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The Application of Statistical Sampling Techniques to the Operational Readiness Inspection

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TECHNIQUES TO THE
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THESIS

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THESIS

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Troy L. Dixon

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Tim Madgett

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ABSTRACT

A Blue Ribbon Commission report to the Air Force Chief of Staff in February 1997 makes several specific recommendations on the conduct of Operational Readiness Inspections. This thesis develops a solution to one of the recommendations of that report; utilize scientifically based sampling techniques to reduce the footprint of the inspection on an evaluated unit. Acceptance sampling, common in industry, is developed for use in the Operational Readiness Inspection. The time saved from this more efficient sampling practice reduces Inspector General time during an evaluation, decreases the footprint, and answers the specific recommendations of the Blue Ribbon Commission.

This thesis explains the construction of acceptance sampling plans and procedures. The changes to the Operational Readiness Inspection for effective application of acceptance sampling are defined and the automatic computation of acceptance plans through a computer spreadsheet application is accomplished. A validation is provided with the results from applying these techniques to an actual Operational Readiness Inspection at Cannon AFB, NM. Acceptance sampling has proven itself in the world of industry in international and military standards. This proven practice, simple in concept, can produce more credible and convincing results in many inspected areas selected for sampling.

THE APPLICATION OF STATISTICAL SAMPLING TECHNIQUES TO THE OPERATIONAL READINESS INSPECTION

1. INTRODUCTION

This thesis provides the Air Combat Command Inspector General (ACC/IG) sound statistical based sampling methods that can be applied to Operational Readiness Inspections (ORIs). ORIs in ACC consist of numerous inspectors evaluating the ability of an operational unit to conduct a wartime mission. Reduction in the size of the IG staff necessitates they evaluate a unit as effectively as possible with their reduced resources; additionally, numerous taskings on operational units requires the IG to evaluate them as quickly as possible to minimize its impact on the inspected unit. It is in this context that this thesis gives the IG a tool to do their job under these new restrictions. We apply acceptance sampling techniques to reduce the effort required of inspectors to evaluate selected processes in the ORI, thus decreasing the total time required to conduct the inspection. Finally, these techniques are not restricted to an ORI, but could be applied to other types of IG inspections.

1.1 Background

The IG uses the ORI as (i) an independent assessment of an operational units capability to carry out Designed Operational Capability (DOC) mission taskings; or, (ii) validating a unit's ability to do its wartime mission. The ORI can be broken down into two major categories, Phase I and II. The Phase I portion of the ORI evaluates the unit's ability to mobilize and deploy to a tasked location; the Phase II portion evaluates the unit's ability to employ its assets at the tasked location. ACC/IG inspectors evaluate hundreds of processes involved in the unit's deployment and employment by categorizing the grading into four major subareas:

(1) Initial Response

(2) Employment

(3) Ability to Survive and Operate (ATSO)

(4) Mission Support

A system of weighting is applied to these four subareas to achieve an overall unit grade (AFI 90-201/ACC Sup 1, 1996:43).

The advent of the post cold war military has seen the size of the US Air Force shrink; however, DOC mission taskings have increased for the remaining forces. Consequently, the IG has increased the size of it's evaluations in order to keep pace with increases in DOC mission taskings. For example, this inflation is seen in the growth of Air National Guard ORIs-- since 1985 they have doubled in length and tripled in cost. The effect on active units is similar, the overall result being units require more time, effort and cost to prepare for these intensive evaluations (Blue Ribbon Commission, 1997:32).

While operational units have decreased in numbers recently, real world taskings, training exercises, and daily training requirements have not. Units find themselves stretched to the limit with high deployment rates; yet at home, these same units are stressed to accomplish the training they missed while deployed to real-world taskings.

The inherent conflict between inspection, preparation, and high operational tempos for ACC units requires that ORIs be as efficient as possible. Furthermore, force reductions have not only hit operational units, they have reduced the size of the ACC/IG twenty-five percent since 1993, with further reductions possible (Nelson, 1997). Thus, increased operations, a growing ORI in size and complexity, and force reductions (including the IG) has compelled the Air Force to review the way ORIs are conducted.

1.2 Problem Statement

In April of 1996, an Air Force Chief of Staff Blue Ribbon Commission (BRC) was created to review organizational evaluations and awards. The report created by this commission and approved by the Chief of Staff in February 1997 makes several specific recommendations on ORIs. Specifically, the problem addressed by this thesis is the recommendation to "...reduce the ORI footprint (as measured by number of inspectors man-days at the installation). Such practices may require greater reliance on carefully selected 'sampling' and other techniques to assess mission performance" (Blue Ribbon Commission, 1997:1,33). Defining an inspector man-day as one inspector evaluating for one duty day, more efficient use of an inspectors time will reduce man-days, thus reducing the ORIs footprint.

1.3 Organization of Research

Statistical sampling is a very broad topic and covers a vast number of techniques and procedures that vary in complexity. In order for an IG inspector to efficiently use any technique, *it has to be straight forward and simple in application.* The scope of this thesis effort centers on the area of acceptance sampling in quality control. Quality should be considered as a conformance to requirements, which is exactly what the ORI is directed at evaluating. On a more general perspective, if ACC is viewed as the producer (the producer of combat) who must rely on the units to provide the raw materials and component parts for the product called combat, and the ORI seeks to ascertain if the lot of material provided by a particular unit should be accepted or rejected, then acceptance sampling has direct applicability (Barnes, 1993:303,317).

Our primary research focuses on applying acceptance sampling to as many specific processes as possible in the conduct of the ORI. There are several sampling techniques that could be applied; specifically, no inspection, 100 percent inspection, spot inspection, constant percentage sampling, and scientific sampling. However, each has its drawbacks. No inspection contradicts the charter of the ORI to verify a unit's capability. A complete one hundred percent inspection is usually not an option due to time constraints, IG manpower and cost (not to mention it is contradicting the BRC's recommendation to reduce the ORI footprint as measured in man-days). Similarly, spot checking is a bad option if the IG is to verify capability. Spot checking as an overall plan would require many aspects of a unit's ability to conduct combat operations go unverified over a large time frame with the infrequency of unit ORIs. Constant percentage sampling, often used if sampling is employed, is a poorer statistical measure of quality as the population sampled fluctuates up and down. The last technique, scientific based sampling, is the emphasis of this thesis (Barnes, 1993:317-318).

Given an evaluated process, the main idea is treating the sampling technique as a black box. The inspector plugs in inputs and receives output in the form of (i) sample size required to evaluate the given process and (ii) the number of fails required to "fail" the process overall. The objective is to reduce the time it takes the inspector to accomplish his evaluations when the risks and the sampling technique are known. The risks are the chance of calling a process bad when it is in reality good and conversely, calling a process good when it is in reality bad.

1.4 Thesis Objectives

Statistical based sampling techniques will answer the recommendation of the BRC on sampling techniques. Chapter II provides the necessary background, development and explanation of all applied sampling techniques. Chapter III explains the methodology used to apply these same techniques to a typical ACC ORI.

The ORI is broken down into those processes where sampling can be applied. The information required to apply the technique will be listed and fully explained in the context of the inspection. The output of the technique will then be administered to the grading procedures.

Chapter IV deals with actual data and shows the net positive decreases in effort gained by using this methodology as a tool to help conduct the unit evaluation. Chapter V provides a summary and makes suggestions on further uses of sampling in the ORI.

2. *LITERATURE REVIEW*

This literature review concentrates on two principal areas in acceptance sampling. First, we review the underlying probabilistic theory in acceptance sampling and the operating characteristic curve; then the development and explanation of several acceptance sampling plans that might have applicability in an ACC ORI.

2.1 Probability and Randomness

An understanding of how acceptance sampling functions, must start with the basic definition of probability. Schilling states, "...probability is defined as the ratio of favorable to total possible equally likely and mutually exclusive cases" (Schilling, 1982:14-15). A classic example is the gambler at a blackjack table where the dealer is using a single deck of cards. Assuming the dealer has shuffled the deck so any card is equally likely to be drawn, what is the probability of a face card? There are fifty-two cards in the deck, and twelve are face cards, so the probability of obtaining a face card is 12/52 = 23 percent. This is the classic definition of probability familiar to most individuals from their primary education (Schilling, 1982:15).

A definition of probability related to use in acceptance sampling is the empirical definition by Schilling, "... probability is regarded as the ratio of successes to total number of trials in the long run ..." (Schilling, 1982:15). One application of this definition (familiar to every baseball fan) is the batting average. A player with a .340 batting average has a thirty-four percent chance of getting a hit the next time at bat. It is this concept of probability that comes into play in developing the operating characteristic curve.

A sample is a portion or subset of a larger population; i.e., a sample of 15 aircraft sorties from a population of 100 sorties flown. The key to making a sample random is how it is selected from the larger population. Schilling states, "... random samples are those in which every item in the lot or population sampled has an equal chance to be drawn ..." (Schilling, 1982:16). *Therefore, each sampled item must have an equal chance of being drawn and that no preference exists for an item in the population* (Duncan, 1986:23, emphasis added). Finally, random samples can be classified into two types -- those *with replacement*, where an item can be selected only once; and, *without replacement*, where every item has an equal chance of being selected each time a new member is sampled from the population. (Levy and Lemeshow, 1991:44). The concepts discussed later in acceptance sampling only deal with random sampling without replacement.

Finally an operating characteristic curve is the probability distribution function for a random variable. Jaran and Gryna define, "... a probability distribution function is a mathematical formula that relates the values of the characteristic with their probability of occurrence in the population. The collection of these probabilities is called a probability distribution ..." (Juran and Gryna, 1993:187). For example, the probability of an item from a sample being defective or non-defective can be described by a probability distribution. Several common probability functions (Table 1) are used in generating operating characteristic curves for different types of acceptance sampling plans.

Table 1

Probability Distributions Used in Acceptance Sampling

Probability Distribution	**Density Function**	**Common Uses**
Hypergeometric	$P(X)=\dfrac{C_{n-X}^{N-m}C_X^m}{C_n^N}$	Sampling from a finite lot without replacement.
Binomial	$P(X)=C_X^n p^X(1-p)^{n-X}$	Sampling from an infinite lot. Sampling from a finite lot with replacement.
Poisson	$P(X)=\dfrac{\mu^x e^{-\mu}}{x!}$	Sampling defects from an area with a possible infinite number of occurrences.
Negative Binomial	$P(X)=C_{x-1}^{n-1}p^x q^{n-x}$	Models the number of random trials required to determine a given number of fails.
Exponential	$P(X)=\dfrac{1}{\mu}e^{\frac{-x}{\mu}}$	Used in evaluating acceptance plans for reliability and life testing of units with a constant failure rate.
Weibull	$P(X)=\dfrac{\beta}{\eta}\left(\dfrac{x-\gamma}{\eta}\right)^{\beta-1}e^{-\left(\frac{x-\gamma}{\eta}\right)^{\beta}}$	Used to model life distributions of units with decreasing, constant, or increasing hazard rates.
Normal	$P(X)=\dfrac{1}{\sigma\sqrt{2\pi}}e^{-\left(\frac{x-\mu}{\sigma}\right)^2}$	Forms basis of a large number of variables acceptance plans.

(Schilling, 1982:60)

2.2 Sampling Risks

When inspecting (even at a 100 percent level) one cannot assume that all bad items will be found in a lot. In other words, the risk *always exists* of not representing the true nature of the lot. Any random sample can misrepresent the lot in two different ways -- it can call the lot good when, in fact, it is bad; or, it can call the lot bad when it is, in fact, good. The literature on sampling gives names to these types of risks (Juran and Gryna, 1993:460).

> 1. *Producers Risk* - When we decide the lot is bad when it is actually good, we make a Type I error. The probability of making a Type I error is α, and is coined producer's risk.
>
> 2. *Consumers Risk* - When we decide the lot is good when it is actually bad, we make a Type II error. The probability of making a Type II error is β, and is coined producer's risk

Ideally you want to identify the level of defective items in a random sample below which you would not accept, thus producing an acceptance sampling plan that will *always* catch the unrepresentative sample and *always* pass the accurate sample. The α and β risks are zero; however, this type of plan does not exist because certain tradeoffs must occur. The best course of action sets the α and β risk low, while keeping the sample size small as compared to the population. Unfortunately, as you drive α and β closer to zero, the sample size approaches the population size, thus defeating the purpose of sampling. For these reasons the accepted values in industry and in the literature for α and β are .05 and .10 respectively.

The acceptance quality level (AQL) is the value the producer wants to be assured of with a very high rate of confidence. Duncan states the standard definition of the AQL as "the poorest level of quality or maximum fraction nonconforming for the supplier's process that the consumer would consider to be acceptable as a process average for the purposes of acceptance sampling (Duncan, 1986:170)".

The second quality level that can be used is the *p* value that corresponds to a $P_a = .10$ (the so-called consumer's risk). A consumer wants to afford some protection from a bad product, or at minimum limit how bad the product quality can be and still have a chance of being accepted. A common term for this limit is the *lot-tolerance fraction nonconforming*; as Duncan states it is the poorest quality the consumer is willing to put up with in a single lot (Duncan, 1986:170).

2.3 The Operating Characteristic Curve

The OC curve forms the basis for the sampling plan by showing the relationship between nonconforming percentage and probability of acceptance, while quantifying the risks α and β. Specifically, the OC curve graphs the percent nonconforming versus the probability of sampling plan acceptance. In other words, for all the possible values of percent defectives, the OC curve shows the probability of acceptance of the area being inspected.

2.3.1 Operating Characteristic Curve Types

Operating characteristic curves can be divided into two major types -- Type A and Type B. These two types differ in the type of process sampled and the type of probability function used to generate the points on the curve. The sample comes from a lot that falls into one of two types -- *infinite* or *isolated.*

Type A Operating Characteristic Curves. The Type A operating characteristic curve is based on the probability of acceptance of an isolated lot; i.e., a finite population. One example of an isolated lot is the one-time production of 500 items, where a random sample taken from this lot constitutes the data for making an accept or reject decision. The vertical axis on a Type A curve (probability of acceptance) is defined as the long run proportion of lots that are accepted if you have an infinite line of lots exactly the same as the one isolated lot (Duncan, 1986:164-165). At each point on the curve you have the probability of accepting a population of N, given that c or less items are defective when the *true* proportion of defectives in the lot is p. This probability is exactly defined by the hypergeometric probability distribution

$$P(X) = \frac{C_{n-X}^{N-m} C_X^m}{C_n^N}.$$

Where $P(X)$ is the probability of getting X failures with the parameters defined as

N = lot size, $N > 0$

n = sample size, $n = 1,2, \ldots, N$

m = number of failures in the lot (pN)

X = number of failures, $X = 0, 1, \ldots, n$ if $m<n$ then $X = 0,1, \ldots m$

and C_b^a represents $\dfrac{a!}{b!(a-b)!}$

The value of a point on the curve is the summation of $X = 0, 1, \ldots, c$.

The type of operating characteristic curve we use are Type A, although we may approximate it with a Type B curve as described in the next paragraph. The shape of the Type A curve is driven by the size of the lot. As the lot size increases, it begins to approximate the shape of a Type B curve for the same sampling plan. Finally, as the lot increases it approaches (for practical purposes) the assumption of an infinite lot associated with a Type B curve (Duncan, 1986:166).

Type B Operating Characteristic Curve. The Type B curve plots the probability of acceptance against the proportion defective of the process that produced the lot (instead of the lot proportion defective as in Type A) (Schilling, 1982:76). The random sample now is no longer considered to be from a single, distinctive lot, but from a continuous process. Mathematically, the process is being sampled directly. Therefore, calculating a point on the Type B curve represents the probability of acceptance (success) from an infinite population given that *c* or less items have failed with a probability of failure *p*. This probability is defined by the binomial probability distribution (Duncan, 1986: 164)

$$P(X) = C_X^n p^X (1-p)^{n-X}.$$

Where *P(X)* is the probability of getting *X* failures with the parameters defined as:

n = sample size, $n > 0$

p = proportion defective, $0 \leq p \leq 1$

X = number of failures, $X = 0, 1, \ldots, n$

Again, the value of a point on the curve is the summation of $X = 0, 1, \ldots, c$.

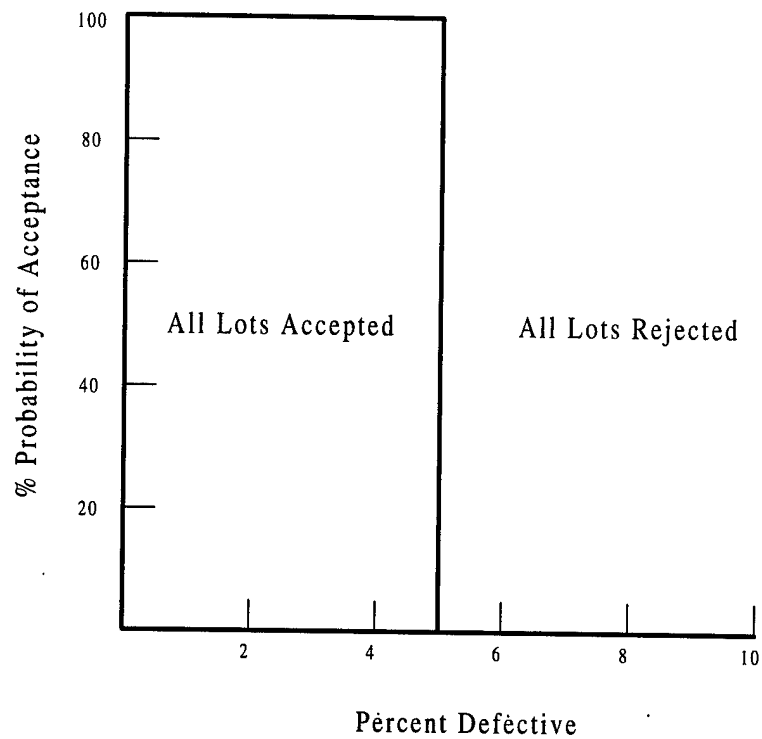


Figure 1. Ideal OC Curve

The curves are unique to the particular sampling plan designed. An ideal OC curve allows the user to perfectly distinguish between conforming samples and nonconforming samples. What this means is that the plan will have 100% probability of acceptance if the population has less than the AQL defectives. If the actual quality is worse, the probability is 0 that the sample will indicate acceptance. For example, suppose we decide on a sampling plan that includes an AQL of 5%, and assume that we can perfectly distinguish between conforming and nonconforming samples. The ideal OC curve for this plan is shown in Figure 1, where the AQL for the curve is 5%. The curve shows that the probability of acceptance is 100% if the inspected area is less than or equal to 5%

nonconforming. It also shows that the probability of acceptance is 0 if the inspected area is greater than 5% nonconforming.

However, as mentioned earlier, every sampling plan has built in error; therefore, it is impossible to attain the ideal curve. More realistically, the OC curve will contain a degree of curvature representing the level of variation inherently involved in the process. In effect, the curvature reflects the fact that there is always the chance of good areas being rejected and bad areas being accepted. For example, Figure 2 presents a curve showing a 100% probability of acceptance when the population contains 0% nonconforming; conversely, it indicates almost 0% probability of accepting populations that contain 30% or more nonconforming.

The curve also has points representing the AQL and RQL plotted. To illustrate, suppose we established the AQL equal to 2.5% and the RQL to be 20% in our mobility bag example. If we assume α is 0.05 and β equals 0.10, the curve at point A shows the probability of acceptance at the AQL of percent defective equals 1 - α or 0.95. (Recalling the definition of AQL, we want populations at this high quality level to pass most of the time.) Conversely, the curve also shows at point B that the probability of acceptance is 0.10 for populations that are at the RQL. Again, this meets our expectations since we want populations at this poor quality level to be found nonconforming most of the time (or at the level of our chosen β, 0.10).

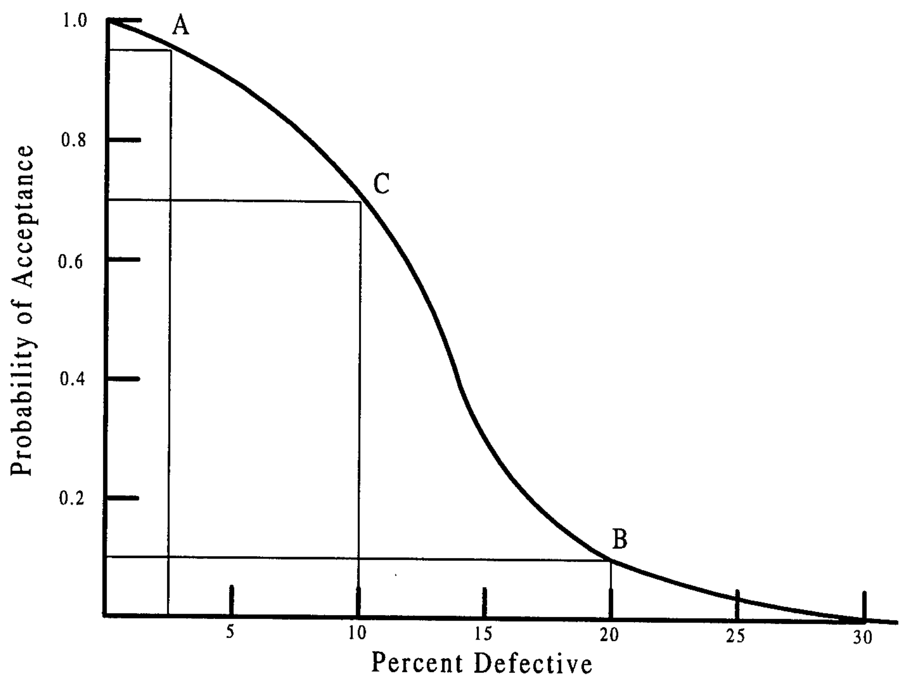


Figure 2. Typical OC Curve

Point C illustrates the infinite number of points located in the gray area previously discussed. As the quality level decreases from the AQL to the RQL, we see a decreasing probability of acceptance as a graphical depiction of the error via the curvature. In other words, curvature is caused by the fact that in the design of our sampling plan we are willing to accept less than perfection. However, this feature also allows us to utilize small sample sizes. If we compressed the graph toward the shape of the ideal OC curve (ultimately realizing the ideal curve when AQL equals RQL), we would then have perfect distinguishability. The only way we to accomplish this would be to eliminate the error (set α and β equal to 0) and *increase the sample size as AQL and RQL approach each other in value*. Thus, to be perfectly distinguishable the sample size would approach the size of the population--in essence 100% sampling. It is this condition that the IG is trying to eliminate.

2.3.2 OC Curve Analysis

Changing different parameters of the sampling plan will have different overall effects. Utilizing the OC curve, it is easy to visualize the changes of the sampling plan due to changes in the parameters. In general, the values necessary for the constructing an OC curve are population size, sample size, acceptance number, and number of defectives allowed. If we hold the population size constant and model the number of defectives as a function of the acceptance number, we can vary the two remaining parameters--acceptance number and the sample size—to illustrate this effect on the OC curve.

Varying the Acceptance Number. Suppose an inspector, in evaluating 200 mobility bags, develops a sampling plan calling for a sample size of 25 and an acceptance number of 3. Curve A in Figure 3 is the OC curve for this sampling plan. Curve B represents the same sampling plan except the acceptance number is now 0, while curve C's acceptance number is 8. Assuming α and β are kept constant, the curves show that as the value of the acceptance number increases, both AQL and RQL will increase.

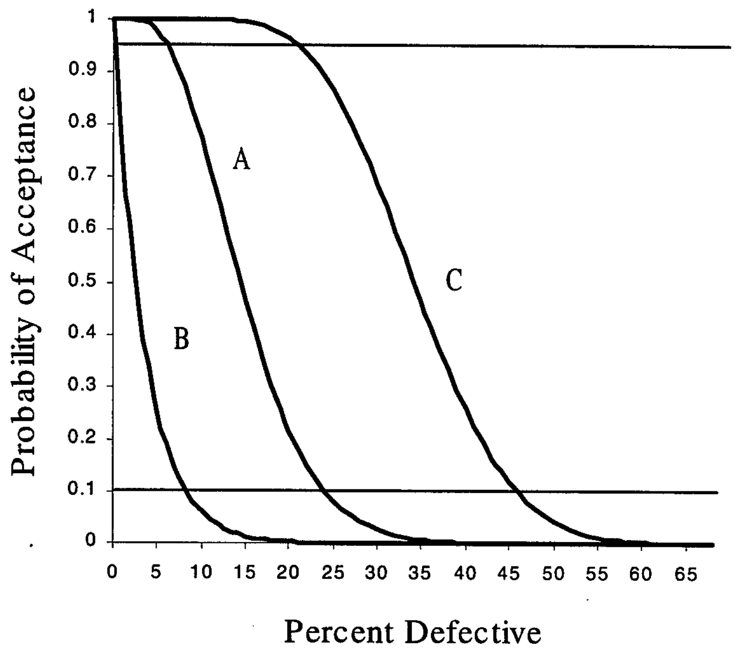


Figure 3. OC Curve Showing Changing Acceptance Number

The horizontal lines at the top and bottom of the chart represent the α and β levels respectively. The intersection of these lines and the OC curves represent the AQL and RQL, whose values obviously increase as acceptance number increases. The actual values are approximated in Table 2.

Table 2. AQL/RQL for Increasing Acceptance Number

Plan	AQL	RQL
A	7.5	24
B	0.1	7.5
C	22	46

This becomes extremely important to an inspector. Once the inspector has decided on a sampling plan, arbitrary changes cannot be made during the course of the inspection. Suppose an inspector is inspecting the population of 200 mobility bags using the plan corresponding to curve A in Figure 3. IF the inspector decides to arbitrarily allow more nonconforming items, the effect is a shift to the right for the OC curve. What this means is that if the inspector allowed 8 nonconforming items, the AQL would effectively increase from the 7.5% desired to 22%. This is almost tripled. Now the inspector will have a 95% probability of passing a population that could be as low as 78% actual conforming. Also, there would be a probability of 10% of passing the population even if it contained only 54% actually conforming elements which is almost double the intended design. The result of increasing the acceptance number is a higher probability of passing populations with much lower actual quality than desired. The opposite is true for lowering the acceptance number. The AQL and RQL will both decrease resulting in a greater difficulty of finding populations conforming, even though they meet the desired quality level. Standards will be much tighter and more difficult to attain. Therefore it is imperative that the inspector follow the designed plan when performing the inspections in the field.

Changing the Sample Size. Changing the sample size in the field will also have an effect on the designed quality levels. Assume our inspector is following the sampling plan just discussed. Curve A in Figure 4 represents the designed sampling plan. Curve B shows the OC curve if the sample size is changed from 25 to 50. Curve C represents the OC curve if the sample size is decreased to 10. As opposed to a shift, changing the sample size effects the steepness of the curves.

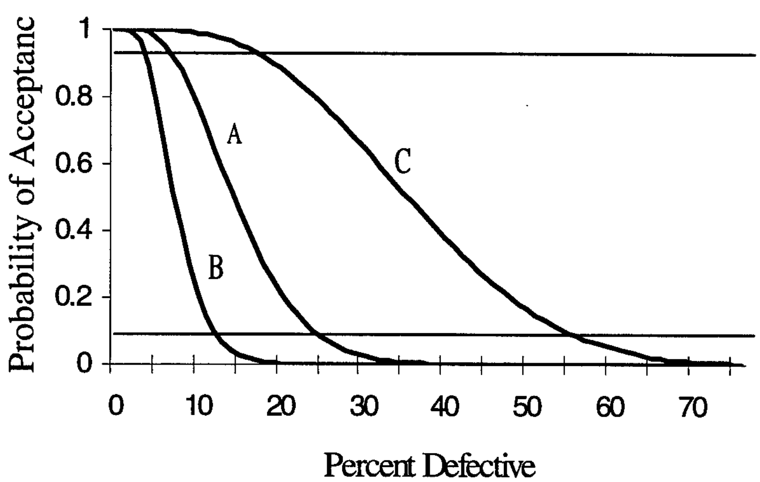


Figure 4. OC Curve with Changing Sample Size

The horizontal lines at the top and bottom of the chart again represent the α and β levels respectively. The intersection of these lines and the OC curves represent the AQL and RQL for each of the three variations. As opposed to a definite shift in the curves, these curves have more of a pivot to them with the pivot at the upper right corner. The actual values are approximated in Table 3.

Table 3. AQL/RQL for Increasing Sample Size

Plan	AQL	RQL
A	7.5	24
B	4.0	12.5
C	18	56

The change in this situation is not as prevalent with respect to AQL as the previous problem. RQL changes more noticeably. However, it is easy to see that the values do change. This situation would be easy to encounter during a real-world inspection. Suppose the inspector inspecting the mobility bags finds out that a coworker becomes ill during the inspection and must now also complete another set of evaluations. Strapped for time, the inspector decides to decrease the number of items to sample. The AQL/RQL values could increase greatly and, in this case, more than doubled. This means that the inspector is now willing to accept conforming populations that have significantly less quality. If the opposite occurs, and the inspector has extra time on a given day, he might decide to give a more thorough inspection and sample more items than planned. This reduces the AQL/RQL values and will force the acceptance of populations with higher quality.

