$\sum_{\bar{d}=0}^{c} \frac{e^{-nD_2}(nD_2)^{\bar{d}}}{d'!} + \bar{d}_2 - d_2{}^{+} = b_2$$

$$nC_I + (N-n)(1-\rho)C_I + \bar{d}_3 - d_3{}^{+} = b_3$$

$$\frac{N-n}{N}\rho D + \bar{d}_4 - d_4{}^{+} = b_4$$

$0 \le n \le N$;
$C_{min} \le c \le C_{max}$
$C_{min} = \max(0, n + d - N)$
$C_{max} = \min(n, d)$
D = the number of defective in the lot where n, c are integers.

The Lexico –graphic goal programing model would then be used to formulate the problem which is given by Model I:
Find n, and c such that:
Lexico –graphically min $\underline{a} = [d_1^-, d_2^+, d_3^+, d_4^+]$

Subject to:
$nC_I + (N - n)(1 - p) C_I + d_3^- - d_3^+ = b_3$
$(N - n)pD/N + d_4^- - d_4^+ = b_4$
where p is defined in equation (viii).
$C_{min} \leq c \leq C_{max}$;
$d_i^-, d_i^+ \geq 0$, i = 1, 2, 3, 4; n, and c are integers
where:
$b_i$ is the aspiration level for goal i, i = 1, 2, 3, 4.

The objectives functions are nonlinear because of the formula of the probability (p), and since n and c are both integers, then MODEL I is a nonlinear integer goal programing model. Such a model would be solved using the appropriate nonlinear integer goal programing package.

### 2.2. A Goal Programing Model When D Is a Stochastic Variable Having a Known Probability Distribution:

Virtually the number of defectives in the lot D is unknown. So, the assumption that D is known would be freed. Thus, we are going to presume that D is not known, but it has a known probability distribution, namely the Gamma distribution with parameters a and $\beta$. This prior probability distribution reflects the researchers' belief about (D). That is:

$$\pi(D) = \frac{\beta^{a+1'}}{a!} D^a e^{-\beta D} \quad \text{(x)}$$

where:
a = 1, 2, 3, ………., ∞
$\beta$ = 1, 2, 3, ………., ∞
D > 0

D would be seen as the percentage of defectives in the lot. When the parameter a equals zero, then D will have an exponential distribution.
If ƒ(d|D) is the conditional probability of d – the number of defectives in a sample of size, n – which has the following Poisson distribution:

$$f(\bar{d}|D) = \frac{e^{-nD_2}(nD_2)^{\bar{d}}}{\bar{d}!} \qquad d' = 0, 1, 2, \dots \propto \quad \text{(xi)}$$

Then the joint distribution ƒ(D, d) would be:

$$f(D, \bar{d}) = f(\bar{d}|D)\, \pi(D) \quad \text{(xii)}$$

$$\frac{\beta^{a+1'}}{a!} D^a e^{-\beta D} = \frac{e^{-nD_2}(nD_2)^{\bar{d}}}{\bar{d}!} \quad \text{(xiii)}$$

Thus, the marginal distribution of d in a sample of size n denoted by g(d) is given by:

$$B(\bar{d}) = \int_D f(D, \bar{d})\, dD \quad \text{(ivx)}$$

$$= \int_D \frac{\beta^{a+1'}}{a!} D^a e^{-\beta D} = \frac{e^{-nD_2}(nD_2)^{\bar{d}}}{\bar{d}!} . dD \quad \text{(vx)}$$

$$= \frac{\beta^{a+1} n^{\bar{d}}}{a!\, \bar{d}!} \int_D \left(\frac{X}{n^{\sim}}\right)^{a+\bar{d}} \times d\, \frac{X}{n^{\sim}} \quad \text{(xvi)}$$

where:
X =Dn", and n" = n + $\beta$.
Therefore,

$$g(\bar{d}) = \frac{\beta^{a+1} n^{\bar{d}} \sqrt{(a+d'+1)}}{a!\, \bar{d}! (\beta+n)^{a+\bar{d}+1}} \quad \text{(xvii)}$$