The 10% Rule. The last possibility I would like to discuss is what I call the 10% rule. One of the rules of thumb currently in widespread use for determining sample size is to always sample 10% of the population. The OC curves in this case will represent a constant acceptance number of 3. However, the population size will increase and the sample size will increase accordingly to maintain a size of 10% of the population. Curves A, B, and C represent populations of 50, 100, and 200 respectively. Figure 5 shows the OC curves for this example.

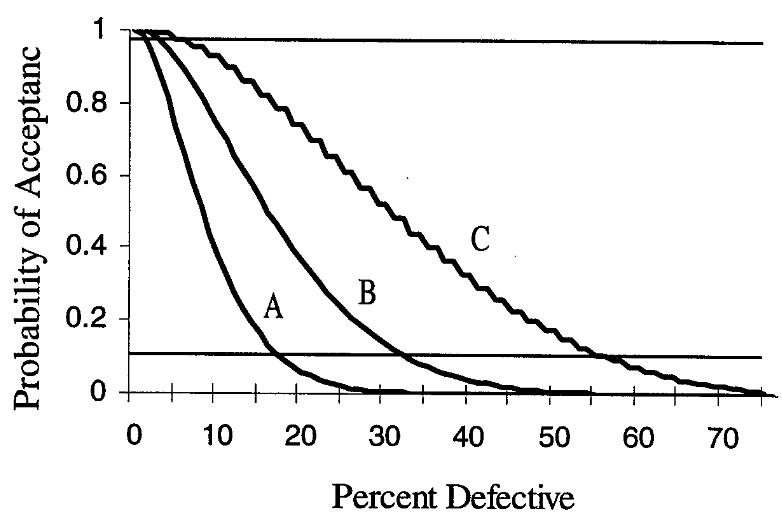


Figure 5. OC Curve with 10% Sample Size, Constant Acceptance Number = 3

The graphs again show a change in steepness. (The stair-step look for curve C is due to the small sample size and rounding in the computations due to the small sample and population sizes.) However, this time the graphs pivot to the right because of both an increase in population size as well as sample size. This figure illustrates the mistaken idea that if the ratio of sample size to population size is constant, the quality protection also remains constant (Wackerly and others, 1996:398-399). Table 4 shows the AQL and RQL for each of the curves.

Table 4. AQL/RQL for 10% Sample Sizes

Plan	AQL	RQL
A	1.5	17.5
B	2.5	32.5
C	5.0	57

As you can see, the AQL only changes slightly. However, it does change. The RQL changes drastically. So, the inspector who uses this technique will have far less quality protection as sample size increases. The absolute size of a random sample is much more important than its relative size compared to the population (Wackerly and others, 1996:400). Figure 6 contains OC curves for populations of 50, 100, and 200 using a constant sample size of 25 and an acceptance number of 1.

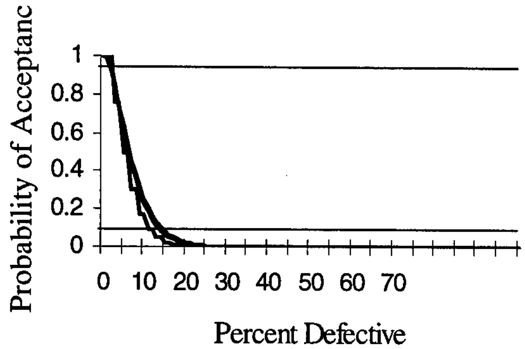


Figure 6. OC Curves Showing Constant Sample Size

The curves are so close together they are almost indistinguishable. If the inspector has any doubt about the sample size to use, the best alternative keep the sample size constant. This carries the assumption that a suitable plan was initially developed.

The value of $\alpha = .05$ and $\beta = .1$ are commonly considered standard in acceptance sampling literature and have proven useful in repeated use over time. Commonly, the two points used to specify the operating characteristic curve are the *AQL* and the *lot tolerance fraction nonconforming*. A supervisor can pick an acceptance plan that passes lots most of the time above a threshold he has picked (*AQL*) and rejects lots most of the time below another threshold he has chosen (*lot tolerance fraction nonconforming*). Note, however the AQL value was identified with a Type B curve, and the lot tolerance fraction nonconforming was identified with a Type A curve. Mathematically, this would only work if the lots are very large, and the Type A and B curves are virtually the same. If lot sizes are small the assumption of a Type B curve will be sufficient. A plan based on a Type B curve as applied to small lots will actually have a β value less than the one used in the acceptance plan's formulation, or the consumer's risk will be more conservative (Duncan, 1986:176).

2.4 Acceptance Sampling Plans

The literature identifies two types of sampling plans that utilize the operating characteristic curve discussed so far-- attributes plans and variables plans. In an attributes plan, a random sample is taken from a lot and each item is classified as a pass or fail. The number of fails is compared with the acceptance number, *c*, for the plan. If the total number of fails is above the *c* value the lot is rejected, if below, the lot is accepted. In a variables plan a random sample is again taken except a measurement of an identified characteristic is made on each item in the sample. The data from these measurements is quantified with a simple statistic, normally a sample average. The observed statistic is compared with a stated value from the plan and a pass or fail decision for the lot is made based on this comparison (Juran and Gryna, 1993:467). Acceptance sampling plans based on variables will not be used in this effort because of the requirements for prior information, complexity, and difficulty in application.

2.4.1 Attributes Plans

Attributes plans are based on single, double, and even multiple sampling of the inspected lot. Single sampling plans make a decision based on a single random sample taken from the lot and compare total defectives in the sample to an acceptance number, *c*.

In a double sampling plan, the number of items first inspected is less than a single sampling plan. The number of defectives found in the first sample is compared to two numbers, an acceptance number and a rejection number. If the total defectives in the first sample is less than or equal to the acceptance number the lot passes; if the total defectives is greater than or equal to the rejection number the lot fails. If the total defectives in the first sample falls between the two numbers, a second sample is taken and now the total defectives from both samples is compared to a new acceptance and rejection number. A multiple sampling plan flows along the same procedure except the number of samples required to make a pass or reject decision of the lot can exceed two (ASCQ 1993:6). The overall idea behind the double and multiple sampling plan is a decision of passing or failing a lot can sometimes be made sooner, or based on a smaller number of sampled items than a more traditional single sample plan.

2.5 Sequential-Sampling Plans

Double and multiple sampling plans try to make a decision on the lot earlier and thus lessen the size of the overall sample taken. If you consider a plan where the sample size is one and there is no limit on the number of samples taken, then you have a sequential sampling plan. This plan is the most efficient at minimizing the sample size and still obtaining a decision on accepting or rejecting the lot (Schilling, 1982:154).

2.5.1 Implementation

In a sequential sampling plan the sample is taken one item at a time from the lot. After each sample is taken a decision is made to accept the lot, reject the lot, or take another sample. The actual total sample size is not known until an accept or reject decision is made, so at the start of the plan the total sample size is unknown. The sampling plan is normally conducted using a chart as shown in Figure 7. The chart's horizontal axis is the number of sample items taken (n) and the vertical axis is the number of total defectives found by the n^{th} sample item. The parallel lines plotted on the axis delineate the reject and accept regions. The total number of fails are plotted as the sample size increases. As long as the plotted points stay between the two parallel lines, the process continues taking samples. Once a plotted point falls on or below the lower line, the lot is accepted. Conversely, when a point falls on or above the upper line, the lot is rejected. The computational method utilized to plot the parallel lines is attributed to A. Wald (1947:45-46).

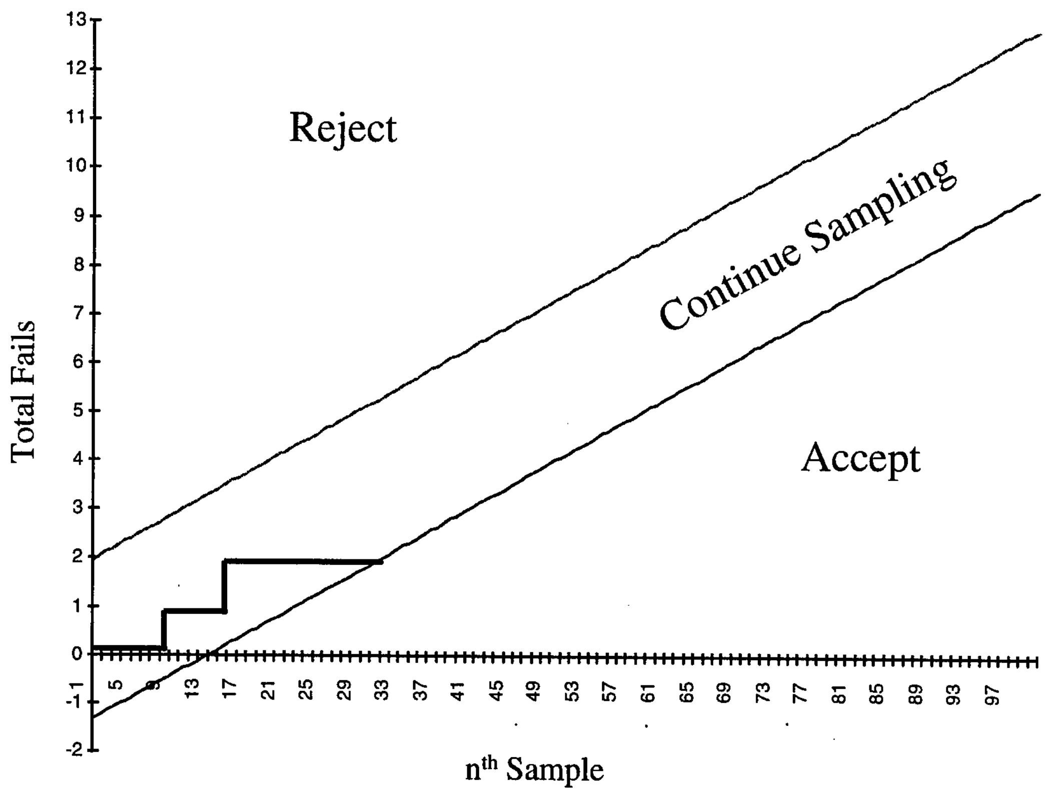


Figure 7. Sequential Sampling Chart

Wald starts with four values; α, β, and two proportions normally associated with an AQL value and a lot tolerance fraction nonconforming value. Wald's method then determines the acceptance and rejection boundaries that will satisfy the requirements of these four values and still produce an efficient sampling plan (Duncan, 1986:196).

2.5.2 Calculation

Given specified values of α, β, p_1' (normally the AQL), and p_2' (normally lot tolerance fraction nonconforming), Wald proves the acceptance and rejection regions are formed by the lines:

$X = -h_1 + sn$	acceptance limit for nth sample taken
$X = h_2 + sn$	reject limit for nth sample taken

where

$$h_1 = \log\frac{1-\alpha}{\beta} \Big/ \log\left[\frac{p'_2(1-p'_1)}{p'_1(1-p'_2)}\right]$$

$$h_2 = \log\frac{1-\beta}{\alpha} \Big/ \log\left[\frac{p'_2(1-p'_1)}{p'_1(1-p'_2)}\right]$$

$$s = \frac{\log\left[\dfrac{1-p'_1}{1-p'_2}\right]}{\log\left[\dfrac{p'_2(1-p'_1)}{p'_1(1-p'_2)}\right]}$$

(Wald, 1947:45-46)

2.5.3 Performance Measures

A sequential plan does have the potential to produce large sample sizes, but on average results in a 50 percent decrease in units inspected over single sampling plans (Barnes, 1993:324). A means of predicting the utility of a sequential plan is calculating the average sample number (ASN) curve for the plan. The ASN curve is a graphical representation of the average number of sampled units per lot used to make an accept or reject decision (Schilling, 1982:100). The average sample number is located on the vertical axis and the percent defective is located on the horizontal axis (Figure 8).

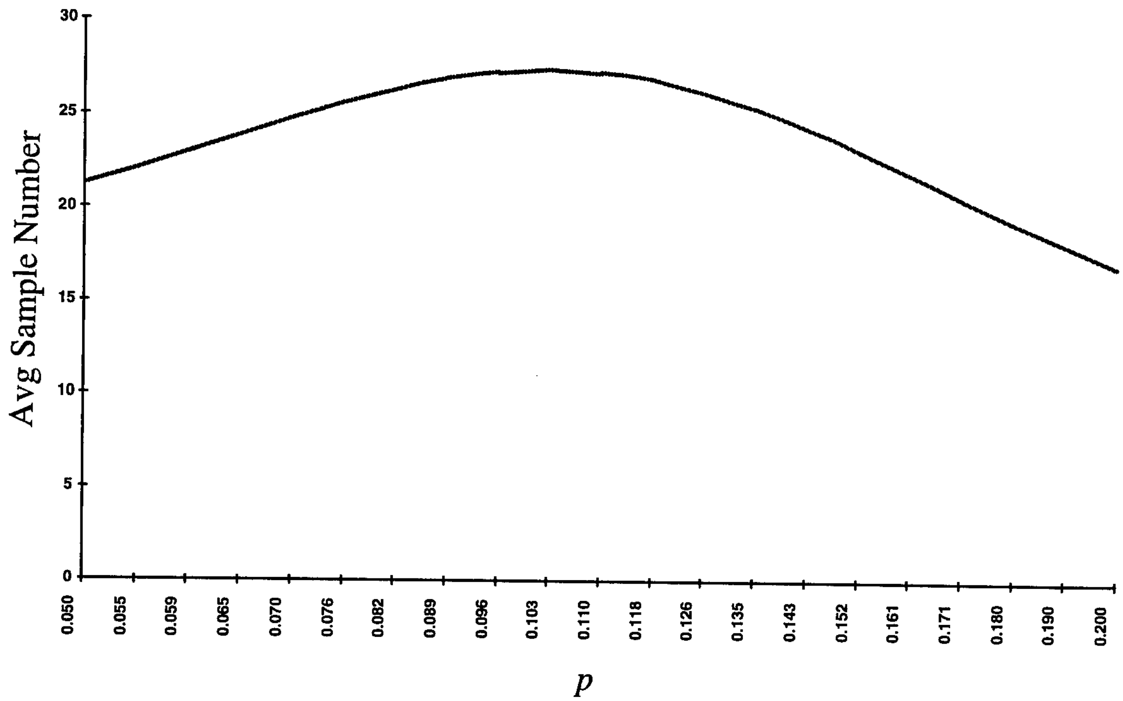


Figure 8. Average Sample Number Curve

The plotted values give an indication of the performance of the sequential plan at varied percent defectives. Duncan gives the computations for five points:

At $p' = p'_1$, $$ASN = \frac{(1-\alpha)h_1 - \alpha h_2}{s - p'_1}$$

At $p' = p'_2$, $$ASN = \frac{(1-\beta)h_2 - \beta h_1}{p'_2 - s}$$

At $p' = s$, $$ASN = \frac{h_1 h_2}{s(1-s)}$$

At $p' = 0$, $$ASN = \frac{h_1}{s}$$

At $p' = 1$, $$ASN = \frac{h_2}{1-s}$$

(Duncan, 1986:199)

These five points allow for an easy rough outline of the ASN curve. The sequential sampling plan leads to low average samples near the extreme values of percent defective, and yields a maximum somewhere between the p_1' and p_2'. It is entirely possible that in this region a sequential plan can lead to a larger sample than a single sampling plan (Duncan, 1986:199).

2.6 MIL-STD-105D.

This document was published in its first form in 1950 (Halpern, 1978:144). The document was developed for the military to control product quality for the procurement process. It has been modified since then and many other sampling schemes have been created with its foundation. It is a single source document that provides sampling procedures and tables for inspection by attributes. It consists of explanations for various types of inspection as well as definitions of the important terms with respect to sampling. All an inspector needs to know is the population size, the AQL desired, and the level of risk desired. The document contains look-up tables that tell the inspector the sample size and the acceptance number. Armed with a good, basic knowledge of the statistics behind the sampling plan, it is very easy for the inspector to use MIL-STD-105D or a document designed in the same manner to design sampling plans for their areas of inspection.

2.7 Characteristics of a Good Plan

Juran has designated certain elements that characterize a good acceptance plan (Juran and Gryna, 1980:418). The AQL/RQL used to define the quality must be based on the needs of the consumer and producer and not be selected for statistical convenience. The risks for error must be quantified and ensure protection from accepting bad lots or rejecting good lots. The plan should minimize the cost of inspection. Sampling should not create more problems than it solves. The plan should be flexible and able to adapt to changing conditions. The plan should utilize all information about the population in its design. The measurements required should be useful in estimating quality. Finally, the plan must be simple and easily explained and administered.

2.7.1 Inspector Pitfalls

There are also various areas that the inspector must be aware of when constructing and implementing a sampling plan. Construction has already been discussed, but there are some underlying assumptions of administering a plan that need to be highlighted.

2.7.2 Randomness

The sample is based on the fact that it must be taken randomly. Out of our 200 mobility bags, the first bag should have the same probability of being included in the sample as the last. Sampling bias is easily introduced if the sample is not random (Juran and Gryna, 1980:434). A simple method to ensure randomness is to assign a number to each individual item in the population. Next, use a random number generator to generate random numbers in an amount equal to the sample size desired. Those random numbers can then be matched up with the numbers given to each item in the population and the result is the random sample. It is easy to introduce bias into the sample. Some of the more common biases include (Juran and Gryna, 1980:434):

1. Always sampling from the same location in the container.
2. Previewing the product then only sampling the items that look either "good" or bad".
3. Always sampling the same batch (e.g. the first 20, the first ten and last ten, all the items produced by the least experienced people, etc.).
4. Avoiding items that are difficult to inspect.
5. These are just a few of the many ways an inspector can introduce bias. The objective is for the inspector to understand bias and take the necessary steps to avoid it.

2.7.3 Consistency

The inspectors must be consistent with their determinations. What is considered conforming and nonconforming must be standardized. An item that fails for Frank should also fail for Sue and all the rest of the inspectors responsible for evaluating that area. The methods of inspection must be the same from lot to lot of the same item. For example, our inspector should evaluate the mobility bags during the ORI at Scott the same way they were evaluated during the ORI at Travis. Without a standardized scheme for the individual items and across the inspectors, bias will be rapidly introduced and the system will be called unfair.

2.8 Sampling Procedures Based on Prior Information (Quality Data)

The question was raised as to how to utilize prior data in sampling strategies. Oliver and Springer (Juran and Gryna, 1980:434) have developed tables that are patterned after MIL-STD-105D that incorporate data on the quality of prior lots into the sampling tables. The plans fall under the category of Bayesian sampling plans. This method uses calculated parameters from past lots and define AQL, RQL, and the risk involved (α and β). The tables then provide sample size and acceptance criteria for the various plans. The steps are (Juran and Gryna, 1980:435):

1. Collect quality data on previous lots of size N and sample size n. Calculate the fraction defective, p, in each sample.
2. Calculate the average fraction defective (EQL or expected quality level) and the standard deviation of fraction defective using standard statistical formulas.
3. Define values for AQL, RQL, and the α and β.
4. Read the plan from the tables.

The Bayesian approach usually requires smaller sample sizes when compared to MIL-STD-105D. The Bayesian approach also requires a probability distribution for incoming quality levels which can be difficult to determine. There are various software programs that are available to aid this process, such as BestFit.

This theory has been slow to develop due to the difficulties with the probabilities of occurrence. Some people believe that the probabilities can be set based on subjective opinions about quality levels while others believe that they should be based on actual data. Many times this data is available but not in a usable form. The data must somehow be converted to probabilities of occurrence and this is where the difficulties lie. If it is not done quantitatively, it will be done intuitively by experts (Juran and Gryna, 1980:438). Therefore, with respect to the ORI, future study should be considered before adopting these practices.

3. METHODOLOGY

When the Blue Ribbon Commission mandated the ORI footprint reduction, their guidance on how to accomplish this included a greater reliance on sampling techniques. However, guidance did not include where - or at what level - the sampling should take place to reduce ORI footprints. For example, sampling could take place in specific subareas within the ORI inspection with all other subareas inspected under the old method. Another option would be to sample only specific items chosen by some method such that for each ORI the total amount of subareas is reduced. Finally, another approach would sample units within the command and sample subareas within the ORI; thus, each unit would not have a recurring ORI schedule and would not have specific subareas evaluated each time. Consequently, applying a technique to reduce inspector mandays during an ORI can be broad in scope.

3.1 Scope Definition

The office responsible for the regulation governing Inspector General activities is the Secretary of the Air Force (SAF)/Inspector General commanded by Lt. Gen Richard T. Swope. The Air Force Instruction (AFI) implementing Air Force policy on IG activities is AFI 90-201. A meeting with the commander on how extensively to use scientific based sampling techniques was conducted in July 1997. Lt. Gen. Swope focused the effort on the ORI only (Swope 1997); i.e., *the scope of sampling efforts should presently be within the actual inspection*. Specifically, the ORI will still be conducted with command directed recurrence, and all subareas presently inspected will continue to be inspected. The emphasis of our effort will be on identifying areas for employing sampling and establishing a technique for properly conducting such sampling. The parent AFI 90-201 from SAF/IG states in Chapter 3 under Operation Readiness Inspection Criteria, "Statistically valid sampling will be used wherever practical as an evaluation method (AFI 90-201 1997:5)". The command emphasis on sampling is evident and the context in which it is applied has been clearly stated; the objective of this research is to implement a theoretically valid and field tested approach for SAF/IG.

The most important part of the sampling problem was gaining acceptance for the idea throughout the Air Force. The IG was convinced that the idea would work; however, if the MAJCOM commanders remained skeptical, the idea would be never be put into practice. Such resistance would occur even though the Air Force IG operated at the Secretary of the Air Force level and was a three star general officer because such polices were general guidance and left open to variation by the individual MAJCOMs (examples of MAJCOMs are Air Mobility Command, Air Combat Command, and Air Education and Training Command.) Specifically, the Air Force IG establishes guidance for the inspection program, but leaves it to each individual MAJCOM to modify that policy and adapt it in a way that best suits their needs. Consequently, the Air Force IG could suggest sampling, but it was fully within the power of the individual MAJCOM to how to specifically utilize the capability. Thus, the usefulness of the sampling idea would be driven by the MAJCOM, and was evident that instituting this methodology would require being part statistician, part educator, and part salesman.

This research effort split the work between applying techniques to Air Combat Command (ACC) and Air Mobility Command (AMC). If we could successfully show applicability of the sampling idea to the ORIs of these two major MAJCOMs, the others would see that they could also benefit from their use.

3.2 Initial Briefings

We were immediately sent to brief the ACC and AMC IG teams for the purpose of introducing the sampling idea, begin the education process, and gain any feedback. We strongly believed that the best way to show the power of the sampling idea was to develop a real-world application. In December of 1996, Langley Air Force Base had completed the most recent ORI given by the ACC IG. During the course of the ORI, the wing flew 160 simulated combat missions. Every aircraft carries a videotape that records all of the engagements encountered during the sortie. For those missions, every tape was graded for mission effectiveness; of those, 2.5% (4 total) were graded as unsatisfactory, or nonconforming. Using those numbers and an AQL of 5% and RQL of 25%, we determined that the graded area could have effectively been evaluated using an acceptance sampling plan of sample size 13 and acceptance number of 2. (The RQL number was obtained by using the IG's employment standards and an α of 0.05 and a β of 0.10.) Obviously this showed a potentially huge amount of savings.

Furthermore, this was a very effective example. Each tape is 30 minutes long, which equates to 88 hours of time devoted solely to watching videotape. Although it is possible to fast forward the tape through periods of inactivity and not all tapes have recorded information that lasts the full 30 minutes, their inspections can have 2-4 evaluators assigned to tape grading. Under these conditions, a sampling plan allowing a 92.6% reduction in the number of tapes required for grading provides definite time savings potential.

In addition to the sampling plan demonstration, we knew there would be a problem with the understanding of error. To help visualize this, we developed a small simulation using SIMPROCESS. (Obviously, such a simulation is not necessary since we already knew the exact number of Type I and II errors. However, the simulation was useful as both a teaching tool and verification mechanism for the IG.) SIMPROCESS is a simulation language that contains a graphical user interface and is based on the MODSIM simulation language. The purpose of the simulation was to give the IG teams a visual example of the errors (α and β). Since the population was conforming, we knew that the probability of encountering a type II error was zero. We recreated the type I error by running the simulation 100 times. The sampling plan determined the population to be nonconforming 4 times out of the 100, as expected the level of α for the type I error set at 0.05.

There were many questions about the error. Initially the simulation only emphasized the point that errors will definitely occur. However, the main concerns came from the perspective of the commander being inspected. If the inspecting commander received an unsatisfactory grade, the argument of sampling error would always be available. Therefore, even though the possibility for error exists, the probability is very small; and, more importantly, completely controlled by the developer of the plan. This fact alone became a major selling point of the sampling strategy.

We gave a briefing at the Worldwide IG Conference in July of 1997. Since many of the same questions were asked by the Air Force's Inspectors General, it was evident that much of the effort of this project would be educational in nature.

3.3 Data Collection

The lack of data was a problem. While the research had a definite educational foundation, the reduction of mandays through the use of sampling techniques was still the driving force. Therefore, we visited for five days each at the IG offices at ACC and AMC. The time was spent searching records and interviewing various team members.

One potential difficulty was immediately confirmed--there was simply not enough adequate data for us to quantify manday reduction. Records were kept on team size, the number of personnel traveling with the team to a base, and the length of the inspection. While initial possibilities existed with this data, we realized that there was not enough detail. The data showed the total mandays for the inspection, but left no concrete data to help identify areas where cuts could be made. What was needed was data pertaining to the amount of time it took to complete each individually inspected item. (For example, we needed to know how much time it took for the inspector to inspect the mobility bags.) Since this data did not exist, we attempted to recreate it through interviews with various team members; but, these results were not accurate to the degree required. This led us to conclude that the only viable method was to accompany the team on an actual ORI. This would be accomplished at a later date.

The second aspect of the trip was to gain insight on the ORI process. While the regulations were available and we had our own personal experiences, we needed information from the perspective of the IG team member. Through these interviews, we confirmed two other suspicions about the ORI process. First, sampling was already being accomplished; and second, sampling had limited applicability to the ORI.

3.3.1 Established Sampling Practices

Members of the IG team were already using sampling procedures. The problem was that none had any basis in statistics and contained the same problems discussed in Chapter Two. The sampling scheme was left to the discretion of the individual inspector, with the 10% rule and 100% sampling frequently used. Another common method discovered was that the inspector would evaluate an arbitrary number of items, then make an overall assessment. If the results to that point were satisfactory, then the inspector was finished. If not, the inspector would continue looking at a few more items in a manner resembling a cross between acceptance and sequential sampling. However, this approach exemplifies the problem associated with changing the sample size discussed in Chapter Two.

Limited knowledge of random sampling was also observed. Many inspectors would attempt to randomly sample but lacked a method for doing so. Often they would sample from the very first items available, then move on to another area if satisfied. Statistically, the probability of choosing the first item was not equal to the probability of choosing the last. Consequently, even though "sampling" was attempted, education was necessary to ensure proper use. If nothing else, we could legitimize the sampling procedure.

3.3.2 Sampling Applicability to the ORI.

The use of sampling for many of the graded areas of an ORI has limited applicability. After all, we are trying to evaluate the capability of an Air Force unit to mobilize and fight a war, not evaluate light bulbs coming off an assembly line. For example, some of the activities involved are very time consuming. A simulated airfield attack scenario can take hours to complete, and there is simply not enough time to create a sufficient sample. Our entering premise is that we would not make the ORI process *longer*, which potentially could occur on many of the items inspected as one-time events. However, there are areas in the ORI where sampling will work. In fact, any area that has more than three items that can be graded will benefit from sampling (two examples are the tapes grading and mobility bags).

3.4 IG Tools

Following these visits, we decided that tools were needed to aid the IG team in the planning, construction, and use of statistical-based sampling. Since the IG selects its inspectors based on proven excellence in their fields, they are not quality control specialists or statisticians. The other constraint is that IG team duty is considered a tour of duty in the Air Force. This means that an individual normally serves on the team for approximately three years, with a work schedule that is extremely hectic and includes a lot of travel. Personnel turnover occurs regularly and team members simply do not have the time or the opportunity to become experts in sampling. Thus, we decided that a product that is easy to use and requires minimum training would be ideal for the IG team members. We also need a medium to provide the tool and allow some education opportunity to ensure its proper use. We decided to develop a spreadsheet program that would compute sampling plans based on IG defined inputs. We also published an internet site on the world wide web from which the spreadsheet could be downloaded, and guidance and education could be obtained.

We made several temporary duty trips throughout the study. Briefings and/or research were accomplished on each of the trips. Table 5 shows the number of days spent during each of the trips.

Table 5

Temporary Duty Days

Date	Site Visited	Lt Col Bailey	Maj Dixon	Maj Madgett
13 May 97		1		
16 Jun 97	SAF/IG	1	1	1
10 Jul 97	ACC/IG	1	1	1
13 Jul 97	AMC/IG		1	1
16 Jul 97	Worldwide IG Conf	1	1	1
14 Sep 97	AMC/IG		5	5
6 Oct 97	ACC/IG		5	
17 Dec 97	ACC/IG		1	1
24 Jan 98	Cannon AFB ORI		6	6
10 Feb 98	Worldwide IG Conf		1	1

3.5 ORI Modifications for Effective Sampling

Identifying the proper areas for a sampling technique is the first step. Currently, sampling is conducted in the ORI; Table 6 represents the broad range of areas mandated by regulation and used by inspectors as a technique to assign a grade. This list is not inclusive--the total number of areas sampled can fluctuate from one inspection to another depending on unique circumstances with a unit. This list can always be expanded, maintained, or reduced; however, the bottom line is areas must be identified first so objective risk levels and quality limits can be determined.

Table 6

Sampled Areas in ORIs

ORI Phase I	ORI Phase II
Alert Recall	Control of Maintenance
Weapons	Control of Operations
Command and Control	Maintenance Support
Pallet Loads	Ground Release Reliability Checks
Command Post	Missile System Reliability
Personnel Processing	Avionics Systems Reliability
Security Awareness	Combat Sortie Effectiveness
Aircraft Generation	Sortie Evaluations
Mobility Bags	Aircrew Chemical Defense Operations
Aircraft Munitions Procedures	ICT Procedures

A key concern in identifying these areas is the "pass" or "fail" grade eventually assigned. The present five-tier grading system cannot be applied to a sampled area. This thesis presents techniques based on the pass or fail of each sampled item and cannot distinguish anything more than a pass or fail for the sampled population. If the sampled area is the only item inspected in a subarea traditionally receiving a five-tier grade, the new grading standard must be modified to pass / fail. However, subareas possessing other inspected inputs in addition to the sampled area can still receive a five-tier grade. The pass or fail grade merely factors into the other inputs for determining the grade. The sampling principles discussed are only applicable to a pass / fail grading system. The present ORI grading system is fairly complex, with many grades conditional on the grades of other subareas; a pass or fail can easily affect other, non-sampled, areas.

Next, identify for sampled areas the evaluation measures to assign the grade on each individually sampled item. This should not require much effort; since all areas currently have a measure of performance establishing a five-tier grade, it simply needs to be redefined in terms of pass / fail. For example, a process could combine what was a satisfactory and above into a pass, and marginal and below into a fail. Often an area or process is evaluated (including perhaps some sort of sampling) then, based on those results plus other actions witnessed by the inspector, a subjective grade is given. In terms of differentiating between objective and subjective, objective is defined as explicitly stating what constitutes a pass and fail. The more common subjective criteria relies on the inspector's expertise to determine if an area is acceptable within regulatory guidance or standards (these standards are not explicitly written in the ORI regulation). In the case of subjective evaluation, the inspector can still apply sampling techniques with a subjective pass/fail call made on each individually sampled item. However, the same inspector should remain throughout the entire sample so the equivalent subjective criteria is applied to each item across the population. Since it is not uncommon for different inspectors to grade the same item differently, a constant criteria for evaluation will prevent this corruption of the sampling process.

Once areas are identified for sampling and the criteria for judging a pass or fail is determined, the input parameters for the sampling plan must be selected. The inputs consist of population size, level of risk (Type I and Type II), acceptance quality level, and the lot-tolerance fraction nonconforming (called the rejection quality level). The population size is straightforward; it is the total amount of items in the area sampled. Often in an ORI the population might be an area that is scheduled only at the beginning; for example, the Integrated Combat Turn (ICT). The actual value of the population will not be known until the end of the inspection. If a sample is based on the scheduled or planned population, the actual population will usually be equal to or less than the planned total. Therefore, the sample size, while not the most efficient, will be conservative in nature and not introduce more risk than necessary. Typically, ORIs rarely increase in length once initiated.

The next input parameter is the level of risk desired for the sample. This constitutes the alpha value for Type I error and beta for Type II error as previously discussed. The industry standards of alpha equal to .05 and a beta equal to .1 are generally accepted both as having withstood the test of time and for being the most efficient. Smaller values will reduce the level of risk, but will also increase sample sizes (dramatically in some cases).

The third parameter is the acceptance quality level (AQL). This level is simply defined as the threshold percentage defective you want to pass within the stated risk limit.

The graph in Figure 3 shows the relationship between AQL, probability of acceptance and the selected alpha risk on the operating characteristic curve.

The last parameter is the rejection quality level or RQL. The RQL is the percent defective you want to fail within the stated risk limit. The graph in Figure 3 also shows the relationship between RQL, probability of acceptance, and beta risk on the operating characteristic curve. An example in applying these parameters can be a population of 100 mobility folders for deploying personnel needing grading. It is desired that if the true quality of folders is a 95 percent pass, then you want the overall population to pass with high probability; if the folders have an 80 percent or below pass rate, you want the overall grade to fail with high probability. Therefore, with a population of 100, the AQL is 1-.95 = .05, and the RQL is 1-.8 = 0.2.

3.5.1 Random Sampling

The big driver behind any sampling strategy is that the sample must represent the parent population. The way to maximize the probability that the sample is representative is to pick a truly random sample, which is defined as each item having an equal probability of being selected. Often in the course of an ORI, the inspected portion is not truly representative of the whole. Commanders will game the system by putting their best forward or controlling who or what is seen. Inspectors will focus their sampling in the front half of the inspection, and evaluate less or none at all in the last portion. True randomness dictates items chosen for evaluation span the entire length of the ORI or come from all portions of the population. There are many techniques to insure randomness, from drawing the selected sample out of a hat to computer driven random number generators. The method chosen by this effort will be described later in the explanation of a spreadsheet based acceptance sampling guide.

3.5.2 AQL, RQL Selection Considerations

The proper selection of an AQL and RQL value depends on several considerations, the most important being the quality desired in the inspected area. These values should be set to the maximum extent possible at the levels considered acceptable and unacceptable. *The point to remember is the area is now being judged as pass or fail only.* A performance level that before was considered only satisfactory or marginal must be evaluated in a pass / fail framework, where it might be considered acceptable for a pass. This perspective comes into play in the relative range between the AQL and RQL values; the closer these values are, the larger the sample size will grow. This makes intuitive sense because you are making a more precise determination. For example, if you decide that 90 percent is the critical value for both AQL and RQL, below 90 percent is unacceptable and above 90 percent is acceptable. The only way to insure a sample can make this precise a determination within these risk limits is to sample nearly the entire population. As you are willing to make a less precise determination using different RQL and AQL values, then the sample size will decrease. Thus, the relative range between the AQL and RQL is directly related to sample size in that as the range grows the sample size will decrease. While, it is possible to choose AQL and RQL values close enough to each other such that the sample size equals the population, no acceptance sampling plan exists for these input parameters. In this case, your quality levels requires you to evaluate the entire population. In practice the task is a balance between a desire to set stringent quality levels and the requirement to make a pass or fail determination based on a sample from the population. One solution is to vary quality levels and calculate the acceptance sampling plans, then compare the tradeoff between quality levels and sampling feasibility.

The AQL quality level can also function in terms of a quality control. Often the sampled area or process is one where performance is measured and reported routinely either to the local command structure or a higher headquarters (e.g., performance measures in aircraft maintenance, weapons effectiveness in training sorties). If acceptable, the reported rate can be used as the AQL value and will function to control performance. Specifically, if the unit reports a rate higher than the true rate, it will lessen their chances of a pass when an acceptance sampling plan is applied. Conversely, if the unit reports a rate lower rate than the true rate, it would increase their chances of a pass; however, the decrease in the reported rate will often draw attention from higher level commanders. The net effect of using the reported rate as the AQL influences units into more accurate reporting.

3.6 Acceptance Sampling Spreadsheet Guide

The next step is to effectively calculate an acceptance sampling plan given the four inputs: population, risk levels, AQL, and RQL. The task is easily done using the help of a computer and a spreadsheet application. The appropriate probability distribution for use in an isolated lot (such as a specific unit's ORI) is the hypergeometric. However, since this distribution is computationally cumbersome approximations are often used instead of actual calculations. Schilling lists the criteria for using approximations in terms of two variables, the sample size and the actual percent defective. A portion of Schilling's list is represented in Figure 9.

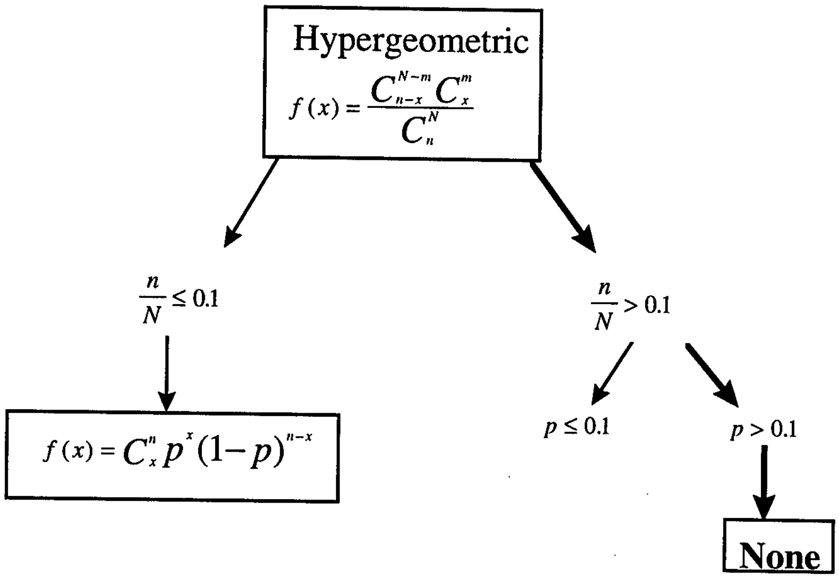


Figure 9. Hypergeometric Approximations

(Schilling, 1982:65)

In the case of an ORI, the sample size will most often exceed one tenth of the population. However, the percent defective can exceed 0.1, so the use of any approximation for the hypergeometric distribution is not warranted.

Schilling handles this situation with an iteration technique that starts with a conservative approximation based on the input parameters, then steps down through varying sample sizes and acceptance numbers to find the most efficient sampling plan (Schilling, 1982:119). Given the input parameters, the first step in the iterative technique is identifying an approximation using an analogous Type B plan. Schilling suggests starting the iteration with a binomial plan's sample size and acceptance number meeting the desired inputs. Acceptance plans based on the binomial distribution are usually graphical in nature and don't offer much use for calculations on an automated spreadsheet. Instead a Poisson distribution approximation producing a sample size and acceptance number is used to start the iteration technique. Sampling plans based on the Poisson distribution give excellent approximations to a binomial based plan (Schilling, 1982:112). Values for the Poisson based sampling plan can be easily accessed in data tables. These tables list various sampling plans based on a operating ratio, R and alpha and beta risk levels. The value $R = RQL/AQL$ is calculated as the primary lookup value to determine the correct row within the correct data table. The value of R for the correct row is the value equal to or just less than the calculated R value. The correct table is based on the risk levels. This identified row yields the starting acceptance number c and the value np, which when divided by the AQL yields the starting sample size (Schilling, 1982:113). The lookup tables are presented in Table 7. With starting values c and n, the iterative technique then calculates the number of defective units that would exist at a percent defective equal to the AQL and RQL, called D_1 and D_2 respectively. The values of c, n , D_1, and D_2 are used to calculate two cumulative hypergeometric probabilities. The spreadsheet lists the value of c as x. The cumulative hypergeometric probability is

Table 7

Poisson Approximation Tables (Schilling, 1982:619)

Values of p_1/p_2 for:				
alpha = .05 beta = .1	alpha = .05 beta = .05	alpha = .05 beta = .01	np_1	c
1.521	1.596	1.743	38.965	49
1.527	1.603	1.752	38.082	48
1.534	1.611	1.763	37.2	47
1.541	1.619	1.773	36.32	46
1.548	1.628	1.784	35.441	45
1.556	1.637	1.796	34.563	44
1.564	1.646	1.807	33.686	43
1.572	1.656	1.82	32.812	42
1.581	1.666	1.833	31.938	41
1.59	1.676	1.846	31.066	40
1.599	1.687	1.86	30.196	39
1.609	1.698	1.875	29.327	38
1.619	1.71	1.89	28.46	37
1.63	1.723	1.906	27.594	36
1.641	1.736	1.923	26.731	35
1.653	1.75	1.941	25.87	34
1.665	1.764	1.96	25.01	33
1.679	1.78	1.98	24.152	32
1.692	1.796	2.001	23.298	31
1.707	1.813	2.023	22.444	30
1.723	1.831	2.046	21.594	29
1.739	1.85	2.071	20.746	28
1.757	1.871	2.098	19.9	27
1.775	1.893	2.127	19.058	26
1.795	1.917	2.158	18.218	25
1.817	1.942	2.191	17.382	24
1.84	1.969	2.226	16.548	23
1.865	1.999	2.265	15.719	22
1.892	2.03	2.307	14.894	21
1.922	2.065	2.352	14.072	20
1.954	2.103	2.403	13.254	19
1.99	2.145	2.458	12.442	18
2.029	2.192	2.52	11.633	17
2.073	2.244	2.588	10.831	16
2.122	2.302	2.665	10.035	15
2.177	2.367	2.752	9.246	14
2.24	2.442	2.852	8.464	13
2.312	2.528	2.968	7.69	12
2.397	2.63	3.104	6.924	11
2.497	2.75	3.265	6.169	10
2.618	2.895	3.462	5.426	9
2.768	3.074	3.707	4.695	8
2.957	3.303	4.019	3.981	7
3.206	3.604	4.435	3.286	6
3.549	4.023	5.017	2.613	5
4.057	4.646	5.89	1.97	4
4.89	5.675	7.352	1.366	3
6.509	7.699	10.28	0.818	2
10.946	13.349	18.681	0.355	1
44.89	58.404	89.781	0.052	0

Values of p_1/p_2 for:				
alpha = .01 beta = .1	alpha = .01 beta = .05	alpha = .01 beta = .01	np_1	c
1.691	1.775	1.938	35.032	49
1.701	1.785	1.952	34.198	48
1.71	1.796	1.965	33.365	47
1.72	1.808	1.98	32.534	46
1.731	1.82	1.994	31.704	45
1.742	1.832	2.01	30.877	44
1.753	1.845	2.026	30.051	43
1.765	1.859	2.043	29.228	42
1.777	1.873	2.06	28.406	41
1.79	1.887	2.079	27.587	40
1.804	1.903	2.098	26.77	39
1.818	1.92	2.118	25.955	38
1.833	1.936	2.139	25.143	37
1.848	1.954	2.162	24.333	36
1.865	1.973	2.185	23.525	35
1.882	1.992	2.21	22.721	34
1.9	2.013	2.236	21.919	33
1.92	2.035	2.264	21.12	32
1.94	2.059	2.293	20.324	31
1.962	2.083	2.324	19.532	30
1.985	2.11	2.358	18.742	29
2.009	2.138	2.393	17.957	28
2.035	2.168	2.431	17.175	27
2.064	2.2	2.472	16.397	26
2.094	2.235	2.516	15.623	25
2.126	2.272	2.564	14.853	24
2.162	2.313	2.615	14.088	23
2.2	2.357	2.671	13.329	22
2.241	2.405	2.733	12.574	21
2.287	2.458	2.799	11.825	20
2.337	2.516	2.874	11.082	19
2.393	2.58	2.956	10.346	18
2.455	2.652	3.048	9.616	17
2.524	2.732	3.151	8.895	16
2.603	2.823	3.269	8.181	15
2.692	2.927	3.403	7.477	14
2.795	3.047	3.559	6.782	13
2.915	3.188	3.742	6.099	12
3.058	3.354	3.959	5.428	11
3.229	3.555	4.222	4.771	10
3.44	3.803	4.548	4.13	9
3.705	4.115	4.962	3.507	8
4.05	4.524	5.506	2.906	7
4.52	5.082	6.253	2.33	6
5.195	5.889	7.343	1.785	5
6.249	7.156	9.072	1.279	4
8.115	9.418	12.202	0.823	3
12.206	14.439	19.278	0.436	2
26.184	31.933	44.686	0.149	1
229.105	298.073	458.21	0.01	0

the sum of the hypergeometric probabilities for $x = 0, 1, \ldots, c$. The first cumulative probability is the probability of acceptance at the AQL based on the probability of getting c failures or less in a random sample of size n, taken without replacement from a lot equal to the population size in which D_1 are failures. This value is then compared to the desired alpha risk. If the cumulative probability is F(x), then to meet the alpha risk level,

$$F(x) \geq 1 - \alpha$$

The second cumulative probability repeats the same calculation except for using the number of failures at the RQL value, D_2. In order to meet the beta risk level,

$$F(x) \leq \beta \text{ at } D_2$$

If these two inequalities hold the sample and acceptance number are feasible, but possibly not the most efficient. Thus, the sample size is reduced by one and the calculations repeated. This process continues until one or both of the inequalities fail; then, the sample size is increased by one while the acceptance number drops by one. The process then repeats. This iterative technique identifies the most efficient sampling plan meeting desired risk and quality levels (Schilling, 1982:113). A sample calculation from the spreadsheet Excel® is in Figure 11, while Figure 10 presents the algorithm. (At the time of this writing, the spreadsheet has not been validated at an actual inspection.)

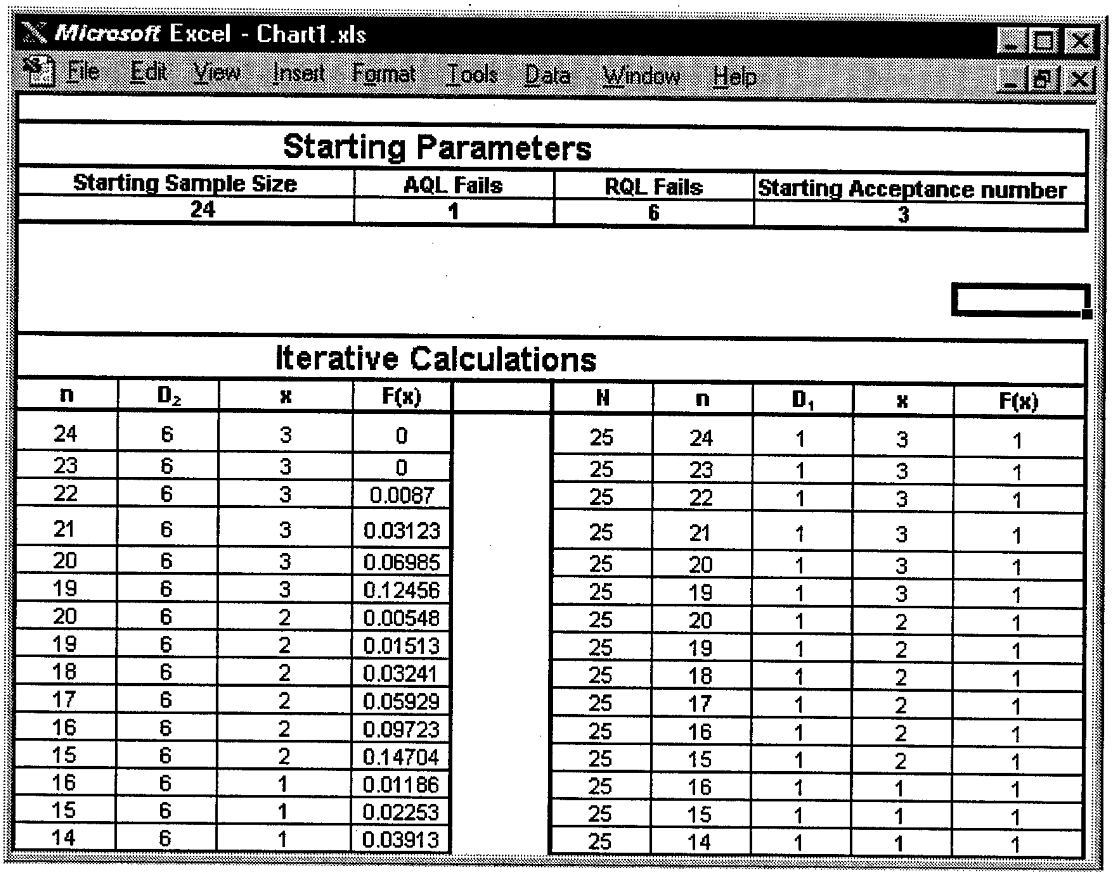
The most efficient sampling plan allows an inspector to make a judgment on a target population, control risk and quality levels as he or she desires, and have a sound mathematical basis for conclusions that are credible and defensible.

Find most efficient sampling plan given inputs

INPUT	population size (N), *AQL*, *RQL*, α, β
OUTPUT	acceptance number (c) and sample size (n)

Step 1	Determine operating ratio $R = RQL/AQL$
Step 2	Access Poisson Approximation table, find appropriate plan based on R, α, β
Step 3	Table provides starting c, and $nAQL$. Starting $n = nAQL/AQL$
Step 3a	If Poisson Approximation table does not have a starting plan, use a plan of $c = (N)(RQL)$ rounded to nearest integer, and $n = N\text{-}1$
Step 4	Determine number defectives at *AQL* called D_1, $D_1=(N)(AQL)$
Step 5	Determine number defectives at *RQL* called D_2, $D_2=(N)(RQL)$
Step 6	Round D_1, D_2 to nearest integer
Step 7	Calculate cumulative hypergeometric probability $F_1(x)$ based on $x = c, N, n$, and D_1
Step 8	Calculate cumulative hypergeometric probability $F_2(x)$ based on $x = c, N, n$, and D_2
Step 9	Evaluate $F_1(x) \geq 1\text{-}\alpha$ and $F_2(x) \leq \beta$, if both inequalities are true then $n = n\text{-}1$
Step 10	If either inequality is false then $c = c\text{-}1$ and $n = n + 1$
Step 11	Do not further reduce c, until a sample size n produces inequalities that are true. Successively drop the sample size and recalculate $F_1(x)$ and $F_2(x)$ until it is confirmed the inequlities do not hold for all smaller values of n.
Step 12	If $n = 0$ then STOP the most efficient plan is the smallest value of c and n in which the inequalities hold, if the inequalities do hold for a smaller value of n then return to Step 7.

Figure 10. Spreadsheet Algorithm



Microsoft Excel - Chart1.xls

File Edit View Insert Format Tools Data Window Help

Starting Parameters

Starting Sample Size	AQL Fails	RQL Fails	Starting Acceptance number
24	1	6	3

Iterative Calculations

n	D_2	x	F(x)		N	n	D_1	x	F(x)
24	6	3	0		25	24	1	3	1
23	6	3	0		25	23	1	3	1
22	6	3	0.0087		25	22	1	3	1
21	6	3	0.03123		25	21	1	3	1
20	6	3	0.06985		25	20	1	3	1
19	6	3	0.12456		25	19	1	3	1
20	6	2	0.00548		25	20	1	2	1
19	6	2	0.01513		25	19	1	2	1
18	6	2	0.03241		25	18	1	2	1
17	6	2	0.05929		25	17	1	2	1
16	6	2	0.09723		25	16	1	2	1
15	6	2	0.14704		25	15	1	2	1
16	6	1	0.01186		25	16	1	1	1
15	6	1	0.02253		25	15	1	1	1
14	6	1	0.03913		25	14	1	1	1

Figure 11. Screen-Shot of Calculation Sheet

3.7 Sequential Sampling Spreadsheet Guide

Often the population in question has all items immediately available for random selection. A classic example is the inventory of mobility bags for an inspected unit. There is another technique available for sampling that can yield smaller sample sizes for the same risk and quality levels. However, it is only an option when the entire population is immediately available for random sampling as in the mobility bag case described. The above described acceptance sampling plan calculation technique will yield the most efficient plan, but a sequential sampling plan can produce a conclusion in a smaller sample, thus saving even more time. The production of a sequential plan merely plots two lines formed by formulas already described in Chapter Two. The inspector using a plotted sequential plan can trace the total failures during the inspection and stop the inspection once the results cross the "pass" line or "fail" line. A computer spreadsheet can easily calculate the slope *s*, and the intercept h_1 and h_2 of these lines based on the inputs of AQL, RQL and risk levels. The lines are then plotted for a number of points on a horizontal axis equal to the actual population size, thus accounting for the slim possibility the actual total sample size becomes large. An example of an Excel® generated sequential sampling plan for application by an inspector is shown in Figure 12.

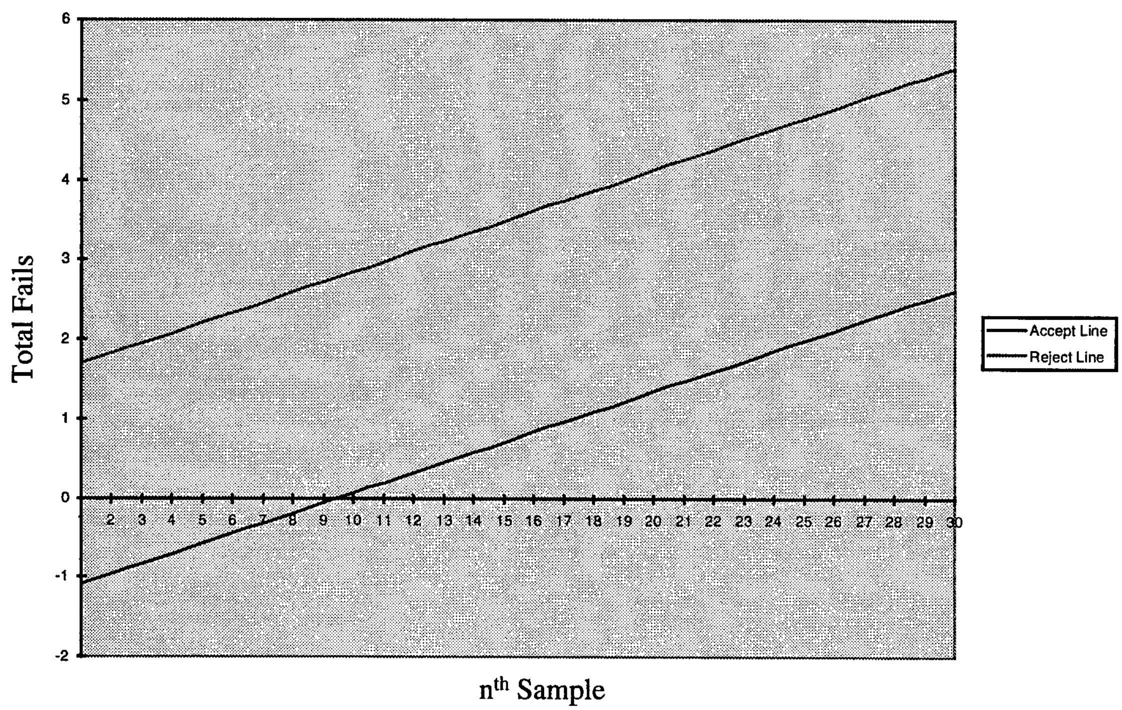


Figure 12. Sequential Sampling Chart

The application of a sequential plan is predicated on every item in the population being available for random selection. Many areas sampled in an ORI are events or processes that span the length of the ORI. Sequential sampling is not a valid technique in this case because as you take another individual sample, all unchosen items are not equally likely for selection since portions of the population are not available.

The integrated combat turn (ICT) is a fine example of a process in which sequential sampling does not have application. During the ORI, as many as seventy ICTs will be performed by a fighter squadron; if you try to apply sequential sampling, only the next ICT is a candidate for evaluation. Since the remainder have not occurred and the ICTs already performed are not available for selection, all ICTs do not have an equal chance of being selected for the next item sampled in the sequential plan.

3.8 Pre Inspection Planning

The total effectiveness of a scientific based sampling strategy rests on good pre-inspection planning in which areas for sampling are identified early. The parameters for each of the sampled areas should be carefully selected (except for the population size). Occasionally the population is known ahead of time; if not, it can be can be determined just prior to the actual inspection. The proper technique should be selected and a computer spreadsheet run to calculate the actual plans. In the ORI, the inspector identifies the items to randomly select, administers the plan, and reports the results.

The determination of a random sample can also be accomplished through a computer spreadsheet. The spreadsheet takes the desired sample size and generates a list of random integers, with no repetitions and no numeric value larger than the population size. These random numbers are then matched with the population that is numbered from one to total population size. The matching set indicates which items in the population to select for a random sample. The spreadsheet can also generate a single random number for a sequential plan, taking into account which have already been selected.

A small collection of acceptance and sequential plans that could have direct applicability in the ORI environment is located in Appendix A. Each plan includes all input parameters and associated OC curves, and the sequential plan also includes an Average Sample Number chart. Appendix B contains enough information to reproduce the Excel® spreadsheet file.

3.9 The Web Site

A web site was developed using Microsoft FrontPage. FrontPage uses a graphic interface and point-and-click technology that allows the user to author web pages without actually writing HTML code. The web site is at the Air Force Institute of Technology Server and has a compact tutorial about sampling and simple single sampling plans. Background information is also included that mirrors the information contained in this paper. The visitor has the capability to download the two theses written on this topic, as well as two different versions of the spreadsheet application. An active link exists to the Air Force Inspector General's web site and future plans are for that office to eventually take over the management of the sampling site.