Thus, the posterior probability of a specified lot fraction defectives (D), given the number of defectives (d) in a sample of size (n) represented by ƒ (D|d) would be:

$$f(D|\bar{d}) = \frac{f(D, \bar{d})}{g(\bar{d})} \quad \text{(xviii)}$$

$$g(\bar{d}) = \frac{\beta^{a+1} n^{\bar{d}} D^{a+\bar{d}} e^{-(\beta+n)D}}{a!\, \bar{d}!} \times \frac{a!\, \bar{d}! (\beta+n)^{a+\bar{d}+1}}{\beta^{a+1} n^{\bar{d}} \sqrt{(a+\bar{d}+1)}} \quad \text{(ixx)}$$

$$\frac{(\beta+n)^{a+\bar{d}+1}\, D^{a+\bar{d}}\, e^{-(\beta+n)D}}{\sqrt{(a+\bar{d}+1)}} \qquad \textbf{(xx)}$$

Thus,

$$f(D|\bar{d}) = G(a+\bar{d},\ \beta+n) \qquad \textbf{(xxi)}$$

That is, the posterior probability distribution of D – the specific fraction of defectives in the lot – is the Gamma distribution with the parameters (a + d) and ($\beta$ + n). The parameters (a) and ($\beta$) could be uniquely determined from the mean (μ) and the standard deviation (σ) of the Gamma prior distribution as follows:

$$\hat{a} = \left[\frac{\bar{X}}{S}\right]^2$$

$$\hat{\beta} = \frac{S^2}{\bar{X}} \qquad \text{(xxii)}$$

In addition to the fact that Gamma prior distribution is mathematically appropriate, it gives, in practice, a variety of distribution patterns distinguishable by the mean and the standard deviation since its parameters could be uniquely determined by (μ) and (σ) (Louzada, et. al., 2019).

Using the posterior distribution to compute (p) – the probability of accepting the lot – the formulation of the objectives of the single inspection plan could be as follows:

- **Goal I: The Producer's Risk (α)**

$$1-\propto = 1-P = 1-\sum_{\bar{d}=0}^{c} \frac{e^{-nD_1}\,(nD_1)^{\bar{d}}}{\bar{d}!} \qquad \textbf{(xxiii)}$$

- **Goal II: The Consumer's Risk (β)**

$$\beta = 1-\sum_{\bar{d}=0}^{c} \frac{e^{-nD_1}\,(nD_1)^{\bar{d}}}{\bar{d}!} \qquad \textbf{(ivxx)}$$

where D1 and D2 are the specified maximum, and minimum values for the random variable, D.

- **Goal III: The Average Lot Inspection Cost (ALIC)**

As mentioned earlier, the average lot inspection, AILC consists of two components:
(i) the sampling cost (Cs) which is made up of the cost of inspection (nCI), and the cost of replacing the defective items in the sample when the entire lot is accepted, i.e., Cr. Thus, the sampling cost is:

$$C_s = nC_I + C_r \sum_{\bar{d}=0}^{c} \bar{d}\, g(\bar{d}) \qquad \textbf{(xxv)}$$

(ii) the rejection cost when the number of defectives in the sample d exceeds the acceptance number c. This cost is made up of inspecting the remaining (N – n) units at cost of ($C_s$) per unit, and the repairing the defective units found at cost ($C_r$) per unit. Hence, the average lot inspection cost would be:

$$ALIC = nC_S + C_r \sum_{\bar{d}=0}^{c} \bar{d}\, g(\bar{d}) + (N-n)C_S \sum_{\bar{d}=c+1}^{n} \bar{d}\, g(\bar{d}) + nC_r \int_0^N Df(D|\bar{d}) \times dD \qquad \textbf{(xxvi)}$$

- **Goal IV: The Average Outgoing Quality (AOQ)**

Following the same reasoning, the average outgoing quality AOQ would be given by:

$$AOQ = \frac{1}{N} \sum_{\bar{d}=0}^{c} \bar{d}\, g(\bar{d}) + \frac{N-n}{N} \int_0^N Df(D|\bar{d}) \times dD \qquad \textbf{(xxvii)}$$