4. RESULTS

In developing of sampling techniques for application in ORIs, the primary measure of effectiveness is manday reduction. The Blue Ribbon Commission states:

> NLT October 1997, reduce the ORI footprint (as measured by number of inspector mandays on the installation). Such practices may require greater reliance on carefully selected "sampling" and other techniques to assess mission performance... Reduction goal is 30 percent in FY99. Interim goal is 10 percent in FY98. (BRC 1997:33)

An effective sampling technique will reduce the amount of inspectors required for evaluating selected areas, reduce the number of total inspectors required on an ORI, and reduce inspector mandays at a Unit. Validating a sampling technique requires monitoring an ORI utilizing current inspection standards and then applying the technique to the sampled areas. The amount of time saved between current practices and the sampling technique measures the true effectiveness. This validation procedure was performed during a Phase I ORI conducted by the ACC IG team during the last week of January 1998.

4.1 Validation

4.1.1 IG Manday Considerations

The Phase I ORI was conducted in conjunction with an actual deployment of one fighter squadron to the Southwest Asia Area of Responsibility (AOR). The unit, Cannon AFB, requested the inspection of their real-world deployment in order to prevent practicing for a simulated deployment and subsequent inspection of a simulated scenario at a later date. (Until recently, inspecting a real-world deployment never satisfied the requirements of an ACC IG Phase I. The Blue Ribbon Commission changed that philosophy and it is now becoming a standard practice.) A typical ACC ORI Phase I conducted under a simulated scenario lasts three days. However, the schedule of departing cargo aircraft prolonged this particular deployment to 5 days. Furthermore, at Cannon's request, the footprint of IG mandays had increased significantly. The length of the Phase I was again increased when the actual deployment of the fighter squadron was canceled because of developments in the Middle East (this occurred the night before the inspection was scheduled to start). The IG and unit commanders reached an agreement to continue the ORI under a modified plan based on the original inspection. The net effect of this change was another day added to the inspection.

The primary measure of effectiveness, mandays, was now artificially large. The comparison of the Cannon Phase I ORI with and without sampling techniques would not show a true representation of manday reduction because the original figure is now inflated. (Cannon's motivation in making this counter-intuitive request is because it saves a considerable amount of effort in the long run, since the fighter squadron will deploy whether the IG is present or not.) Therefore, we validated our approach by substituting manday reduction with pure time savings. Unfortunately, no other ORIs were available for validation within the time window of this project; however, if the sampling technique can be shown to save considerable time, then a manday reduction can be inferred as well.

4.1.2 Sampled Areas

The Phase I ORI is primarily a deployment of personnel and aircraft; the number of areas in the inspection is limited as compared to a longer Phase II. In the case of Cannon's Phase I, certain areas that would be available for inspection in an artificial scenario were not applicable in a real-world deployment. Thus, the corresponding list of areas appropriate for sampling is also reduced. The list of applicable areas is listed in Table 8.

Table 8

Cannon ORI Sampled Areas

Area Inspected	Description
9mm Pistols - Function	Proper Functioning of all deployed 9mm Pistols
9mm Pistols - Documentation	Proper Documentation of Deploying Weapons
Mobility Bags	Proper Contents of Deploying Mobility Bags
Command Post - SORTS	Proper Content and Documentation of SORTS Reports
AMMO Loading	Proper Loading of Ammunition in Deploying Aircraft
C5 Pallet Load	Proper Loading of pallets on C5s
C141 Pallet Load	Proper Loading of Pallets on C141s
Mobility Folders	Proper Documentation in Deploying Mobility Folders
Personnel Processing	Proper Handling of Deploying Personnel
Aircraft Acceptance	Proper Preparation of Deploying Aircraft

Inspectors in the majority of the sampled areas were monitored to ascertain if random samples were taken. In most cases, 100 percent of the population was sampled; therefore, random sampling was not an issue, except for mobility folders. In this case, we noted that the inspectors biased their selection toward the first half of the available population. Inspectors were asked to make a pass or fail determination on each sampled item, and record the results and total time for the evaluation. Normally, individual item results are only documented, if at all, in remarks below a five-tier grade in the final inspection report. However, the inspectors commented this change in how they graded their evaluation was not significant, although it was critical for our comparison purposes. The results of their samples are shown in Table 9.

Table 9

Cannon ORI Sampled Areas - Results

Area Inspected	Population	Sample	Passes	Fails	Time (min)
9mm Pistols-Function	24	4	4	0	30
9mm Pistols-Documentation	24	24	24	0	15
Mobility Bags	267	26	25	1	35
Command Post-SORTS	20	20	0	20	75
AMMO Loading	18	4	4	0	240
C5 Pallet Load	57	57	56	1	109
C141 Pallet Load	17	17	17	0	40
Mobility Folders	281	96	90	6	180
Personnel Processing	281	281	262	19	1200
Aircraft Acceptance	23	23	19	4	920

4.1.3 Time Savings

The appropriate acceptance sampling plans were then calculated for the areas listed in Table 5. The inputs for each area consists of the given population size, an alpha risk of .05, a beta risk of 0.1, and AQL and RQL values of .05 and 0.25 respectively. The risk limits are considered fairly standard, though we note that lower risk levels will increase the sample sizes, and thus lessen time savings. While the quality levels depend on an inspector's values, the listed values approximate regulatory guidance as listed in the ACC IG AFI 90-201. Specifically, when the guidance lists a five-tier grade, the AQL of .05 (a 95 percent pass rate) translates to an Outstanding or Excellent grade. Similarly, the RQL of 0.25 (a 75 percent pass rate) represents a low satisfactory or below grade. Different quality levels will obviously effect sample sizes and time savings, but as a base line comparison these parameters will show the capability of the technique.

Once the appropriate acceptance plan was calculated, a determination was made if the sampled area would have also passed or failed using the acceptance plan. The results mirrored the conclusions of the IG inspectors in all cases except one, aircraft acceptance. In all areas except three (mobility folders, personnel processing, and aircraft acceptance) the acceptance plan produced the same outcome -- either all items passed, all failed, or the number of failures was less than the calculated acceptance number. Although an analytical solution is available, the IG organization requested a simple simulation to show the reliability of the acceptance plan. A small Monte Carlo simulation was performed. Two of the three remaining areas whose total number of failures exceeded the acceptance number were evaluated using a random draw from the population with the failed items identified and constant throughout all the runs. A total of one hundred repetitions were made. If the total fails in the random sample was less than the acceptance number, the area passed. The results of these simulation runs are located in Table 10.

The third area not evaluated, aircraft acceptance, was not applicable for a Monte Carlo simulation. The present way aircraft acceptance is graded is not directly based on total passes and fails, but on generating a set number of aircraft in a given time period. Aircraft failed at one point can be accepted later, and as long as the required number of aircraft is generated on time the grade is passing. The acceptance sampling plan was generated as an example for grading this area if a standard based on passes (not time) is instituted. A simulation of this inspected area with four failures out of twenty-three will have a high failure rate if the unit actually generated their required aircraft on time and passed. The sampled areas with failures in excess of a calculated acceptance number are listed in Table 10. The table shows the number of repetitions in the simulation and overall pass rate.

Table 10

Pass Rates for Random Draws

Sampled Area	**Repetitions**	**Pass rate**
Mobility Folders	100	100%
Personnel Processing	100	93%
Aircraft Acceptance	N/A	N/A

Considering the inspection is only conducted once, the results in Table 10 show the probability is very high that the acceptance plan will produce the same results as the IG inspectors.

The time per *area inspected* in the sample can be calculated from the data in Table 9 by dividing the total time by the number sampled. The time required for the acceptance plan is the product of the acceptance plan's sample size and the average time per sampled item. The time delta between the actual IG inspector's total time and the acceptance plan's total time shows the time savings (- indicates time *increase*). The results of the Cannon ORI are listed in Table 11.

Table 1

Validation Results

Area Inspected	Sample Size	Acceptance Number	Time Required (min)	Time Savings (min)
9mm Pistols-Function	12	1	90	-60
9mm Pistols-Documentation	12	1	8	7
Mobility Bags	25	3	34	1
Command Post-SORTS	11	1	41	34
AMMO Loading	10	1	600	-360
C5 Pallet Load	18	2	34	75
C141 Pallet Load	11	1	26	14
Mobility Folders	25	3	47	133
Personnel Processing	25	3	107	1093
Aircraft Acceptance	11	1	440	480
			TOTAL	**1417**

4.2 Acceptance Plans

The total possible time savings from using an acceptance plan with the listed input parameters is quite evident. Moreover, the smaller sample sizes show a single inspector can inspect an area that might have originally required two or more, with obvious implications for reducing mandays. Furthermore, our comparison between the two methods in evaluating a particular area shows that the current practice does not account for risk. Finally, in some cases acceptance plans require a larger sample size than normally deemed appropriate by an inspector.

5. CONCLUSIONS

5.1 Overview

The recommendations of the Blue Ribbon Commission are critical to reshape the way the Air Force handles inspections in light of the changing nature of today's operations. High operational tempos are stressing the force; thus, anything the Air Force directly controls should be used to minimize this stress on the service. The utilization of scientific-based sampling in the conduct of an ORI is an incremental step in the right direction of streamlining and modernizing inspection practices. This small step will hopefully start a movement towards less obtrusive ORIs in the annual schedule of Air Force Operational Units. Acceptance sampling has proven itself in the world of industry through international and military standards. This proven practice, simple in concept, can produce more credible and convincing results in any inspected area selected for sampling.

5.2 Conclusions

Acceptance sampling in an ORI will stand or fall based on the perceptions of both the consumer (the IG inspector) and the producer (the inspected unit). If the technique is perceived as credible, fair, and useful, the inspection community will adopt these same techniques that have been used over the past 50 years. At a minimum, acceptance sampling is as good as the ad-hoc techniques currently used simply because inspectors rely on their judgment. The acceptance techniques will not take away this judgment, but supplement it with a sampling plan that properly accounts for risk levels. This not only gives the inspector a sound defensible result, but provides the inspected unit a better chance of getting the right call while reducing the impact of an inspectors subjective judgment. The method is obviously more efficient at saving time. Acceptance sampling will help the IG community realize the mandated man-day reduction.

Finally, this approach implicitly recognizes the operational world is complex and difficult -- people make mistakes and training is always an inherent part of the process. Acceptance sampling realistically rejects a zero failures approach. By allowing for the fact that mistakes or failures will occur, this tactic will have intuitive appeal for any inspected unit. This approach also makes the process credible for the IG inspector who often has additional goals of motivating and training the people he inspects. The spreadsheet approach to calculating plans makes the mathematical part of acceptance sampling automatic and transparent. Since IG inspectors are now equipped with laptop computers, our spreadsheet can facilitate the use of acceptance sampling.

5.3 Recommendations and Future Development

The application of scientific-based sampling in the IG world is wide open. The Major Commands in the Air Force all have unique missions that their respective IGs must validate and inspect. Acceptance sampling has a robust range of application, although specific approaches or customized techniques might be warranted within the broad range of missions. For example, in specific types of missions there can be no tolerance for failure: thus, sampling based on an acceptance number of zero might apply. This effort only looked at the ORI; however, the IG conducts other types of inspections where various types of approaches might be more suited than acceptance sampling.

Another area for future research is the inclusion and use of prior information on the sampled area. However, often some information is known about the area or process and certain Bayesian acceptance sampling techniques utilize this prior information with the effect of decreasing the sample sizes. The operating characteristic curve is calculated with all levels of percent defective possible.

The scope of sampling can also be expanded. The IG could sample units from within the command instead of a set an annual schedule, or even sample specific units together in larger scenarios resembling the new Air Expeditionary Forces currently employed in the Middle East. These questions can even be of how often to sample a unit based on annual performance measures, past inspections, and chosen indicator variables. The population can become all operational units within a command, where the sample now becomes which units to inspect in a given year.

Finally, the IG force tries to incorporate past performance into a unit's inspection. The question is how to accomplish this and still maintain the goal of validating performance standards. What kind of data to use, how to use it, how to collect, and how to sample from the data are all areas that suggest future research for the modernizing force.

5.4 Summary

The presented sampling techniques in this thesis effort will accomplish their intended goal. The inspector can make an evaluation efficiently and quickly. The effort required to make this evaluation is minimal and the present ORI structure is left relatively unaffected. The inspector only has to spend a minimal amount of time determining the plan, and then conduct the inspection. Smaller IG teams and smaller inspections are an increasing trend; acceptance sampling is a valid way to accomplish the same level of validation of a unit within these constraints.

APPENDIX A

Input Parameters	
Population	50
AQL	0.05
RQL	0.2
Alpha	0.05
Beta	0.1

Acceptance Sampling Plan	
Sample Size	27
Acceptance Number	3

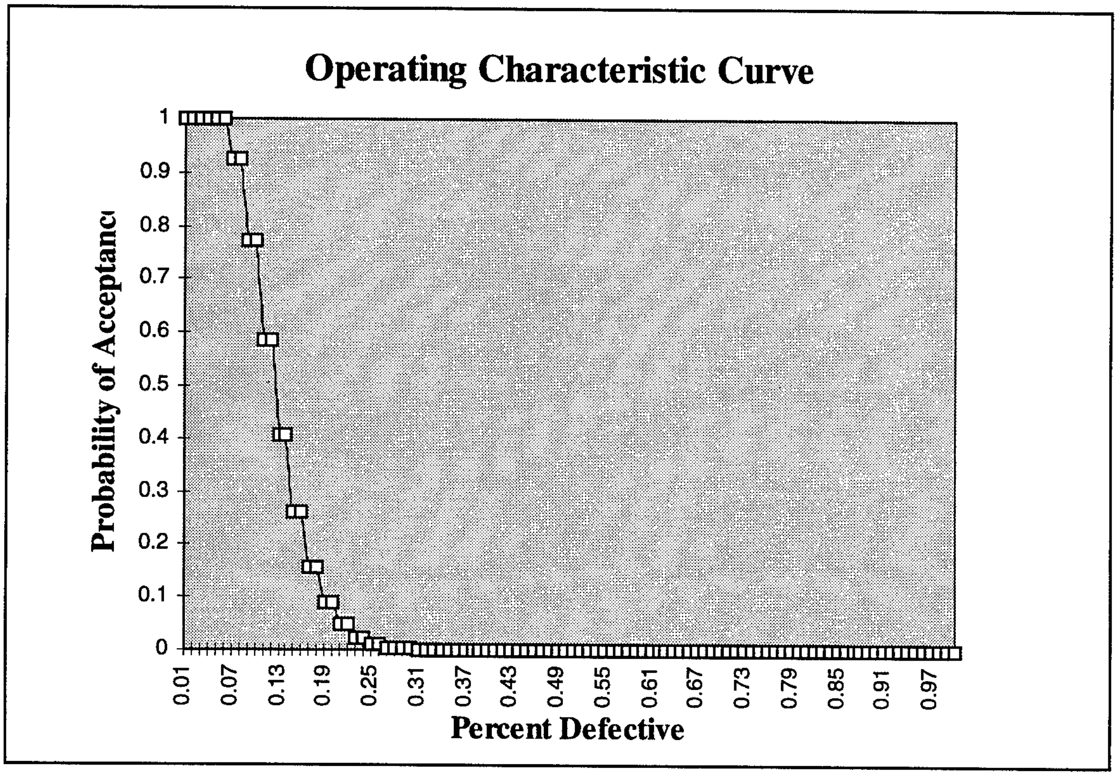
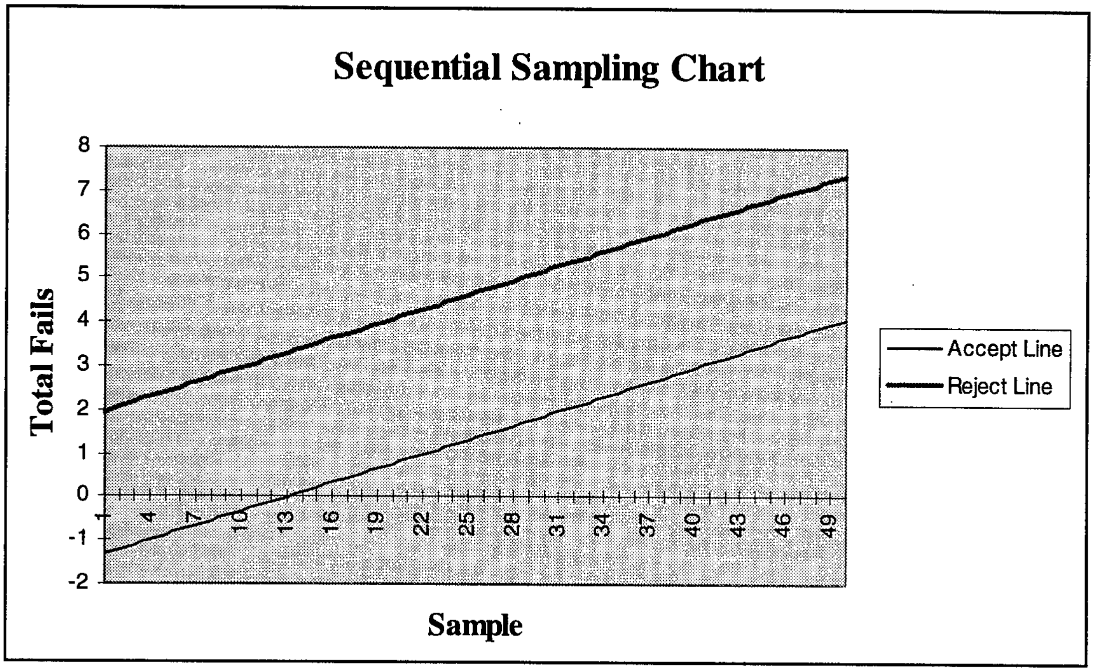


Figure 13. Acceptance Plan, N = 50

Sequential Plan



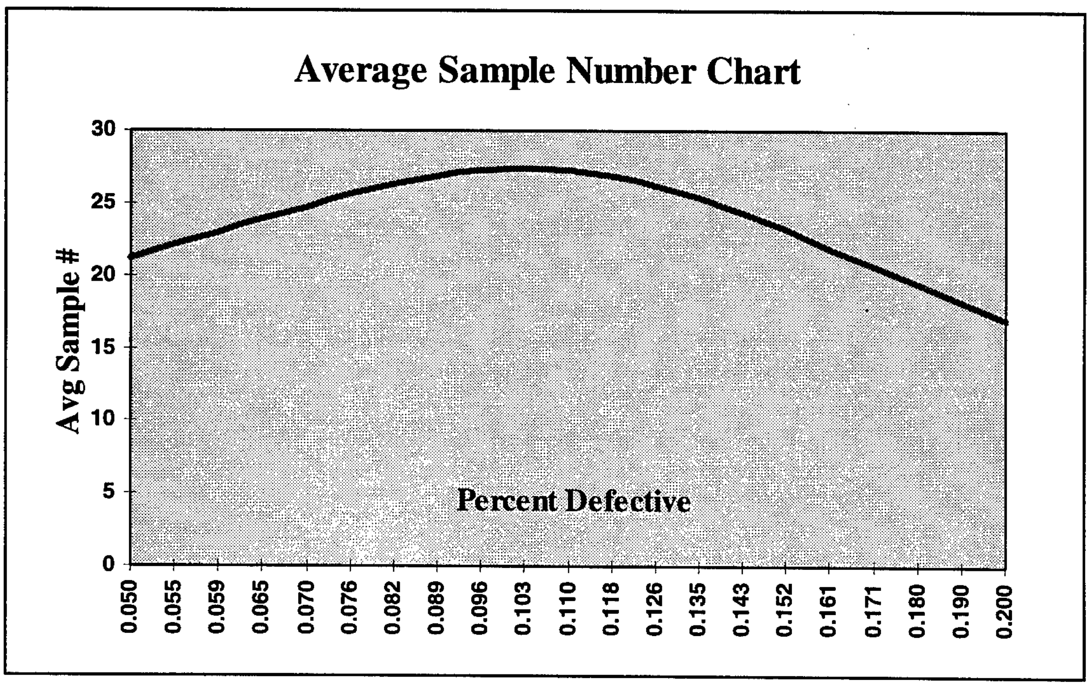


Figure 14. Sequential Plan, N = 50

Input Parameters	
Population	75
AQL	0.05
RQL	0.2
Alpha	0.05
Beta	0.1

Acceptance Sampling Plan	
Sample Size	29
Acceptance Number	3

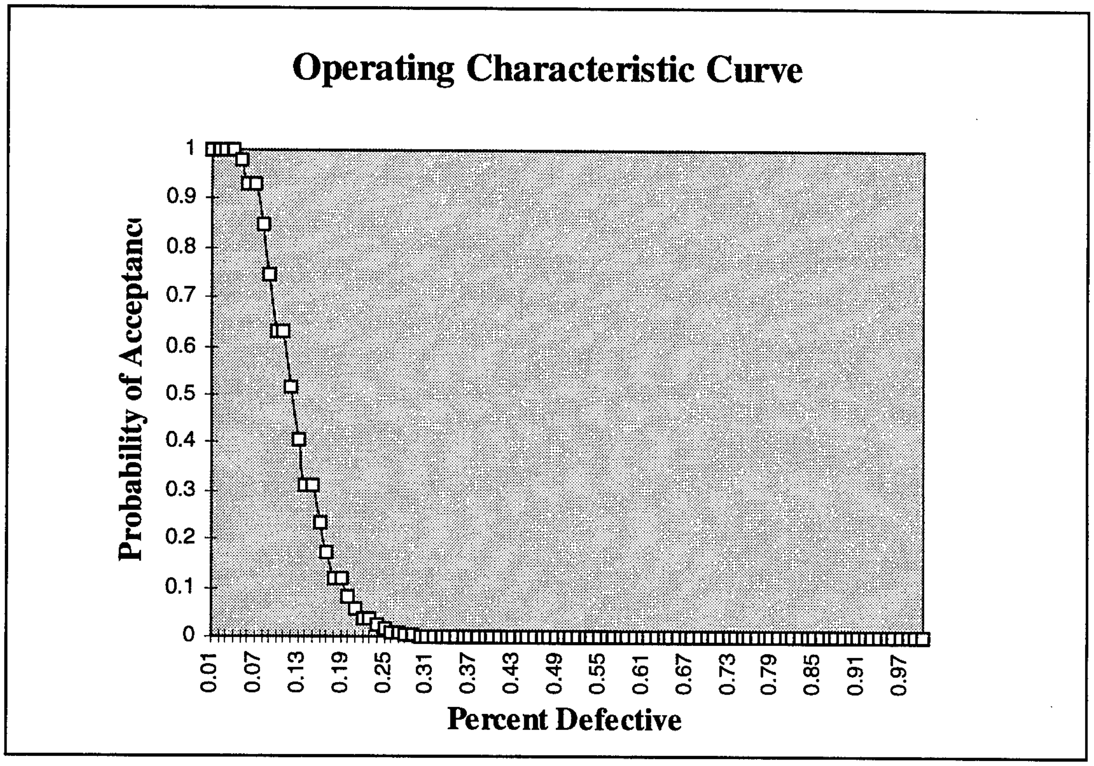
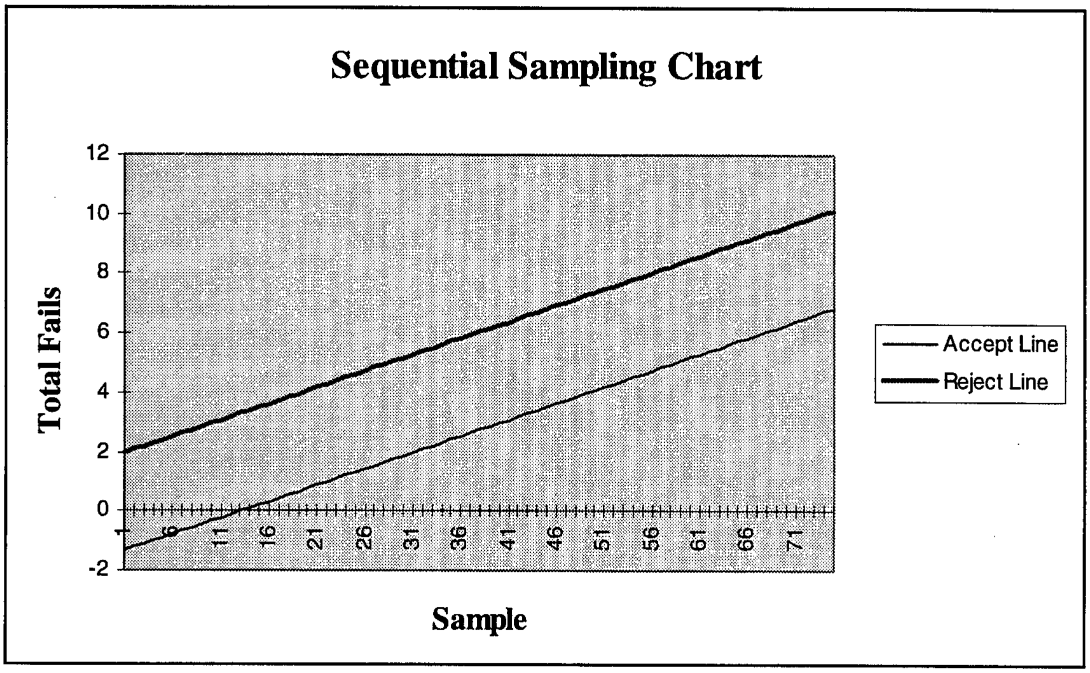


Figure 15. Acceptance Plan, N = 75

Sequential Plan



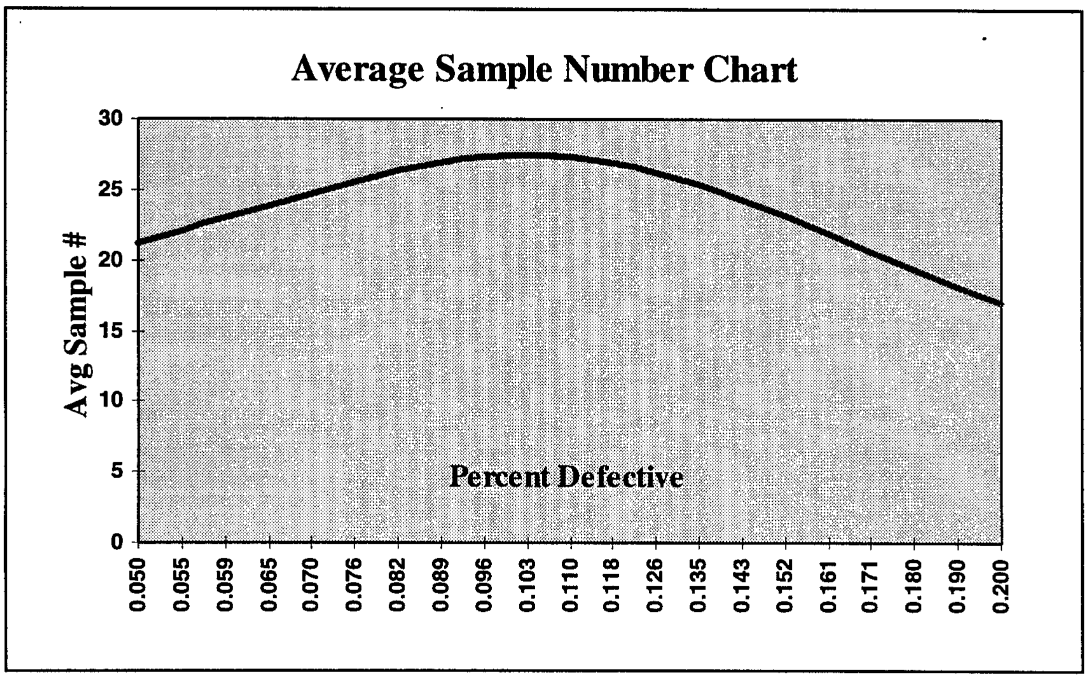


Figure 16. Sequential Plan, N = 75

Input Parameters	
Population	100
AQL	0.05
RQL	0.2
Alpha	0.05
Beta	0.1

Acceptance Sampling Plan	
Sample Size	29
Acceptance Number	3

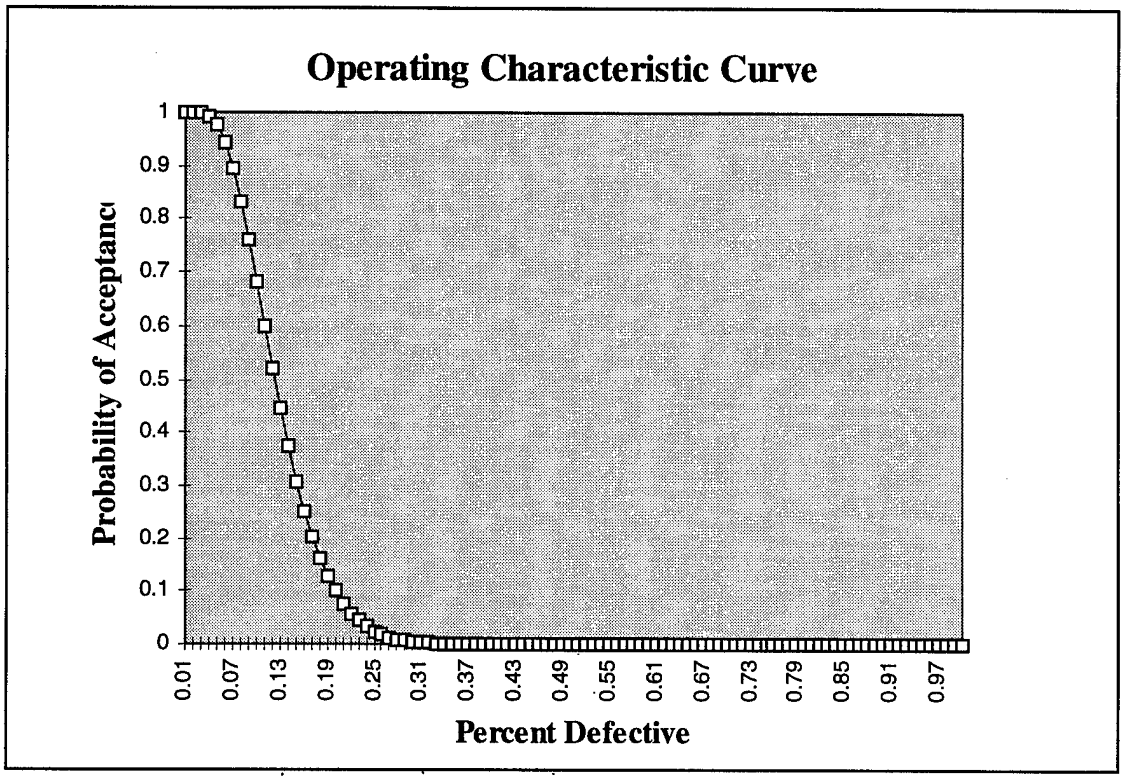
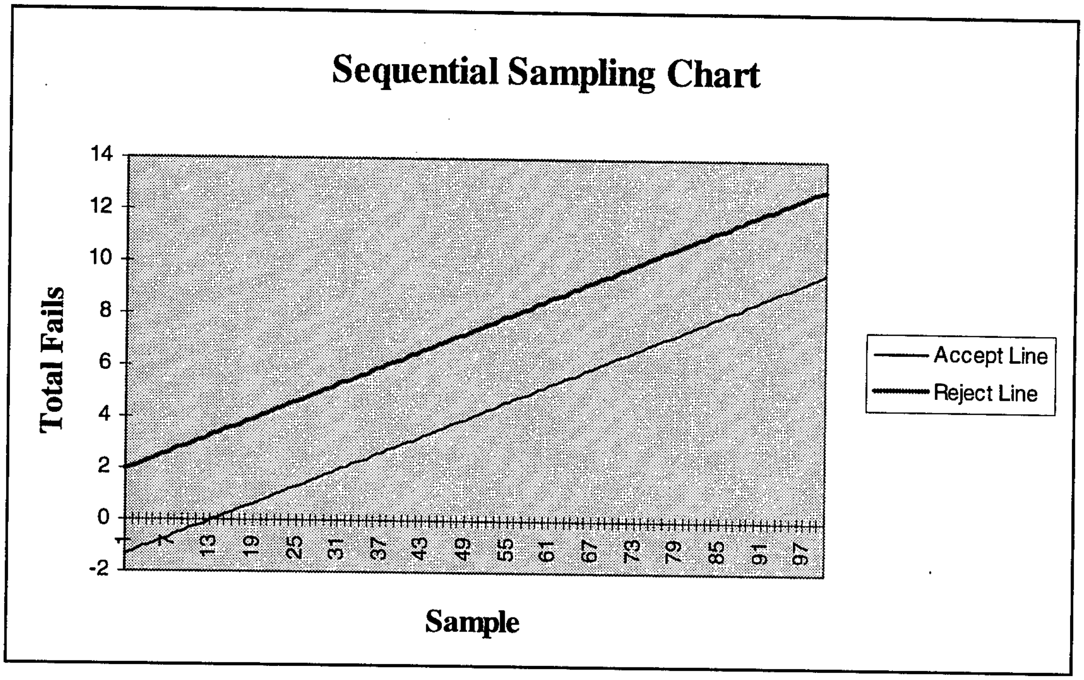


Figure 17. Acceptance Plan, N = 100

Sequential Plan



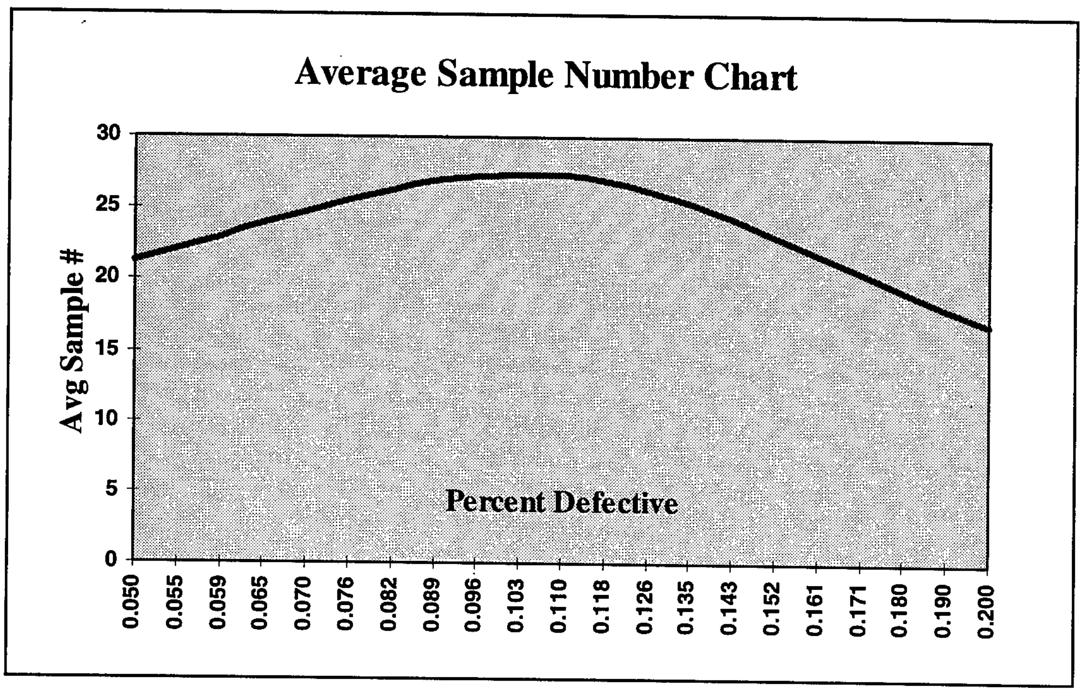


Figure 18. Sequential Plan, N = 100

Input Parameters	
Population	125
AQL	0.05
RQL	0.2
Alpha	0.05
Beta	0.1

Acceptance Sampling Plan	
Sample Size	30
Acceptance Number	3

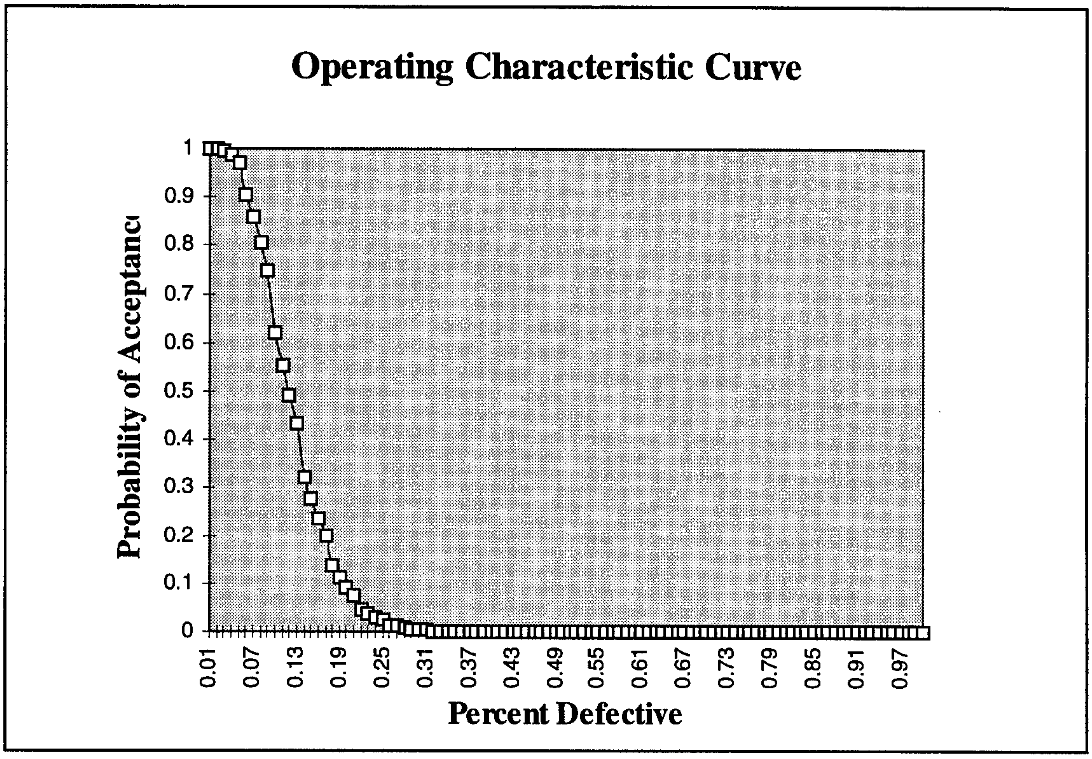
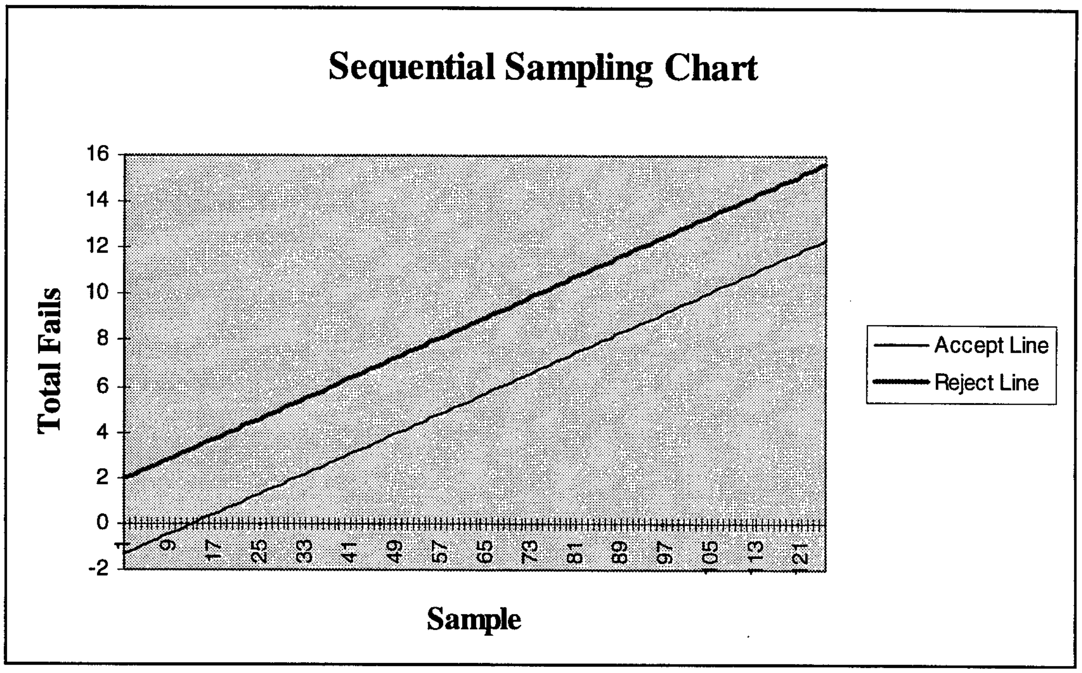


Figure 19. Acceptance Plan, N = 125

Sequential Plan



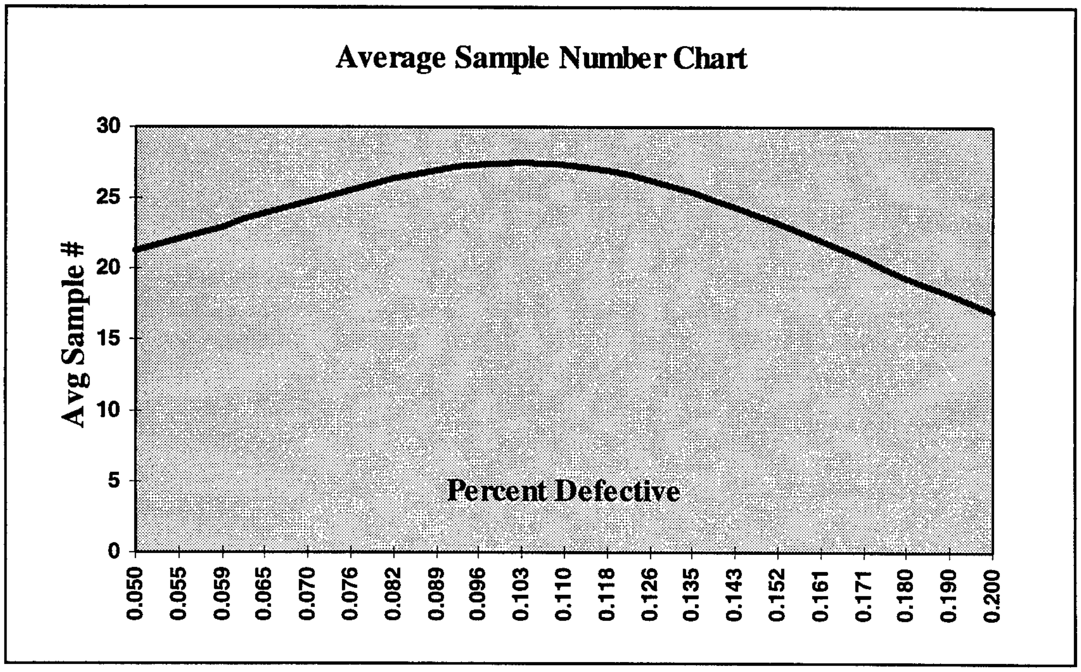


Figure 20. Sequential Plan, N = 125

Input Parameters	
Population	150
AQL	0.05
RQL	0.2
Alpha	0.05
Beta	0.1

Acceptance Sampling Plan	
Sample Size	36
Acceptance Number	4

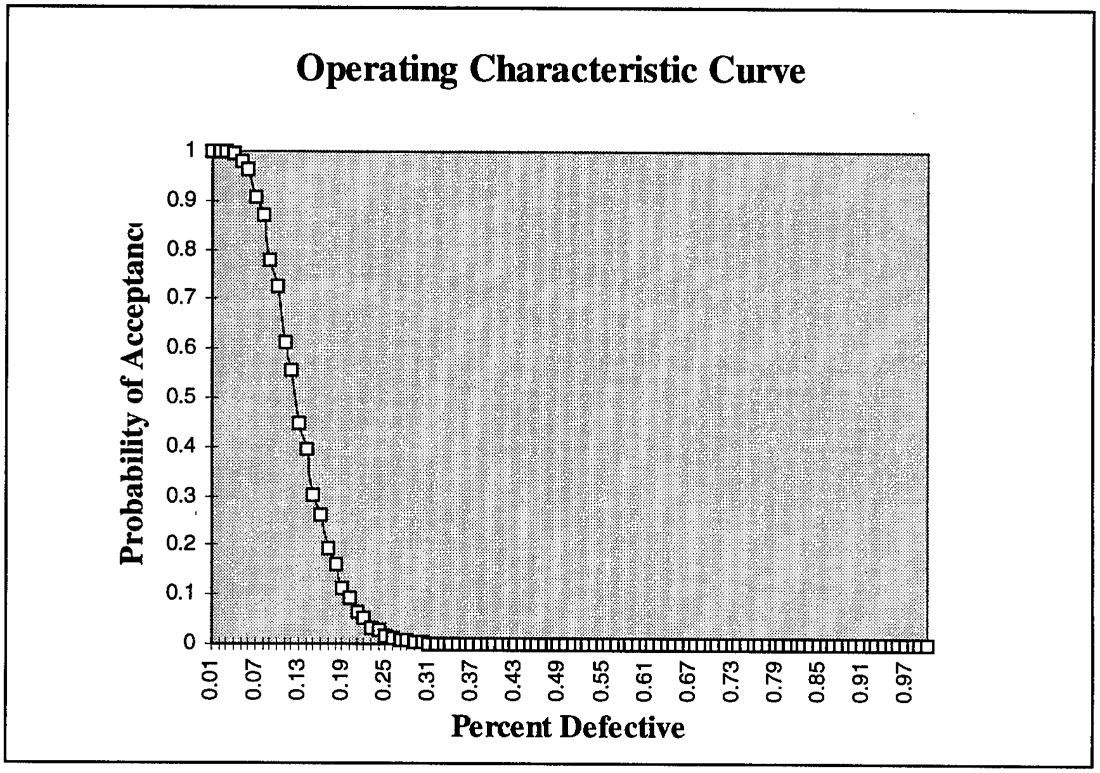
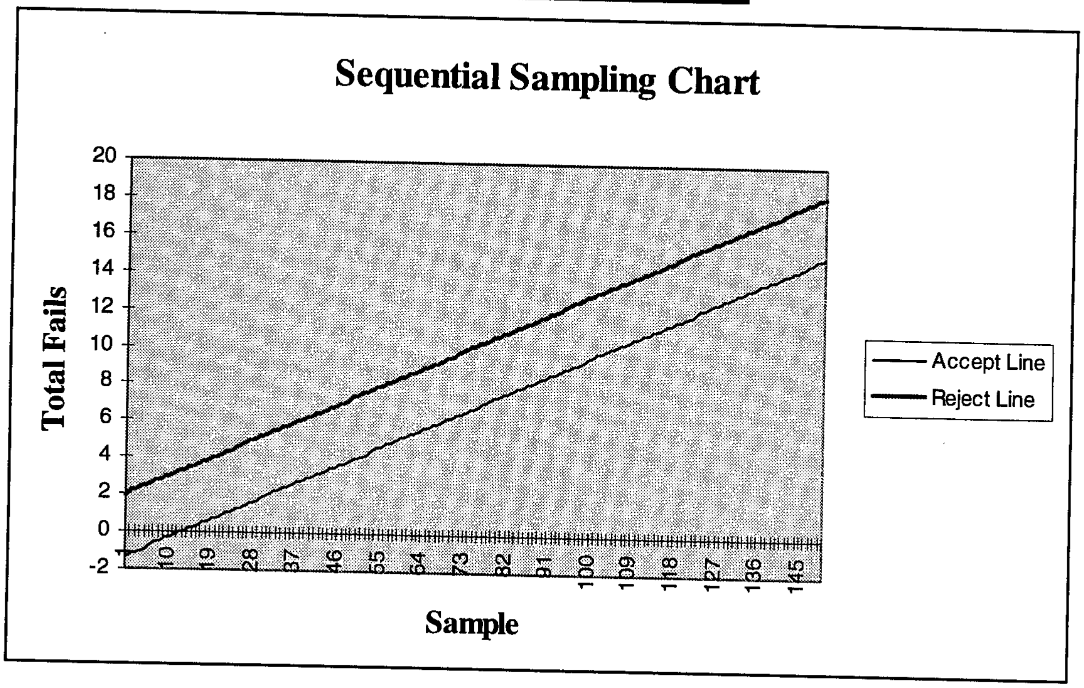


Figure 21. Acceptance Plan, N = 150

Sequential Plan



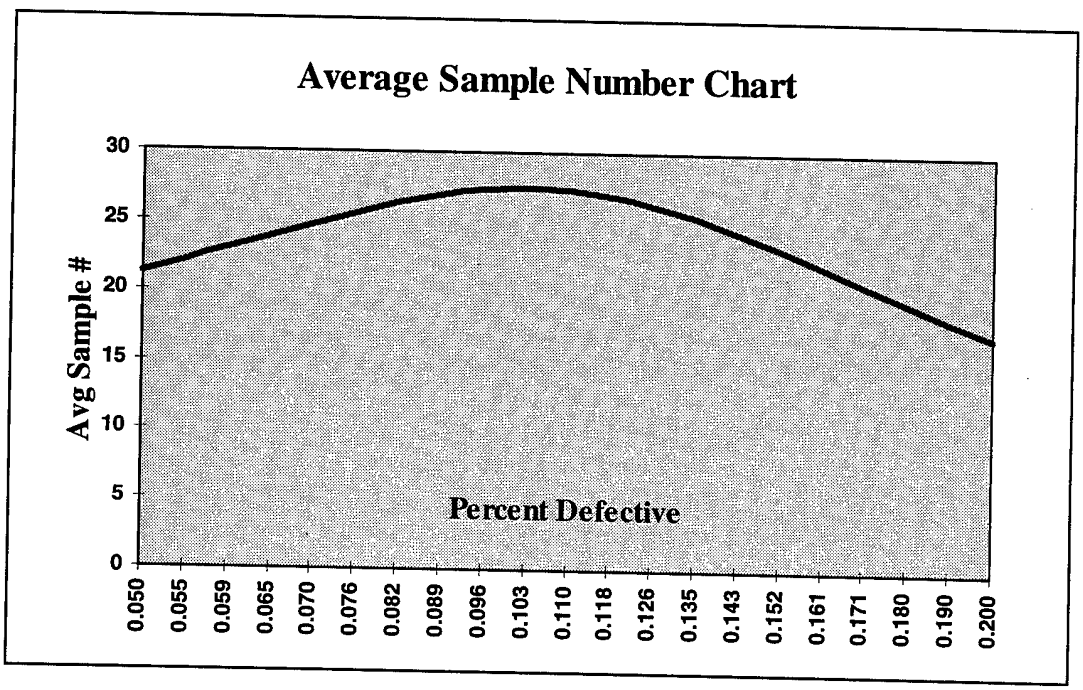


Figure 22. Sequential Plan, N = 150

Input Parameters	
Population	175
AQL	0.05
RQL	0.2
Alpha	0.05
Beta	0.1

Acceptance Sampling Plan	
Sample Size	36
Acceptance Number	4

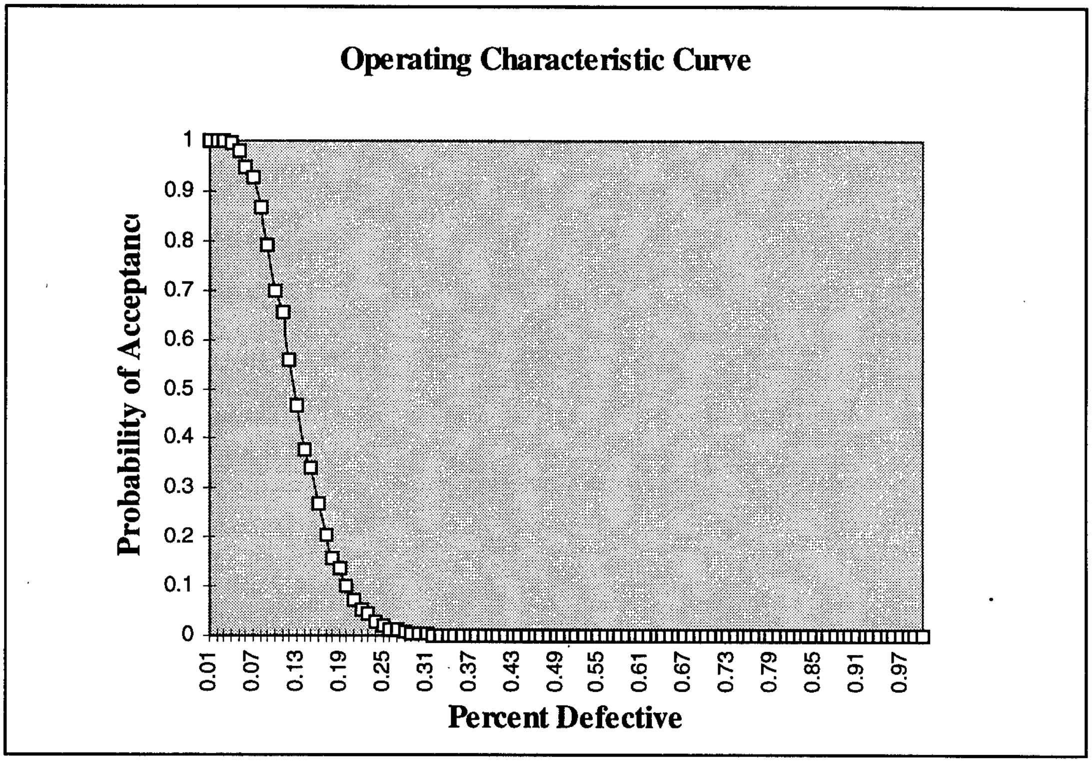
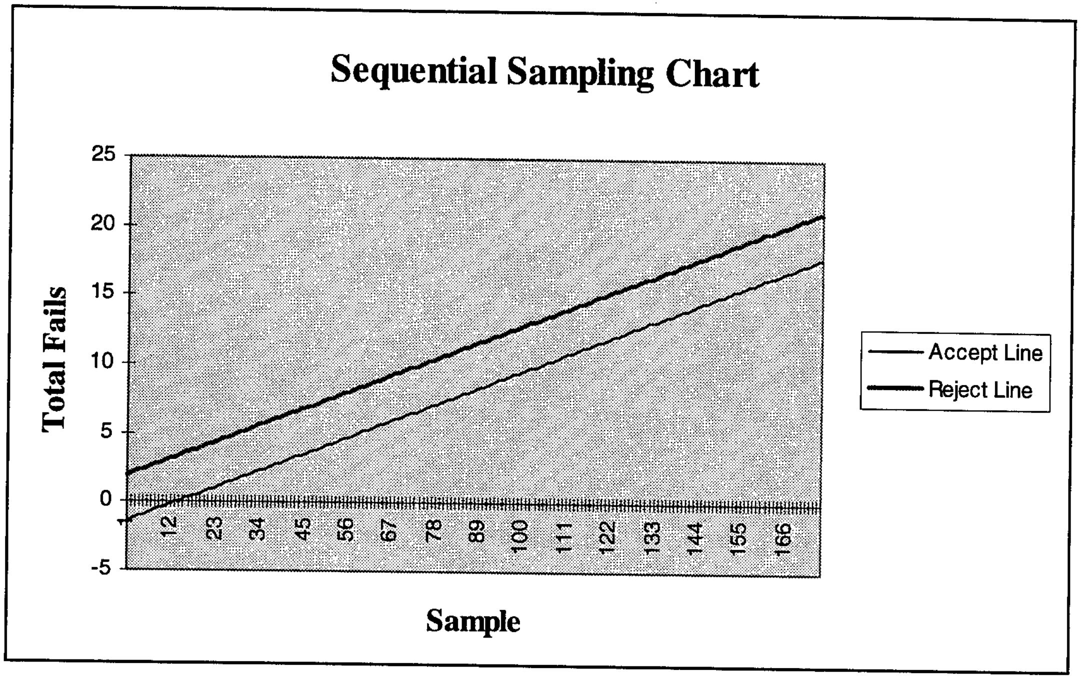