**Model II:**

$$1-\sum_{\bar{d}=0}^{c} \frac{e^{-nD_1}\,(nD_1)^{\bar{d}}}{\bar{d}!} + \bar{d}_1 - {d_1}^{+} = b_1$$

$$1-\sum_{\bar{d}=0}^{c} \frac{e^{-nD_2}\,(nD_2)^{\bar{d}}}{\bar{d}!} + \bar{d}_2 - {d_2}^{+} = b_2$$

$$nC_S + C_r \sum_{\bar{d}=0}^{c} \bar{d}\, g(\bar{d}) + (N-n)C_S \sum_{\bar{d}=c+1}^{n} \bar{d}\, g(\bar{d}) + nC_r \int_{0}^{N} Df(D|\bar{d}) \times dD + \bar{d}_3 - d_3^{+} = b_3$$

$$\frac{1}{N} \sum_{\bar{d}=0}^{c} \bar{d}\, g(\bar{d}) + \frac{N-n}{N} \int_{0}^{N} Df(D|\bar{d}) \times dD + \bar{d}_4 - d_4^{+} = b_4$$

Eventually, the complete Lexico – graphic goal programing model when the fraction of the defectives in the lot D is a random variable is given by MODEL II:

Find n, and c such that:

Lexico –graphically min $\underline{a} = [d_1^-, d_2^+, d_3^+, d_4^+]$

Subject to:

$0 \leq n \leq N$;

$0 \leq c \leq n$;

$d_i^-, d_i^+ \geq 0$, i = 1, 2, 3, 4;

As it can be seen, the ranges of n and c have changed since the lot defectives D are no longer fixed. MODEL II could be solved for the optimal n and c the same way as MODEL I.

## 3. Conclusion

Two models were suggested for the optimal single acceptance sampling plan. The models were developed using goal programing terminology. Four conflicting objectives were considered: the producer's risk, the consumer's risk, the average lot inspection cost, and the average outgoing quality. The first model, i.e., MODEL I assumed a constant known lot fraction defective D. The second model, i.e., MODEL II presumed that the lot fraction defective D has a prior Gamma distribution function. Both models should be solved using an appropriate nonlinear integer goal programing package.

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# خطة أخذ عينات القبول الأمثل: نماذج برمجة الهدف

**فؤاد سعيد يوسف سعد[1]، فيح الرحمن تاج الدين إبراهيم شاع الدين[2]، محمد أبو القاسم محمد حسنين[3]، حمود محمد سعد آل عمر[4]**

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**الملخص:**

معاينة القبول هي أسلوب إحصائي يستخدم للمساعدة في اتخاذ القرار بقبول أو رفض منتج وفقًا لعينة عشوائية من وحدات المنتج، وعندما يتم استخدام المعاينة بشكل صحيح تصبح وسيلة فاعلة للجودة. رقم القبول وقوام العينة هما الهدفان الرئيسيان لأي خطة لمعاينة القبول، تهدف هذه الدراسة لبناء نموذجين لبرمجة الهدف لتحديد قيمة كل من رقم القبول وقوام العينة وفقًا لأربعة أهداف متضاربة. استخدمت الدراسة برمجة الهدف العددية غير الخطية. افترض النموذج الأول أن نسبة المعيب في الشحنة معلومة وثابتة، بينما افترض النموذج الأخر أن هذه النسبة متغير عشوائي يخضع لتوزيع قاما. النموذجان الناتجان عبارة عن نماذج برمجة هدف عددية غير خطية، وعليه يمكن حل هذه النماذج باستخدام أي حزمة برمجة هدف غير خطية.

**الكلمات المفتاحية:** برمجة الهدف ليكسيكو البيانية؛ خطة معاينة القبول؛ مخاطر المنتج؛ مخاطر المستهلك؛ متوسط تكلفة فحص الشحنة؛ متوسط الجودة المنسحبة.