Figure 23. Acceptance Plan, N = 175

Sequential Plan



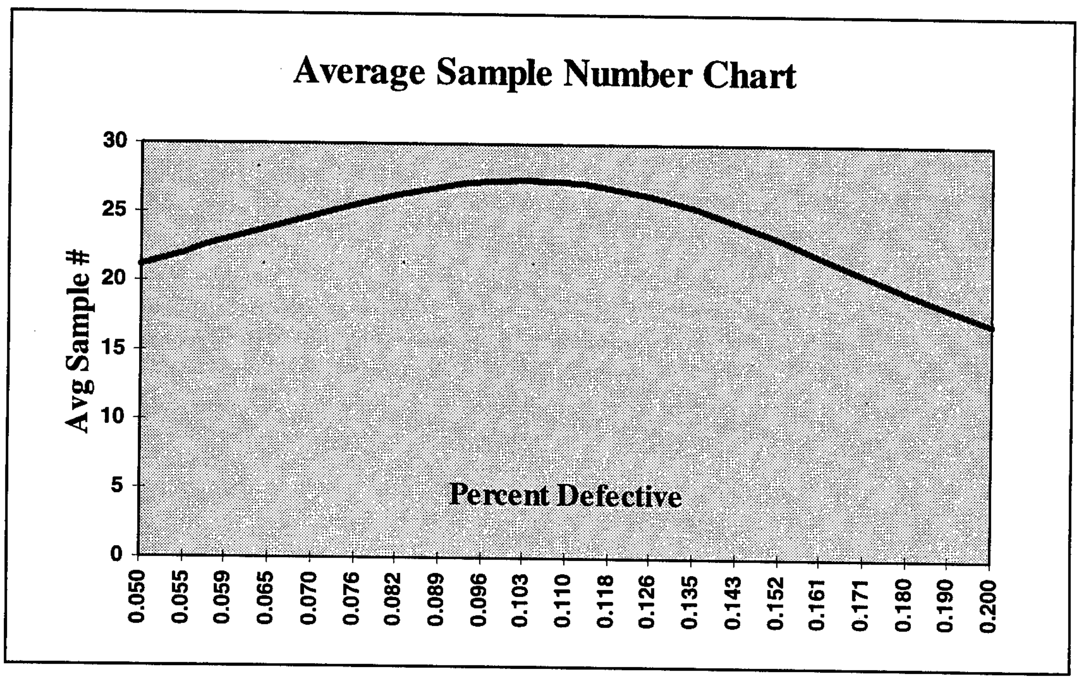


Figure 24. Sequential Plan, N = 175

Input Parameters	
Population	200
AQL	0.05
RQL	0.2
Alpha	0.05
Beta	0.1

Acceptance Sampling Plan	
Sample Size	37
Acceptance Number	4

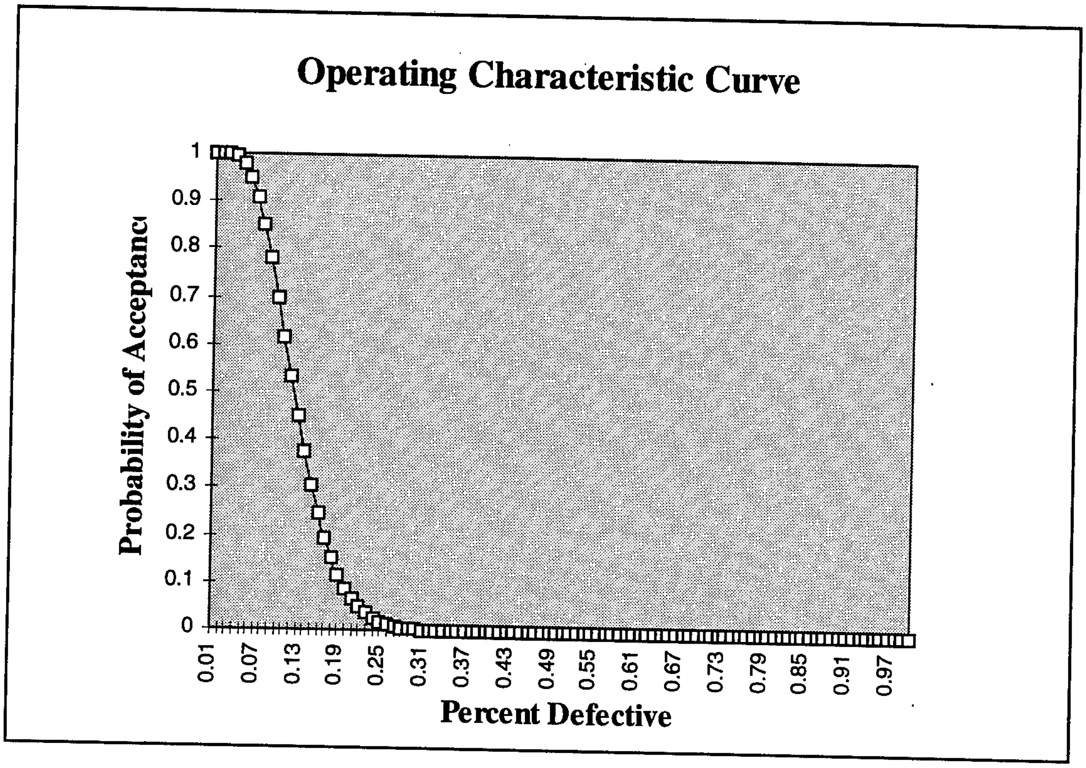
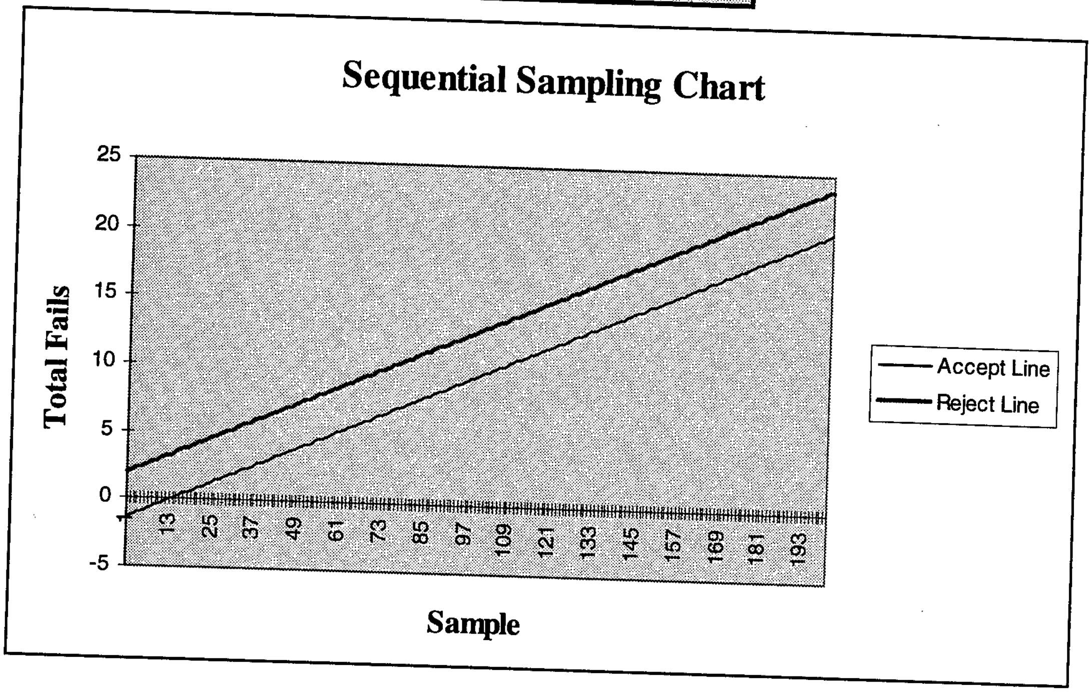


Figure 25. Acceptance Plan, N = 200

Sequential Plan



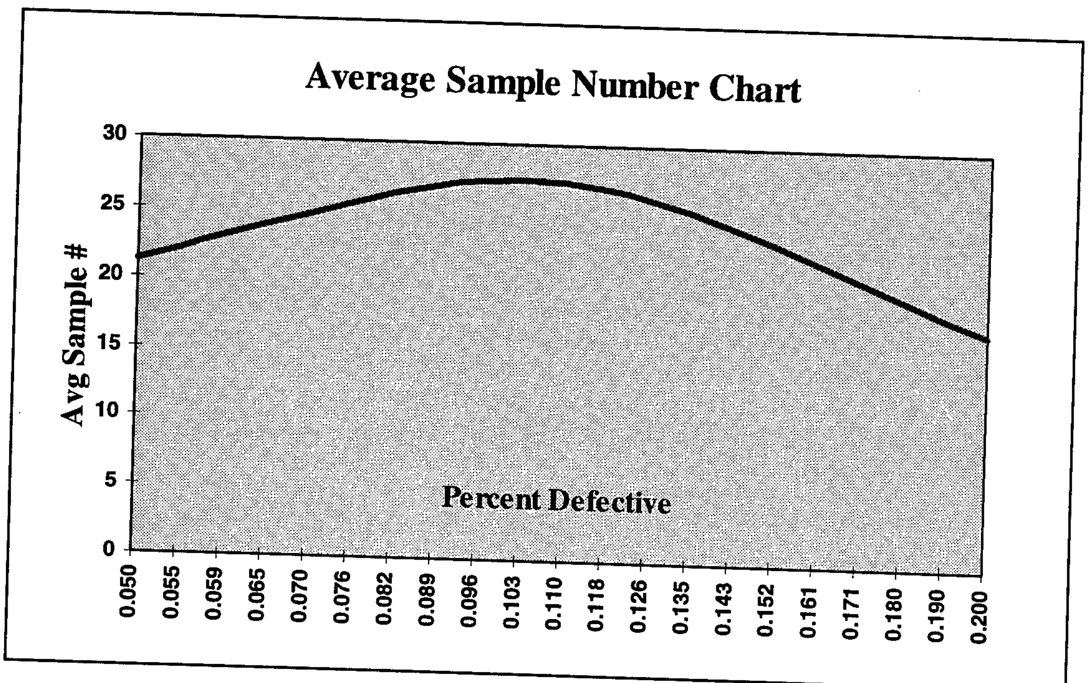


Figure 26. Sequential Plan, N = 200

Sampling Plan Worksheet

Figure 27. Screen Capture of Sampling Plan Worksheet

Cell Formulas

Cell N8: =Single!Q20
Cell N9: =Single!R20

Macros Used by Worksheet

START Button:

```
'Displays the dialog box and links the edit boxes to cells on the Single Sheet
Sub GetInfo_Show()
   DialogSheets("GetInfo").Show
   Population = DialogSheets("GetInfo").EditBoxes("Edit Box 4").Text
   AQL = DialogSheets("GetInfo").EditBoxes("Edit Box 5").Text
   RQL = DialogSheets("GetInfo").EditBoxes("Edit box 6").Text
   Sheets("Single").Range("E2") = Population
   Sheets("Single").Range("F2") = 1 - AQL
   Sheets("Single").Range("G2") = 1 - RQL
   ShowErrorMessage
End Sub
```

RANDOMIZE SAMPLE Button:

```
'Code for move to random sheet
Sub MoveToRandomSheet()
   Worksheets("Random").Activate
   Range("J3").Select
End Sub
```

SEQUENTIAL SAMPLE Button:

```
'Code for move to Seq Sample sheet
Sub MoveToSeqSampleSheet()
   Worksheets("Seq Sample").Activate
   Range("L8").Select
End Sub
```

VARIATIONS ON SAMPLING PLAN Button:

```
'This code moves you to the Variations Sheet
Sub GoToVariations()
   Worksheets("Variations").Activate
   ActiveSheet.Range("A1").Select
End Sub
```

Go To Acceptance Sampling Calculation Sheet Button:

```
'Code for move to Single sheet
Sub MoveToSingleSheet()
   Worksheets("Single").Activate
   Range("L6").Select
End Sub
```

HELP ON/OFF Button:

```
'Code for help button on Sampling Plan sheet
Sub ShowSamplingPlanHelp()
   ActiveSheet.TextBoxes("SamplingPlanHelpText").Visible = _
     Not ActiveSheet.TextBoxes("SamplingPlanHelpText").Visible
End Sub
```

Operating Characteristic Curve for Acceptance Plan Button:

```
'This code moves you to the OC curve on the OC sheet
Sub GoToOCCurve()
   Worksheets("OC CURVE").Activate
   ActiveSheet.Range("H5").Select
End Sub
```

Displayed Help Text Boxes

Acceptance Sampling Spreadsheet Guide Help

This sheet acts as the intro sheet for the spreadsheet guide. To start the spreadsheet guide, press the start button. A dialog box will appear that has various inputs. The first "edit" box is the "population" box. Input into this box the total size of the lot to be sampled. It should only be input in a integer value, no fractions. The second box is AQL, place the level you want to pass with high confidence. For example if you want the lot to pass with high confidence when 95% of the items are good (a .05 percent defective), then place .95 in the AQL box. The next box is RQL, place the level you want to fail with high confidence. Again, if you want the lot to fail with high confidence for a failure rate of the items in the population below 75%, then enter .75 into the box. All three boxes must have a value in the format described for the spreadsheet to work. The remaining inputs are two groups, one called "alpha" and one called "beta". Default values are already selected, other values can be selected for higher confidence, but this will increase sample sizes, sometimes to an amount that no sampling plan would be available. Once inputs are made, select OK and the spreadsheet will calculate automatically. The outputs will be listed next to sample size and acceptance number. The sample size is self explanatory, the acceptance number is the maximum number of failures you can have within the sample and still pass overall. If the word "FAIL" shows up after calculation, this indicates that the inputs are such that no sampling plan is available. Most likely, you are requesting a plan with the AQL and RQL values so close that you need to sample 100% to insure the desired confidence levels. If you desire to see the calculations made to arrive at the solution, press the "Go to acceptance sampling calculation sheet" button, follow sheet instructions.

In order to pick a random sample from the population, select the "Randomize Sample" button and you will go to a sheet that will accomplish this. Follow instructions on that sheet.

If you desire to use a sequential sampling plan based on the inputs you entered from the start button, press the "sequential sample" button. This will take you to a sheet that will describe the process, follow sheet instructions.

If you desire to know what different AQL and RQL values would do to the sampling plan based on the input population number and confidence limits, press the "Variations on Sampling Plan" button. It will take you to a sheet that will show you the results from varying AQL nd RQL values, follow sheet instructions. Calculations involved with this sheet can take awhile. You must make at least one input through the start button and finish calculations, prior to going to this sheet.

Figure 28. Displayed Text Box from HELP ON/OFF Button

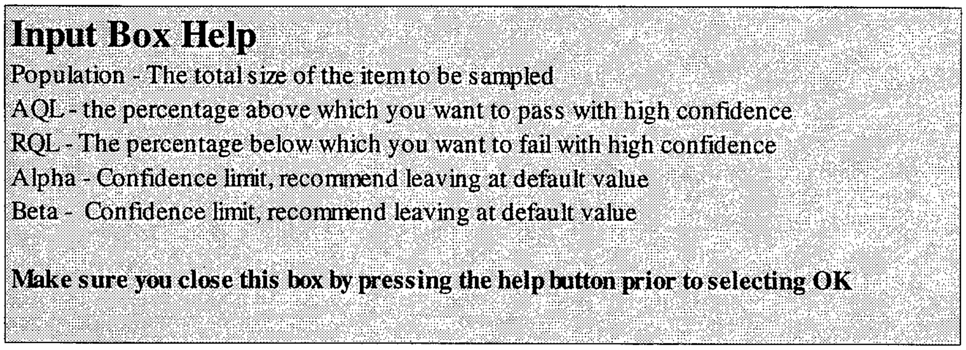


Figure 29. Displayed Text Box from Help On/Off Button on Input Parameters Dialog

Random Worksheet

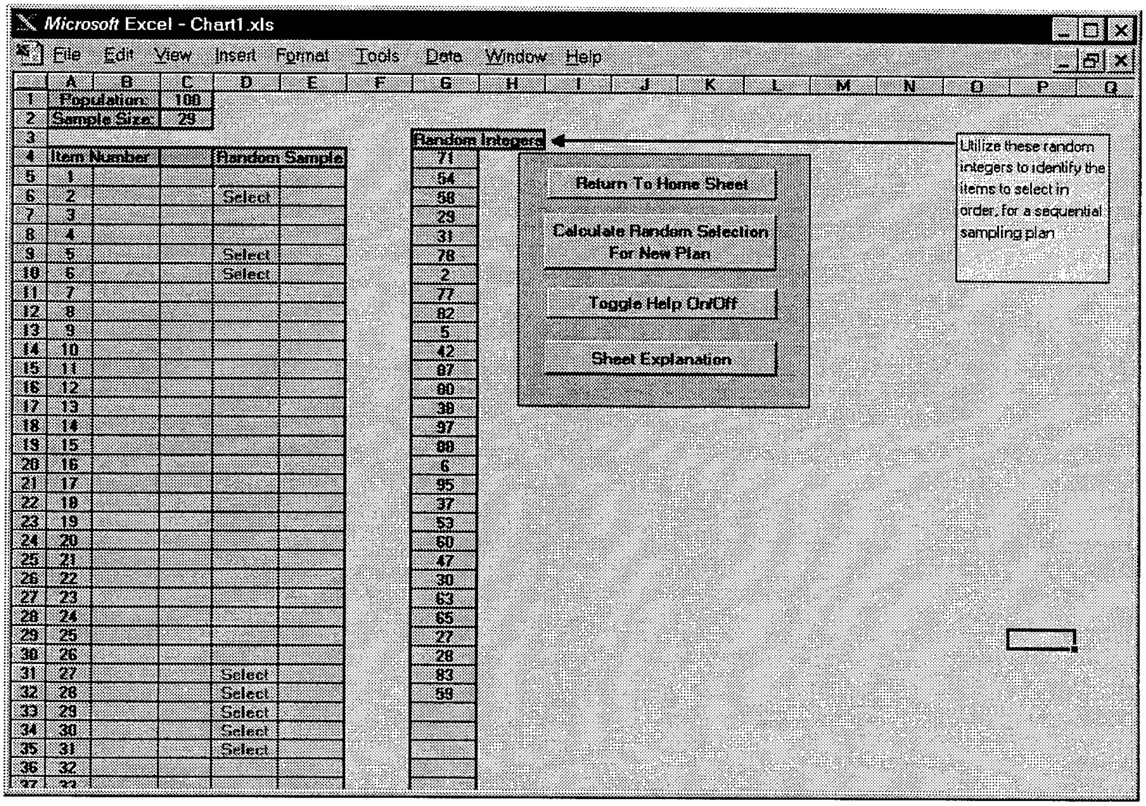


Figure 30. Screen Capture of Random Worksheet

Cell Formulas

Cell C1: =Single!E2

Cell C2: =Single!Q20

Cell A5: 1 *'Starts the item number list'*

Cell A6 to A400: =IF(ISNUMBER(A5),IF(A5<$C$1,A5+1," ")," ")

'Enumerates the item list down to the population size and no farther'

Macros Used by Worksheet

Return to Home Sheet Button:

```
'Code for all return to home sheet buttons
Sub ReturnToHomeSheet()
  Worksheets("Sampling Plan").Activate
  Range("A1").Select
End Sub
```

Calculate Random Selection For New Plan Button:

'This macro produces a set of random numbers equal to the sample size and bounded in value by the population size

```
Sub GetRandomNums()
  Upperbound = Sheets("Random").Range("C1")
  SampleSize = Sheets("Random").Range("C2")
  'Clears previous random sample selects
  For y = 1 To 400
    Sheets("Random").Cells(y + 4, 4) = " "
    Sheets("Random").Cells(y + 3, 7) = " "
  Next y
  'Calculate the random numbers
  For Count = 1 To SampleSize
  'Produce a random number
    Sheets("Random").Cells(Count + 3, 7)=Application.RoundUp(Rnd*Upperbound, 0)
    If Count > 1 Then
  'Check to see if current random number is equal to one already selected
      For x = 1 To Count - 1
       If Sheets("Random").Cells(Count + 3, 7) = Sheets("Random").Cells(x + 3, 7)
Then Check = True
      Next x
  'If the current random number is repeated, select another and recheck until all unique
      Do While Check = True
       Sheets("Random").Cells(Count+3,7)=Application.RoundUp(Rnd*Upperbound, 0)
       Check = False
       For z = 1 To Count - 1
       If Sheets("Random").Cells(Count + 3, 7) = Sheets("Random").Cells(z + 3, 7)
Then Check = True
       Next z
      Loop
    End If
  'Assign a select title to the appropriate row
    Hold = Sheets("Random").Cells(Count + 3, 7)
    Sheets("Random").Cells(Hold + 4, 4) = "Select"
  Next Count
End Sub
```

Toggle Help On/Off Button:

'Code for help button on Random Sheet

```
Sub ShowRandomSampleHelpText()
  ActiveSheet.TextBoxes("RandomSampleHelpText").Visible = _
   Not ActiveSheet.TextBoxes("RandomSampleHelpText").Visible
End Sub
```

Sheet Explanation Button:

```
'Code for detailed help button on Random Sheet
Sub ShowDetailedRandomSampleHelp()
   ActiveSheet.TextBoxes("DetailedRandomSampleHelp").Visible = _
     Not ActiveSheet.TextBoxes("DetailedRandomSampleHelp").Visible
End Sub
```

Text Boxes

Random Sample Selection Help

This worksheet will let you determine a perfectly random sample from a population. The first requirement is to assign all items in the population a number or have a means of differentiating between the first, tenth, etc. Then press the "Calculate Random selection" button and the worksheet will automatically display the items to sample by placing "Select" next to the item number. The list under "random integers" is the actual random numbers calculated. Thses numbers can be used in the order they are listed to supply the slections for a sequential samplin plan. The bottem line behind a random selection is every item has an equal probability of being selected. A more detailed explanation of the worksheet "inner workings" is located on the sheet explanation text box, accessed by the sheet explanation button.

Cells with "red dots" in them have additional information

Figure 31. Text Box Displayed by Toggle Help On/Off Button

Detailed Random Sample Worksheet Instructions

The primary function of this sheet is to pick a random sample out of a population effortlessly. The column under "Item number" will automatically display increasing numbers up to the total population number which is input though the start dialog box. The "calculate random sample" button is linked to the macro "GetRandomNums" located in the worksheet Module3. The macro outputs a random number, then outputs a second random number and checks all random numbers above it to make sure the number in not repeated. If it is, it outputs another random number and rechecks. It will repeat until it has only unique random numbers. Then the macro will output another number and repeat the checkprocess. It outputs random numbers in this manner until the number of random numbers equals the sample size. The macro then labels the appropriate item number with "Select". The details of the macro are documented in the macro itself.

Figure 32. Text Box Displayed by Sheet Explanation Button

Single Worksheet

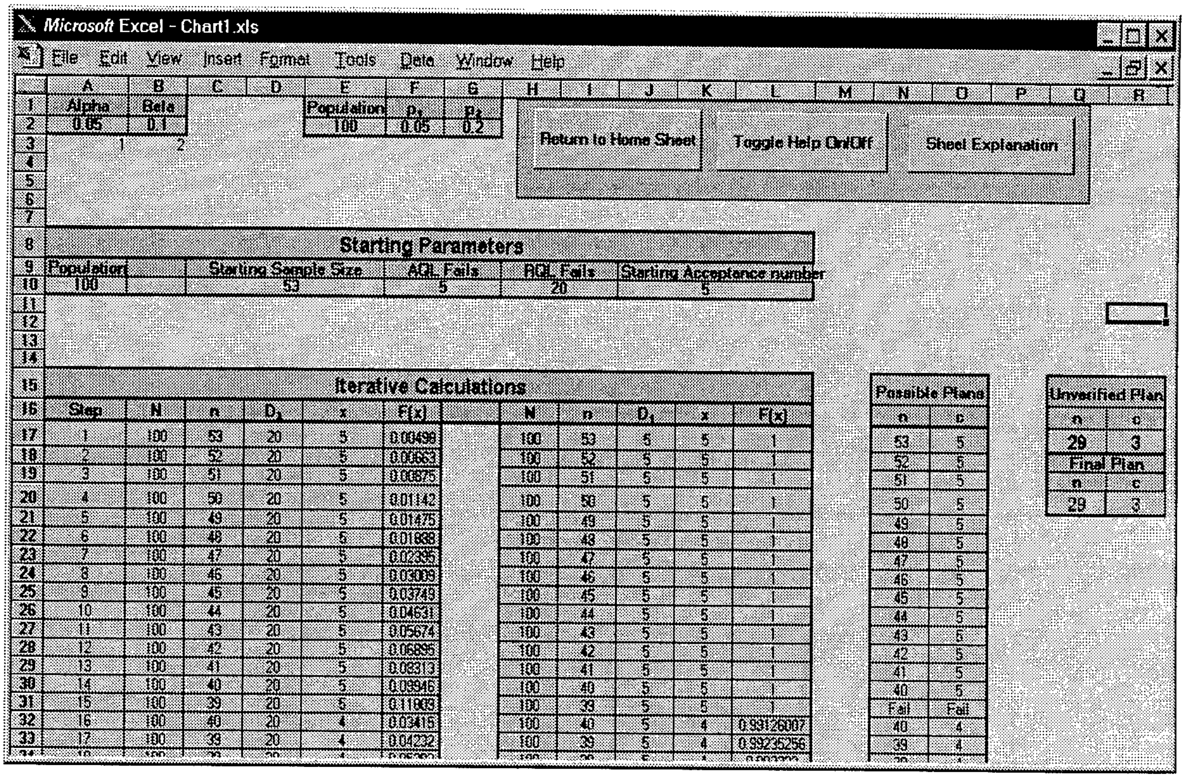


Figure 33. Screen Capture of Single Worksheet

Cell Formulas

Cell A2: =IF(A3=1,0.05,0.01) *'Determines alpha value based on number in Cell A3, which is linked to Input Parameter Dialog Box'*

Cell B2: =IF(B3=2,0.1,IF(B3=3,0.05,IF(B3=1,0.01,0))) *'Determines beta value based on number in Cell B3, which is linked to Input Parameter Dialog Box'*

Cell E2: *'Population size linked to Input Parameter Dialog Box'*

Cell F2: *'AQL linked to Input Parameter Dialog Box'*

Cell G2: *'RQL linked to Input Parameter Dialog Box'*

Cell A10: =E2 *'Repeats Population size'*

Cell D10: =IF('Data Table'!C67>=E2,E2-1,'Data Table'!C67) *'Pulls in starting sample size from Data Table worksheet, if the data table determines a number equal to or larger that the population size, then the starting sample size is set to the population size minus one'*

Cell F10: =ROUND(F2*E2,0) *'Determines the number of fails at the AQL rounded to the nearest integer'*

Cell H10: =ROUND(G2*E2,0) *'Determines the number of fails at the RQL rounded to the nearest integer'*

Single Worksheet

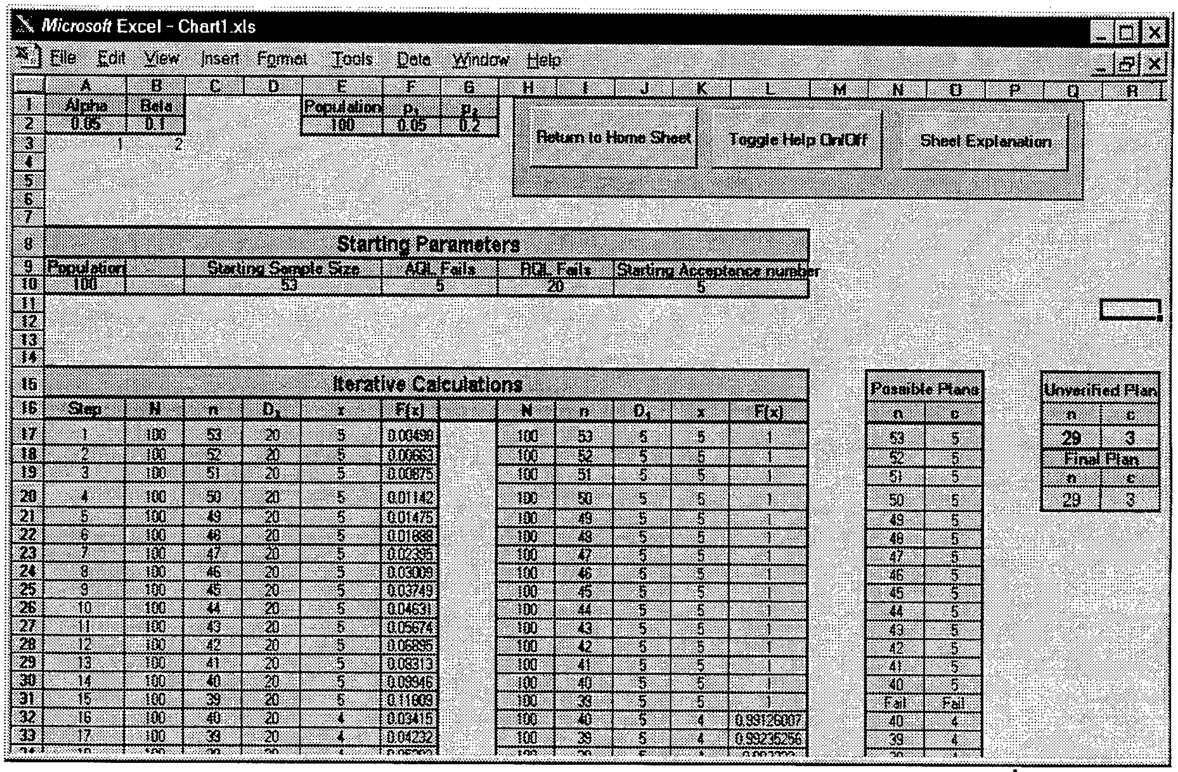


Figure 33. Screen Capture of Single Worksheet

Cell Formulas

Cell A2: =IF(A3=1,0.05,0.01) *'Determines alpha value based on number in Cell A3, which is linked to Input Parameter Dialog Box'*

Cell B2: =IF(B3=2,0.1,IF(B3=3,0.05,IF(B3=1,0.01,0))) *'Determines beta value based on number in Cell B3, which is linked to Input Parameter Dialog Box'*

Cell E2: *'Population size linked to Input Parameter Dialog Box'*

Cell F2: *'AQL linked to Input Parameter Dialog Box'*

Cell G2: *'RQL linked to Input Parameter Dialog Box'*

Cell A10: =E2 *'Repeats Population size'*

Cell D10: =IF('Data Table'!C67>=E2,E2-1,'Data Table'!C67) *'Pulls in starting sample size from Data Table worksheet, if the data table determines a number equal to or larger that the population size, then the starting sample size is set to the population size minus one'*

Cell F10: =ROUND(F2*E2,0) *'Determines the number of fails at the AQL rounded to the nearest integer'*

Cell H10: =ROUND(G2*E2,0) *'Determines the number of fails at the RQL rounded to the nearest integer'*

Single Worksheet

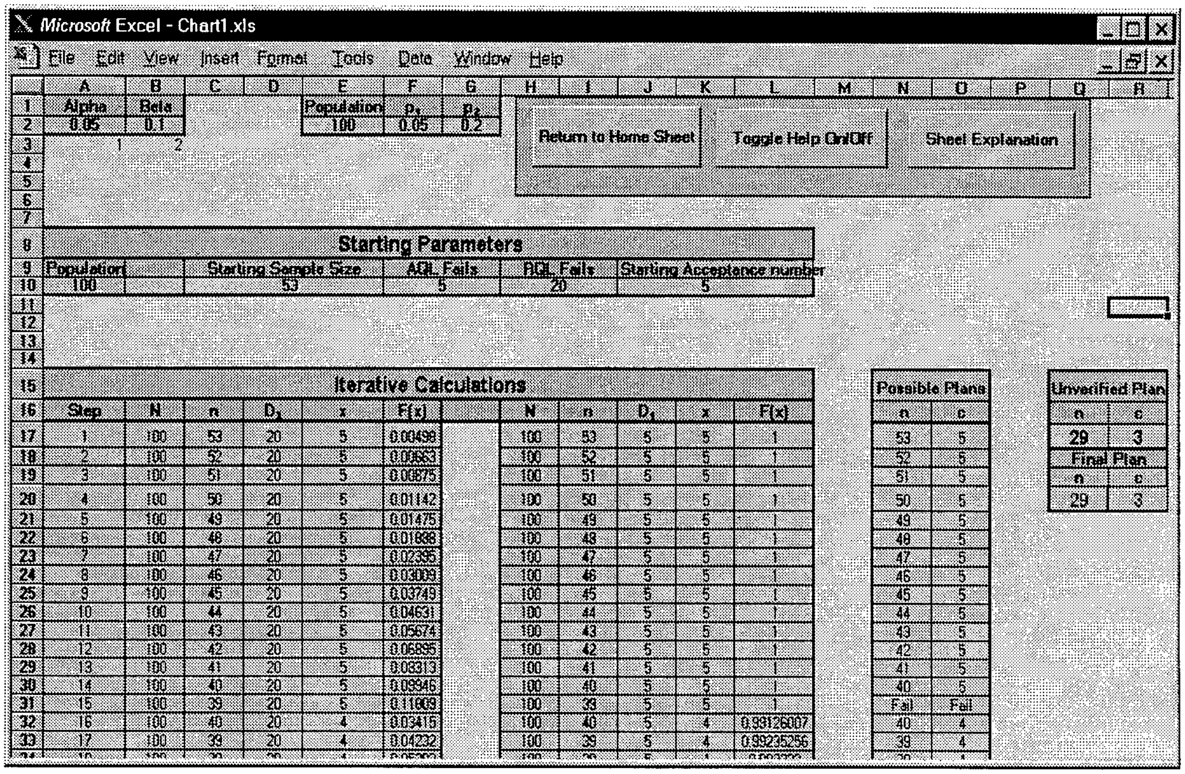


Figure 33. Screen Capture of Single Worksheet

Cell Formulas

Cell A2: =IF(A3=1,0.05,0.01) *'Determines alpha value based on number in Cell A3, which is linked to Input Parameter Dialog Box'*

Cell B2: =IF(B3=2,0.1,IF(B3=3,0.05,IF(B3=1,0.01,0))) *'Determines beta value based on number in Cell B3, which is linked to Input Parameter Dialog Box'*

Cell E2: *'Population size linked to Input Parameter Dialog Box'*

Cell F2: *'AQL linked to Input Parameter Dialog Box'*

Cell G2: *'RQL linked to Input Parameter Dialog Box'*

Cell A10: =E2 *'Repeats Population size'*

Cell D10: =IF('Data Table'!C67>=E2,E2-1,'Data Table'!C67) *'Pulls in starting sample size from Data Table worksheet, if the data table determines a number equal to or larger that the population size, then the starting sample size is set to the population size minus one'*

Cell F10: =ROUND(F2*E2,0) *'Determines the number of fails at the AQL rounded to the nearest integer'*

Cell H10: =ROUND(G2*E2,0) *'Determines the number of fails at the RQL rounded to the nearest integer'*

Cell K10: ='Data Table'!C65 *'Transfers starting acceptance number from Data Table worksheet'*

Cell A17: 1 *'Starts the enumeration of calculation steps'*

Cell B17: =A10 *'Repeats population size for iterative calculations'*

Cell C17: =D10 *'Repeats starting sample size for iterative calculations'*

Cell D17: =H10 *'Repeats total number of fails at RQL value'*

Cell E17: =IF(K10<=H10,K10,H10) *'Repeats starting acceptance number, if the value from the data table is greater than the total number of fails at the RQL, then it returns the total number of fails at the RQL, cell H10'*

Cell F17: =CumHyperGeom(E17,C17,D17,B17) *'Calculates the cumulative hypergeometric probability based on the given arguments, uses user-defined CumHyperGeom function'*

Cell H17: =A10 *'Repeats population size for iterative calculations'*

Cell I17: =D10 *'Repeats starting sample size for iterative calculations'*

Cell J17: =F10 *'Repeats total number of fails at AQL value'*

Cell K17: =E17 *'Repeats the acceptance number determined in the same row in column E'*

Cell L17: =CumHyperGeom(K17,I17,J17,H17) *'Calculates the cumulative hypergeometric probability based on the given arguments, uses user-defined CumHyperGeom function'*

Cells N17 to N400: =IF(AND(F17<=$B$2,L17>=1-$A$2),I17,"Fail") *'Determines if the sample size and acceptance number for the corresponding row meets the risk limits, if true, then returns the sample size for that rows calculation'*

Cells O17 to O400: =IF(AND(F17<=$B$2,L17>=1-$A$2),K17,"Fail") *'Determines if the sample size and acceptance number for the corresponding row meets the risk limits, if true, then returns the acceptance number for that rows calculation'*

Cell Q17: =MinNumber(N17:N400,E2) *'Return the minimum number in the range of cells N17 to N400, this is the minimum calculated sample size, uses user-defined function MinNumber'*

Cell R17: =MinNumber(O17:O400,K10) *'Return the minimum number in the range of cells O17 to O400, this is the minimum calculated acceptance number, uses user-defined function MinNumber'*

Cells A18 to A400: =IF(ISNUMBER(C17),A17+1," ") *'Returns the step number for each iteration until finished with calculations, then returns a blank'*

Cells B18 to B400: =IF(ISNUMBER(A18),B17," ") *'Returns the population size for each iteration until finished with calculations, then returns a blank'*

Cells C18 to C400: =IF(AND(F17<=$B$2,L17>=1-$A$2,C17>1),C17-1,IF (N16="Fail, IF(C17>1,C17-1," "),C17+1)) *'Returns the sample size for the a row's calculation, if the previous row's sample plan was within risk limits, it decreases the sample size by one; if the row previous was not feasible, it increases the sample size by one; if the two previous rows were not feasible it will still decrease by one'*

Cells D18 to D400: =IF(ISNUMBER(A18),D17," ") *'Returns the number of fails at the RQL value for each row's calculations; returns a blank when the calculations are done'*

Cells E18 to E400: =IF(AND(F17<=$B$2,L17>=1-$A$2),E17, IF(N16="Fail", E17,E17-1)) *'If the previous row's plan was feasible, returns the same acceptance number again; if the previous row's plan is not feasible but two rows previous is also not feasible, returns the same acceptance number again; if the previous row is not feasible and two previous is feasible, the acceptance number is decreased by one'*

Cells F18 to F400: =IF(ISNUMBER(C18),CumHyperGeom(E18,C18,D18,B18), " ") *'Calculates the cumulative hypergeometric probability based on the given arguments, uses user-defined CumHyperGeom function; returns a blank when the iterations are done'*

Cells H18 to H400: =IF(ISNUMBER(A18),H17," ") *'Returns the population size for each iteration until finished with calculations, then returns a blank'*

Cells I18 to I400: =IF(ISNUMBER(C18),C18," ") *' Repeats the sample size value in the column C; returns a blank when iterations are done'*

Cells J18 to J400: =IF(ISNUMBER(A18),J17," ") *'Returns the number of fails at the AQL value for each row's calculations; returns a blank when the calculations are done'*

Cells K18 to K400: =IF(ISNUMBER(E18),E18," ") *'Repeats the acceptance number from that row in column E'*

Cells L18 to L400: =IF(I18>0,CumHyperGeom(K18,I18,J18,H18)," ") *'Calculates the cumulative hypergeometric probability based on the given arguments, uses user-defined CumHyperGeom function; returns a blank when the iterations are done'*

Cell Q20: =IF(R20="FAIL","FAIL",Q17) *'Repeats the value of cell Q17 if the acceptance number in cell R20 is not a "FAIL"; else returns a "FAIL"*

Cell R20: =IF(O17="FAIL",IF(R17=K10,"FAIL",R17),R17) *'Determines if the first iteration fails and the acceptance number does not change from the starting acceptance number, then the acceptance number is returned as a "FAIL"*

Macros Used by Worksheet

Return to Home Sheet Button:

```
'Code for all return to home sheet buttons
Sub ReturnToHomeSheet()
  Worksheets("Sampling Plan").Activate
  Range("A1").Select
End Sub
```

Toggle Help On/Off Button:

```
'Code for help button on Single sheet
Sub ShowSingleSampleHelp()
  ActiveSheet.TextBoxes("SingleSampleHelpText").Visible = _
    Not ActiveSheet.TextBoxes("SingleSampleHelpText").Visible
End Sub
```

Sheet Explanation Button:

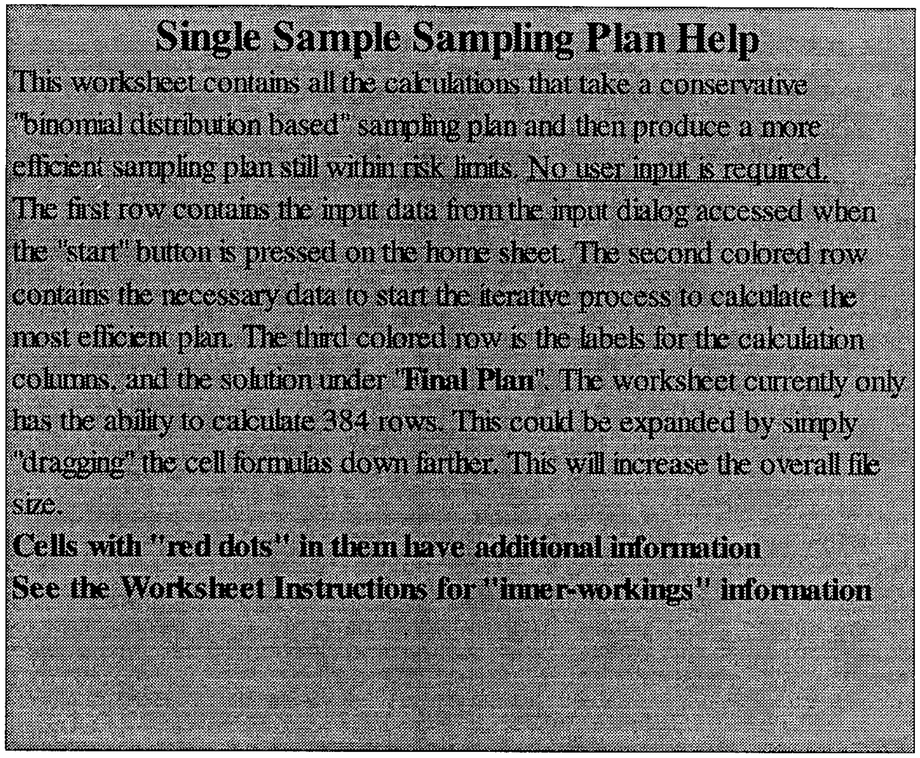
```
'Code for detailed help button on Single Sheet
Sub ShowSingleSampleSheetHelp()
   ActiveSheet.TextBoxes("SingleSampleSheetHelpText").Visible = _
     Not ActiveSheet.TextBoxes("SingleSampleSheetHelpText").Visible
End Sub
```

User-Defined Functions

```
'Code for function that return a minimum number in a range of values that can have text
'and numbers. List is the range of data, Population is the number to start comparison on
Function MinNumber(List, Population)
        MinNum = Population
        For Each Item In List
        'Make sure the cell contents is a number
                If Application.IsNumber(Item) Then
                  If Item < Population Then
                       MinNum = Item
                  End If
                End If
        Next Item
        MinNumber = MinNum
End Function

'Code for function that gives the cumulative hypergeometric probability. Function
'calculates discrete probabilities for each value of x and checks to make sure none are
'an error value. Then sums the non-error calculations
Function CumHyperGeom(x, n, m, Population)
        For Counter = x To 0 Step -1
           Hold = Application.HypGeomDist(Counter, n, m, Population)
           If Application.IsError(Hold) Then
               Hold = 0
               Sum = Sum + Hold
             Else
               Sum = Sum + Hold
           End If
         Next Counter
        CumHyperGeom = Sum
End Function
```

Text Boxes



Single Sample Sampling Plan Help

This worksheet contains all the calculations that take a conservative "binomial distribution based" sampling plan and then produce a more efficient sampling plan still within risk limits. No user input is required. The first row contains the input data from the input dialog accessed when the "start" button is pressed on the home sheet. The second colored row contains the necessary data to start the iterative process to calculate the most efficient plan. The third colored row is the labels for the calculation columns, and the solution under "**Final Plan**". The worksheet currently only has the ability to calculate 384 rows. This could be expanded by simply "dragging" the cell formulas down farther. This will increase the overall file size.

Cells with "red dots" in them have additional information

See the Worksheet Instructions for "inner-workings" information

Figure 34. Displayed text Box for Toggle Help ON/OFF Button

Single Sample Worksheet Detailed Instructions

This sheet goes through a detailed explanation of the procedures and calculations for the worksheet. The sheet autocalculates, so no action is required, this text box is purely for documentation.

The first colored row has inputs linked to the "dialog box" activated when the start button is hit on the home sheet. Cells A2 and B2 get their values from a nested "IF" formula based on the contents of cells A3 and A4. Cells A3 and A4 are linked to the "radio buttons" on the input dialog box referenced above. The values of E2, F2, and G2 are linked to the edit boxes on the input dialog box through the macro procedure "GetInfo_Show" located in worksheet "module2".

The second colored row has values necessary to start the iterative calculations. Cell A10 is simply linked to cell E2. Cell F10 and H10 are the rounded product of the AQL or RQL percentage and the population, E2. The values are rounded because you cannot have anything other than an integer number of failures.The starting sample size, D10, and the starting acceptance number K10 are linked to the Data Table worksheet and are the principal outputs of that sheet. If the "data table" requires a starting sample size greater than the population, the starting sample size is lessened to one less than the population.

The third colored row indicates the start of the calculations and the hart of the worksheet. Column descriptions are in the cell notes (the little red dots). The workings or the iterative process start with the "starting" sample size and acceptance number. These are the only values that change in the calculations. The other columns except for the "F(x)" column remain constant. Starting with the first iterative row (row 17), working from left to right, cell F17 calculates the probability of getting E17 or less failures in a random sample of C17 taken from a lot of B17 size of which D17 failures exist. This probability is calculated using a user-defined funtion of the cumulative hypergeometric distribution located in the worksheet called module1. The same process is repeated for cell L17, using the values in H17,I17, J17, and K17. The probability in F17 is compared to the beta vale (it shold be less than or equal) and the probability in L17 is compared to the alpha value(itshould be greater than or equal). If the probabilities pass this comparison, the accepatnce number and sample size qualify and are displayed in cells N17 and O17. If one or both fail, a "FAIL" is displayed in the cells. The iterative process now reduces the sample size by one in the next row and repeats. If the row results in a "Fail" in columns N and O after a previous valid plan, then on the next row, the sample in increased one and the accceptance number is decreased one. The process continues. The iterations continue to step the sample size and acceptance number down until there are no more plans that meet the alpha and beta limits.

The last calculations occur in columns Q and R. Cells Q17 and R17 use a user-defined function in module1 to find the minimum number in columns N and O. Cells Q20 and R20 check to see if the minimum plan is valid. They do this by looking at the final answer compared to the starting plan from the "Data Table" sheet. If the starting plan is the same as the final answer and the first row of calculations indicated a "FAIL", then with the given input parameters, a sampling plan is not possible or warrented.

Figure 35. Displayed Text Box for Sheet Explanation Button

OC Curve Worksheet

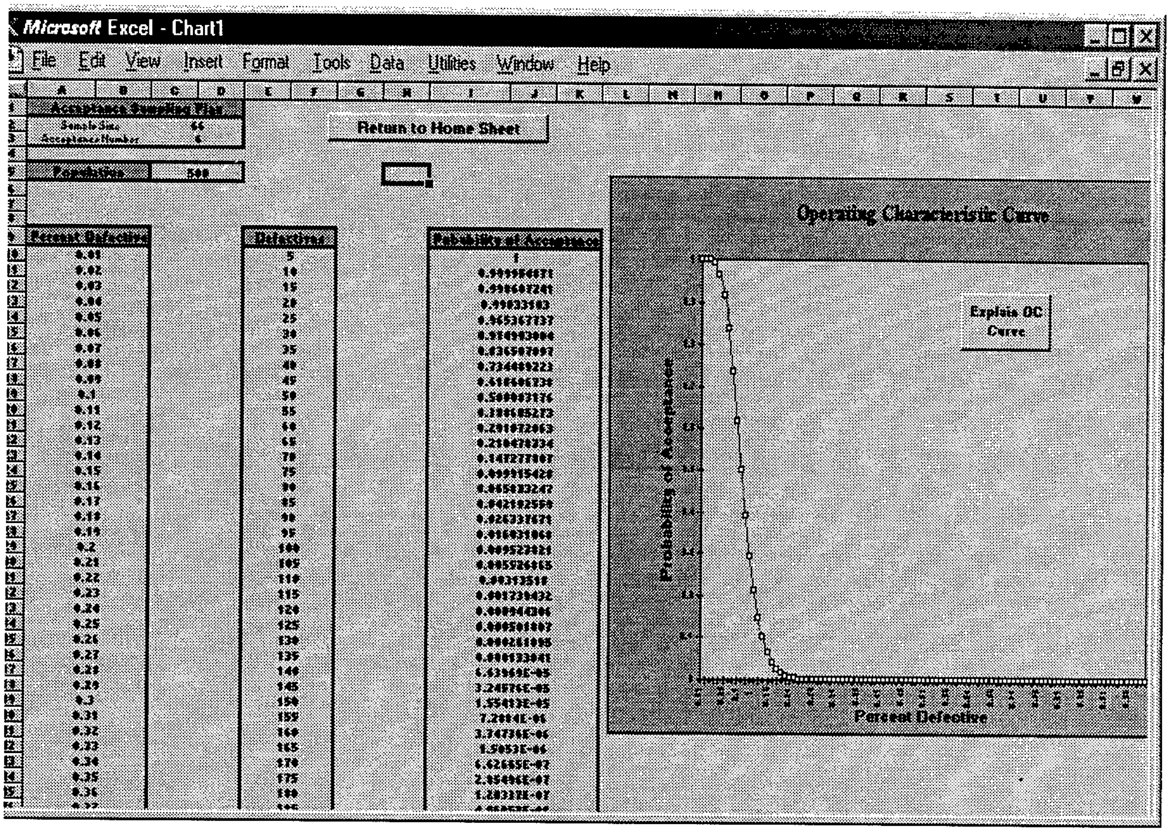


Figure 36. Screen Capture of OC Curve Worksheet

Cell Formulas

Cell C2: =Single!Q20 *'Repeats Most Efficient Sample Size'*

Cell C3: =Single!R20 *'Repeats Most Efficient Acceptance Number'*

Cell C5: =Single!E2 *'Repeats the population size'*

Cell A10: 0.01 *'The first x-coordinate in the OC Curve'*

Cells A11 to A109: =0.01+A10 *'Enumerates the x-coordinates .01 at a time'*

Cells E10 to E109: =ROUND($C$5*A10,0) *'The number of defectives in the population given in cell C5, given the percent defective from the cell in the same row in column A; the number is rounded to the nearest integer'*

Cells I10 to I109: =CumHyperGeom($C$3,$C$2,E10,$C$5) *'Returns the cumulative hypergeometric probability based on the arguments in parenthesis; the user-defined function CumHyperGeom is used'*

Macros Used by Worksheet

Return to Home Sheet Button:

```
'Code for all return to home sheet buttons
Sub ReturnToHomeSheet()
   Worksheets("Sampling Plan").Activate
   Range("A1").Select
End Sub
```

Explain OC Curve Button:

```
'Code for help button on OC Curve on OC Curve Sheet
Sub ShowOCHelp()
   ActiveSheet.TextBoxes("OCHelpText").Visible = _
     Not ActiveSheet.TextBoxes("OCHelpText").Visible
End Sub
```

Text Boxes

Operating Charateristic Curve Help

This graph shows the probability of acceptance of the inspected lot (with the given sampling plan) for varying percent defectives. Percent defective can be defined as 1 - pass rate. The graph will show how the plan meets the specified risk limits. If you plot a vertical line from the AQL value until it hits the plotted curve, the distance above the curve will be equal to or less than the alpha value. Likewise, at the RQL value the distance below the curve will be equal to or less than the beta value. If you know or suspect the true pass rate in a population, you can look at the OC curve and see the probability of passing the given acceptanc plan for that pass rate.

The curve on the graph may have some flat segements and not appear smooth for plans based on low populations. This is because at a given percent defective you can only have an integer number of failures, I.e. you cannot have 2.3 failures only 2. This rounding effect can cause the probability of acceptance at percent defective values close to each other to be the same. This "non-smooth" effect will lessen with growing population size. It has no effect on the validity of the sampling plan.

Figure 37. Displayed Text Box for Explain OC Curve Button

Displayed Graphs

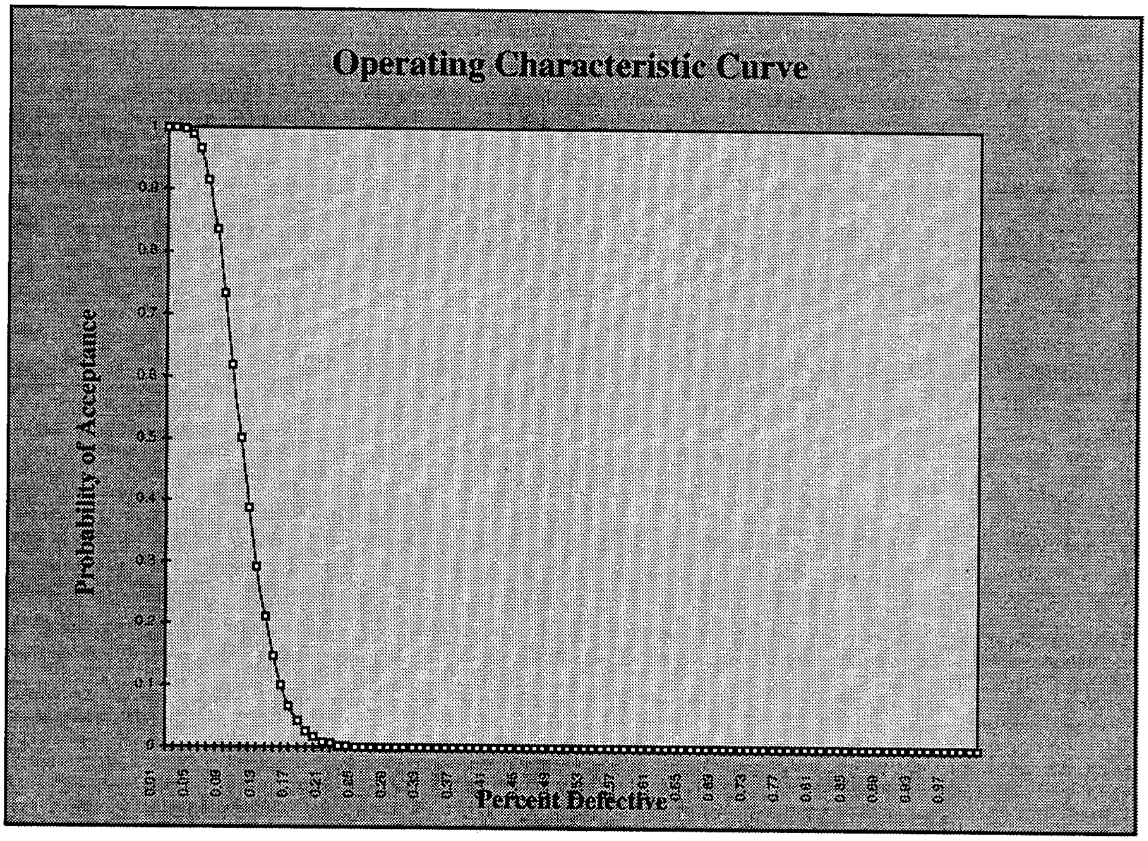


Figure 38. Displayed OC Curve

Seq Sample Worksheet

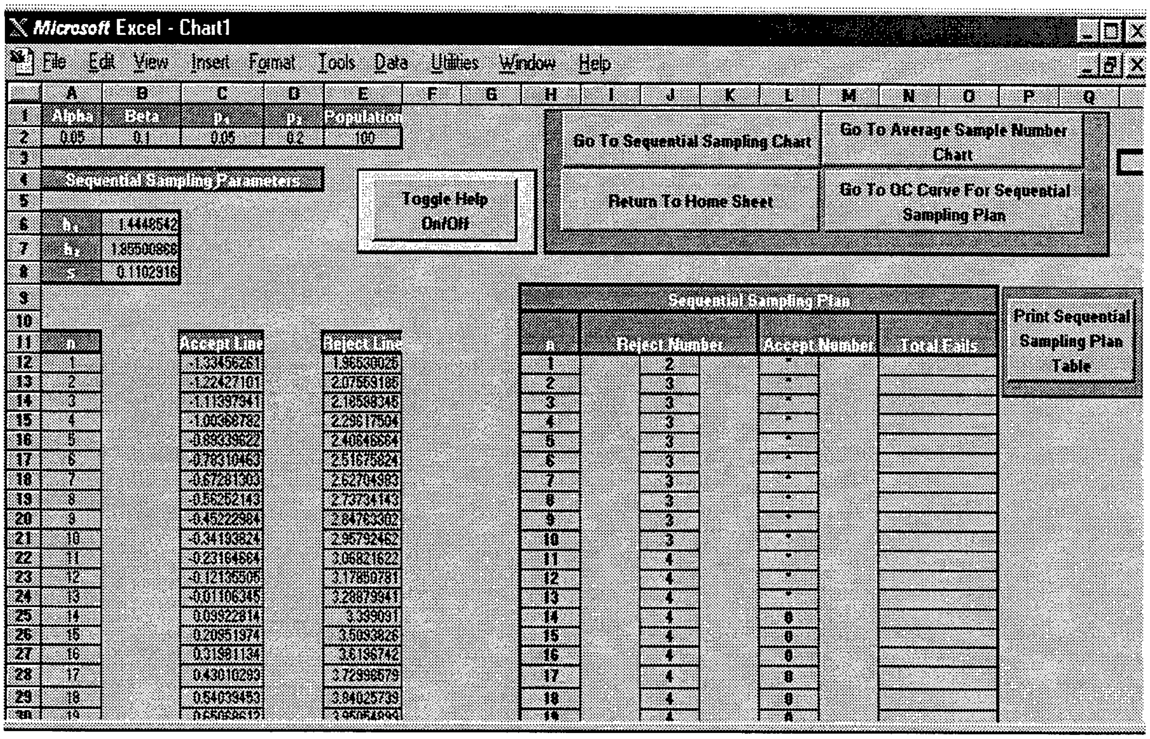


Figure 39. Screen Capture of Sequential Sampling Worksheet

Cell Formulas

Cell A2: =Single!A2 *'Repeats alpha risk level from Single worksheet'*

Cell B2: =Single!B2 *'Repeats beta risk level from Single worksheet'*

Cell C2: =Single!F2 *'Repeats the AQL value from Single worksheet'*

Cell D2: =Single!G2 *'Repeats the RQL value from Single worksheet'*

Cell E2: =Single!E2 *'Repeats the population value from Single worksheet'*

Cell B6: =(LN((1-A2)/B2))/(LN(D2/C2)+LN((1-C2)/(1-D2))) *'Returns the value of* h_1 *using the formula on page 2-17'*

Cell B7: =(LN((1-B2)/A2))/(LN(D2/C2)+LN((1-C2)/(1-D2))) *'Returns the value of* h_2 *using the formula on page 2-17'*

Cell B8: =(LN((1-C2)/(1-D2)))/(LN(D2/C2)+LN((1-C2)/(1-D2))) *'Returns the value of s using the formula on page 2-17'*

Cell A12: 1 *'The first point on the sequential sampling chart'*

Cells A13 to A(population size + 11): =IF(A12<E$2,A12+1," ") *' Returns the number of the next point until the number of points equals the population size, then returns blanks'*

Cells C12 to C(population size + 11): =IF(ISNUMBER(A12),(B$8*A12)-B$6," ") *'Returns the value of the accept line corresponding to the point in column A, same row; uses the equation of the accept line given on page 2-17, returns a blank when the number of plotted points equals the population size'*

Cells E12 to E(population size + 11): =IF(ISNUMBER(A12),(B$8*A12)+B$7, " ") *'Returns the value of the reject line corresponding to the point in column A, same row; uses the equation of the reject line given on page 2-17, returns a blank when the number of plotted points equals the population size'*

Cell H12: 1 *'The first point on the table form of the sequential sampling chart'*

Cells H13 to H(population size + 11): =IF(H12<E$2,H12+1," ") *'Returns the number of the next point in the table form of the sequential chart until the number of points equals the population size, then returns blanks'*

Cells J12 to J(population size + 11): =IF(ISNUMBER(A12),ROUNDUP(E12,0), " ") *'Returns the first integer number above the reject line at that point on the horizontal axis of the sequential sampling chart'*

Cells L12 to L(population size + 11): =IF(ISNUMBER(A12),IF(C12<=0,"*", ROUNDDOWN(C12,0))," ") *'Returns the first integer below the accept line at that point on the horizontal axis of the sequential sampling chart'*

Macros Used by Worksheet

Toggle Help ON/OFF Button:

```
'Code for detailed help button on Sequential Sample Sheet
Sub ShowDetailedSequentialSampleHelp()
  ActiveSheet.TextBoxes("SeqSampleHelpText").Visible = _
   Not ActiveSheet.TextBoxes("SeqSampleHelpText").Visible
End Sub
```

Go To Sequential Sampling Chart Button:

```
'This code moves you to the chart on the sheet
Sub GoToSeqSamplingChart()
  ActiveSheet.Range("Z2").Select
End Sub
```

Return To Home Sheet Button:

```
'Code for all return to home sheet buttons
Sub ReturnToHomeSheet()
  Worksheets("Sampling Plan").Activate
  Range("A1").Select
End Sub
```

Go To Average Sample Number Chart Button:

```
'This code moves you to the chart on the sheet
Sub GoToSeqSamplingAvgSample()
  ActiveSheet.Range("BA49").Select
End Sub
```

Go To OC Curve For Sequential Sampling Plan Button:

```
'This code moves you to the chart on the sheet
Sub GoToSeqSamplingOCcurve()
   ActiveSheet.Range("AT3").Select
End Sub
```

Print Sequential Sampling Plan Table Button:

```
'This code allows the user to print via a button the sequential sampling table
Sub PrintSeqTable()
   Sheets("Seq Sample").Select
   LastRow = Sheets("Seq Sample").Range("Population") + 11
   SeqTableBlock = "H9:O" & LTrim(Str(LastRow))
   Range(SeqTableBlock).Select
   ActiveSheet.PageSetup.PrintArea = Selection.Address
   ActiveSheet.PageSetup.Orientation = xlPortrait
   ActiveWindow.SelectedSheets.PrintOut Copies:=1
   ActiveSheet.PageSetup.Orientation = xlLandscape
   ActiveSheet.PageSetup.PrintArea = ""
   Sheets("Seq Sample").Range("L8").Select
End Sub
```

Text Boxes

Sequential Sampling Worksheet Help

This worksheet gives a complete and automatic sequential sample plan for a set of input parameters. The input parameters are in cells A1 to E1 and repeat the inputs for the acceptance sampling plan. In order to build a sequential sampling plan, you have to build the sequential sample chart which has two parallel lines that determine a "pass" and "fail" region. The cell range B6 to B8 has the necessary values to plot these lines. Cell B6 has the y intercept for the line that borders the fail region, cell B7 has the y intercept for the line that borders the pass region. The value in B8 is the slope of the two parallel lines. Now knowing the formula for the two lines, the value of each line at points one to the population size is calculated in the columns under cell C11 and E11. This calculation of points is represented by the graph found by pressing the "Go To Sequential Sampling Chart" button. The sequential chart does not update each time a new sampling plan is calculated, therefore, the "Update Chart Button" must be pressed each time you calculate a new plan. The button is located next to the chart. A button next to the chart also allows you to print the sequential sampling chart for application of a plan. The way you interpret the graph for application can best be described as taking a sample one item at a time, and making a pass, fail or continue sampling call after each sample taken. In the sequential graph, the horizontal axis is the sample size, taken one item at a time. It span from one to the total population size, because you could possibly take a total sample size approaching the population size. The vertical axis is the total number of failures as you take each sample. The graph of total fails as sample size increases will either cross the fail line, pass line or remain between the two lines. If the plot of total fails crosses a line, then you are done. As long as the plot of total fails remains between the two lines, you continue taking single samples.

The columns from H9 to M9 is a chart representing the sequential graph in another fashion. The column under H11 is the sample size or the same as the horizontal axis in the graph. In this chart you must remember the total number of failures as they add up. The column under J11 and L11 represent the number of failures that will put you into the pass or fail region for the corresponding sample (row). If you have an asterisk in the "Accept" column, that means you do not have the minimum sample size yet to pass into the "pass region" with no failures. An example, you are on the 10th sample taken, for that row the reject number is 3 and the accept number is 0. This means if you have more than 3 failures total when you take the tenth sample, you are in the "fail" region now and the lot fails. If the total fails is still zero, then you have passed into the pass region and the lot has passed.

A couple of diagnostic graphs are also produced. One graph shows the "Average Sample Number". This chart shows the average number of items you could expect to sample using a sequential sampling plan for a given percent defective within the sampled lot. For example, if your lot of items has an actual percent defective of 10% (ten percent are fails), then find this value on the horizontal axis, go up to the graphed line to find the expected total number of sampled items. The second diagnostic graph is the "Operating Characteristic Curve". This graph shows the probability of acceptance (the lot passes) for a given percent defective. The horizontal graph shows the percent defective and the vertical axis shows the probability of acceptance. The horizontal axis will always range from the inputted AQL to the RQL value. The Operating Characteristic Curve allows you to analyze the expected performance of the plan at varying percent defectives for the sampled lot.

Figure 40. Sequential Sampling Worksheet Help Text Box

Seq Sample Worksheet Graphs

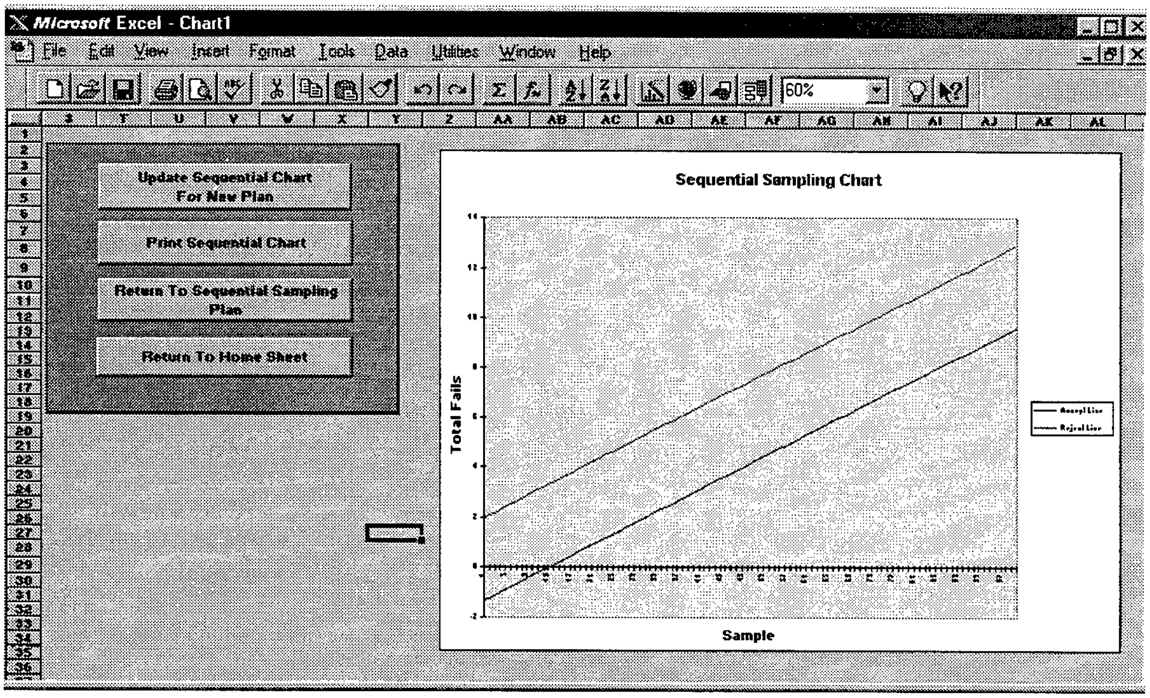


Figure 41. Screen Capture of Sequential Chart on Seq Sample Worksheet

Macros Used by Sequential Chart

Update Sequential Chart For New Plan Button:

```
'This macro allows a chart to be updated with new information that is of a
'different size than the previously graphed data
Sub PlotSequentialChart()
   Sheets("Seq Sample").Select
   'This check allows you to delete the old chart then redraw
   If Range("AE10") = True Then
      ActiveSheet.DrawingObjects("SeqChart").Select
      Selection.Delete
   End If
   Range("Z2").Select
   'Work-around to input the new range of data into the chartwizard command
   LastRow = Sheets("Seq Sample").Range("Population") + 11
   SeqChartBlock = "C11:C" & LTrim(Str(LastRow)) & ",E11:E"&
LTrim(Str(LastRow))
   ActiveSheet.ChartObjects.Add(1264.5, 21, 585, 289.5).Select
   Application.CutCopyMode = False
   'Redraw based on new range of data
   ActiveChart.ChartWizard Source:=Sheets("Seq Sample").Range( _
```

```
    SeqChartBlock), Gallery:=xlLine, Format:=2, PlotBy:= _
    xlColumns, CategoryLabels:=0, SeriesLabels:=1, HasLegend:=1, _
    Title:="Sequential Sampling Chart", CategoryTitle:="Sample", _
    ValueTitle:="Total Fails", ExtraTitle:=""
Selection.Width = 603.75
Selection.Height = 436.5
'Chart is given a name for reference to later
Selection.Name = "SeqChart"
ActiveSheet.ChartObjects("SeqChart").Activate
ActiveChart.ChartTitle.Select
With Selection.Font
    .Name = "Arial"
    .FontStyle = "Bold"
    .Size = 14
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlNone
    .ColorIndex = xlAutomatic
    .Background = xlAutomatic
End With
ActiveChart.Axes(xlValue).AxisTitle.Select
With Selection.Font
    .Name = "Arial"
    .FontStyle = "Bold"
    .Size = 12
    .Strikethrough = False
    .Superscript = False
    .Subscript = False
    .OutlineFont = False
    .Shadow = False
    .Underline = xlNone
    .ColorIndex = xlAutomatic
    .Background = xlAutomatic
End With
ActiveChart.Axes(xlCategory).AxisTitle.Select
With Selection.Font
    .Name = "Arial"
    .FontStyle = "Bold"
    .Size = 12
    .Strikethrough = False
    .Superscript = False
```

```
        .Subscript = False
        .OutlineFont = False
        .Shadow = False
        .Underline = xlNone
        .ColorIndex = xlAutomatic
        .Background = xlAutomatic
    End With
    ActiveChart.SeriesCollection(2).Select
    With Selection.Border
        .ColorIndex = 3
        .Weight = xlMedium
        .LineStyle = xlContinuous
    End With
    With Selection
        .MarkerBackgroundColorIndex = 2
        .MarkerForegroundColorIndex = 1
        .MarkerStyle = xlNone
        .Smooth = True
    End With
    ActiveChart.SeriesCollection(1).Select
    With Selection.Border
        .ColorIndex = 5
        .Weight = xlHairline
        .LineStyle = xlContinuous
    End With
    With Selection
        .MarkerBackgroundColorIndex = 2
        .MarkerForegroundColorIndex = 1
        .MarkerStyle = xlNone
        .Smooth = True
    End With
    ActiveWindow.Visible = False
    Windows("chart1.xls").Activate
    'give cell a true value to indicate next time redrawn that a previous drawn chart exists
    Range("AE10").Value = True
    Range("Y2").Select
End Sub
```

Print Sequential Chart Button:

'This code allows the user to print via a button the sequential sampling chart

```
Sub PrintSeqChart()
    Sheets("Seq Sample").Select
    Range("Z2:AL35").Select
    ActiveSheet.PageSetup.PrintArea = Selection.Address
```

```
    ActiveWindow.SelectedSheets.PrintOut From:=1, To:=1, Copies:=1
    ActiveSheet.PageSetup.PrintArea = ""
    Sheets("Seq Sample").Range("L8").Select
End Sub
```

Return To Sequential Sampling Plan Button:

```
'This code moves you to a spot on the sheet
Sub GoToSeqSampling()
    ActiveSheet.Range("M8").Select
End Sub
```

Return To Home Sheet Button:

```
'Code for all return to home sheet buttons
Sub ReturnToHomeSheet()
    Worksheets("Sampling Plan").Activate
    Range("A1").Select
End Sub
```

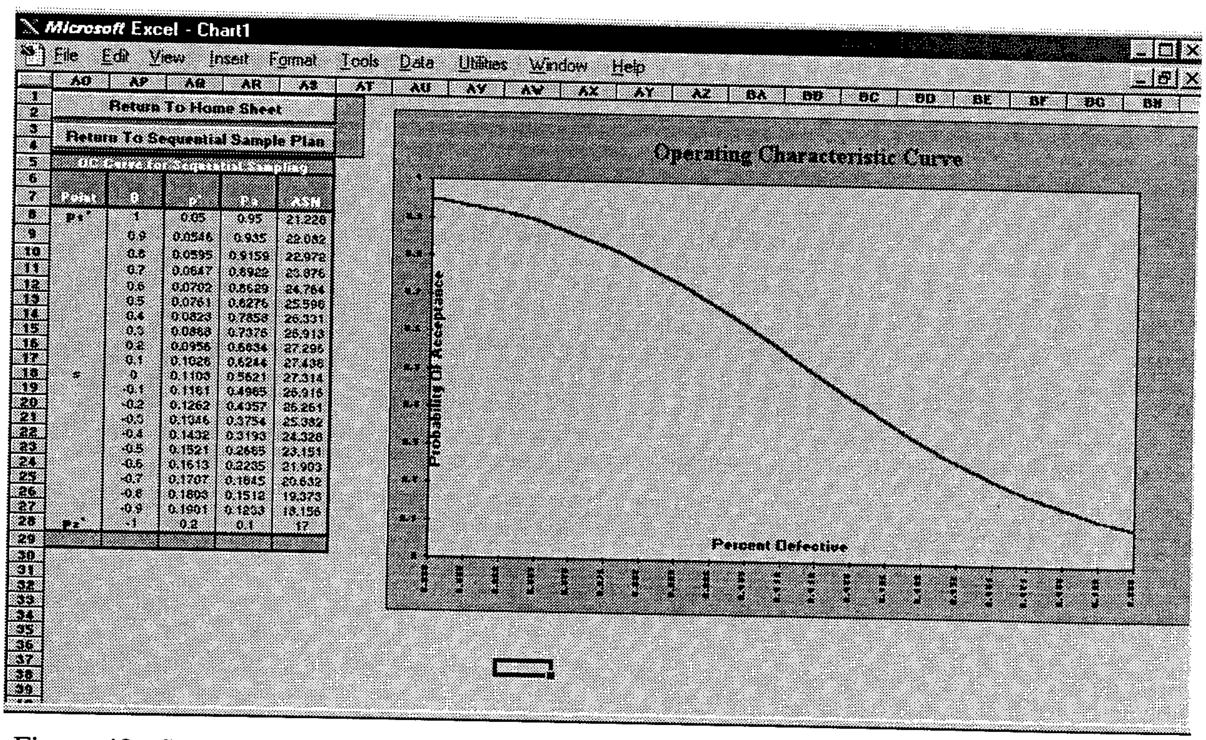


Figure 42. Screen Capture of Operating Characteristic Curve on Seq Sample Worksheet

Macros Used by Operating Characteristic Curve

Return To Home Sheet Button:

```
'Code for all return to home sheet buttons
Sub ReturnToHomeSheet()
   Worksheets("Sampling Plan").Activate
   Range("A1").Select
End Sub
```

Return To Sequential Sample Plan Button:

```
'This code moves you to a spot on the sheet
Sub GoToSeqSampling()
   ActiveSheet.Range("M8").Select
End Sub
```

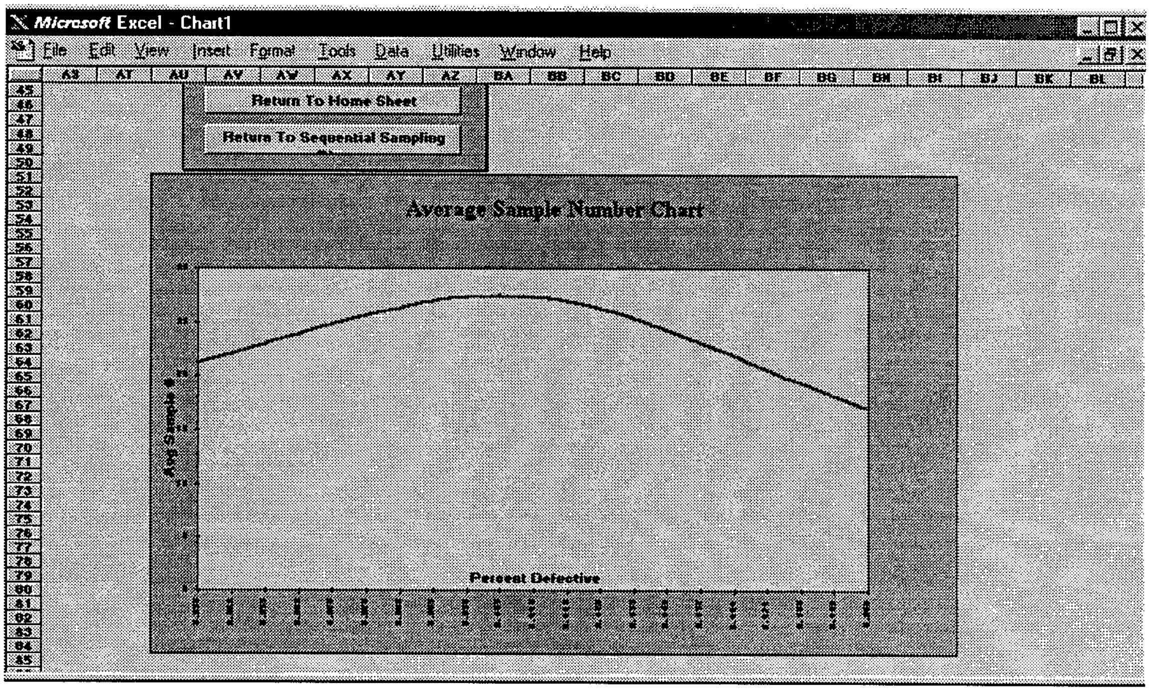


Figure 43. Screen Capture of Average Sample Number Chart on Seq Sample Worksheet

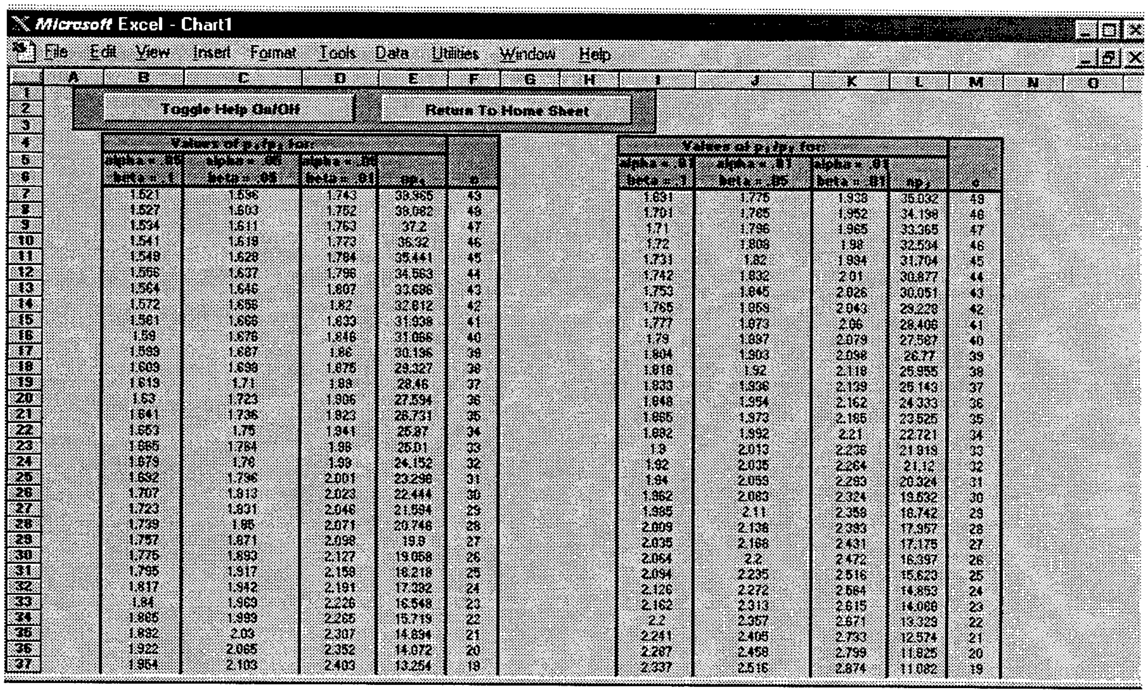
Macros Used by Average Sample Number Chart

Return To Home Sheet Button:

```
'Code for all return to home sheet buttons
Sub ReturnToHomeSheet()
   Worksheets("Sampling Plan").Activate
   Range("A1").Select
End Sub
```

Return To Sequential Sampling Plan Button:
'This code moves you to a spot on the sheet
```
Sub GoToSeqSampling()
   ActiveSheet.Range("M8").Select
End Sub
```

Data Table Worksheet



Values of p_1/p_0 for: alpha = .05 beta = .1	alpha = .05 beta = .05	alpha = .05 beta = .01	np_1	c
1.521	1.596	1.743	39.965	49
1.527	1.603	1.752	39.082	48
1.534	1.611	1.763	37.2	47
1.541	1.619	1.773	36.32	46
1.549	1.628	1.784	35.441	45
1.556	1.637	1.796	34.563	44
1.564	1.646	1.807	33.686	43
1.572	1.656	1.82	32.812	42
1.581	1.666	1.833	31.938	41
1.59	1.676	1.846	31.066	40
1.599	1.687	1.86	30.196	39
1.609	1.698	1.875	29.327	38
1.619	1.71	1.89	28.46	37
1.63	1.723	1.906	27.594	36
1.641	1.736	1.923	26.731	35
1.653	1.75	1.941	25.87	34
1.665	1.764	1.96	25.01	33
1.679	1.78	1.98	24.152	32
1.692	1.796	2.001	23.296	31
1.707	1.813	2.023	22.444	30
1.723	1.831	2.046	21.594	29
1.739	1.85	2.071	20.748	28
1.757	1.871	2.098	19.9	27
1.775	1.893	2.127	19.058	26
1.795	1.917	2.158	18.218	25
1.817	1.942	2.191	17.382	24
1.84	1.969	2.226	16.548	23
1.865	1.999	2.265	15.719	22
1.892	2.03	2.307	14.894	21
1.922	2.065	2.352	14.072	20
1.954	2.103	2.403	13.254	19

Values of p_1/p_0 for: alpha = .01 beta = .1	alpha = .01 beta = .05	alpha = .01 beta = .01	np_1	c
1.691	1.775	1.938	35.032	49
1.701	1.785	1.952	34.198	48
1.71	1.796	1.965	33.365	47
1.72	1.808	1.98	32.534	46
1.731	1.82	1.994	31.704	45
1.742	1.832	2.01	30.877	44
1.753	1.845	2.026	30.051	43
1.765	1.859	2.043	29.228	42
1.777	1.873	2.06	28.408	41
1.79	1.887	2.079	27.587	40
1.804	1.903	2.098	26.77	39
1.818	1.92	2.118	25.955	38
1.833	1.936	2.139	25.143	37
1.848	1.954	2.162	24.333	36
1.865	1.973	2.185	23.525	35
1.882	1.992	2.21	22.721	34
1.9	2.013	2.236	21.919	33
1.92	2.035	2.264	21.12	32
1.94	2.059	2.293	20.324	31
1.962	2.083	2.324	19.532	30
1.985	2.11	2.358	18.742	29
2.009	2.138	2.393	17.957	28
2.035	2.168	2.431	17.175	27
2.064	2.2	2.472	16.397	26
2.094	2.235	2.516	15.623	25
2.126	2.272	2.564	14.853	24
2.162	2.313	2.615	14.088	23
2.2	2.357	2.671	13.329	22
2.241	2.405	2.733	12.574	21
2.287	2.458	2.799	11.825	20
2.337	2.516	2.874	11.082	19

Figure 44. Screen Capture of Data Tables

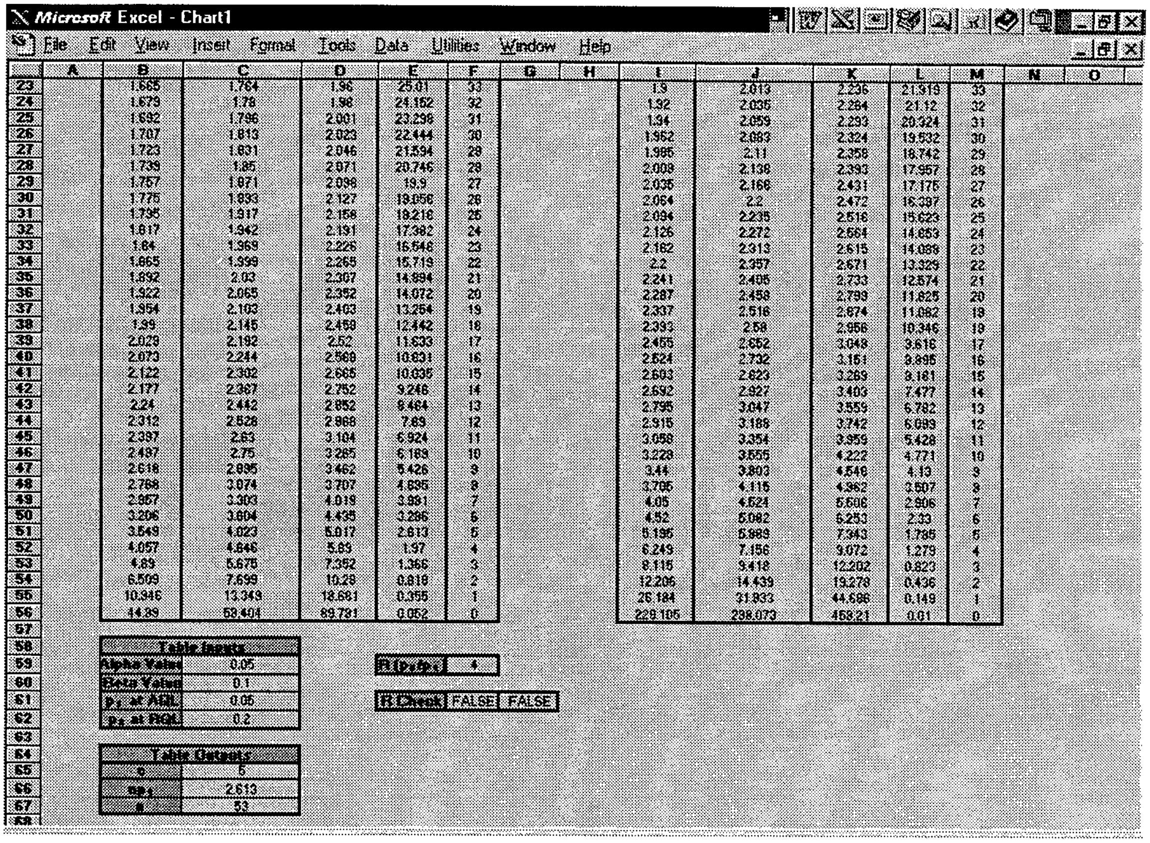


Figure 45. Screen Capture of Lookup Calculations on Data Table Worksheet

Cell Formulas

Cell C59: =Single!A2 *' Repeats alpha risk level'*

Cell C60: =Single!B2 *' Repeats beta risk level'*

Cell C61: =Single!F2 *'Repeats AQL value'*

Cell C62: =Single!G2 *'Repeats RQL value'*

Cell F59: =C62/C61 *'Calculates operating ratio to use as a lookup value'*

Cell C65: =IF(F61=FALSE,IF(C59=0.05,IF(C60=0.1,VLOOKUP(F59,B7:F56,5), IF(C60=0.05,VLOOKUP(F59,C7:F56,4),IF(C60=0.01,VLOOKUP(F59,D7:F56,3)))),IF(C60=0.1,VLOOKUP(F59,I7:M56,5),IF(C60=0.05,VLOOKUP(F59,J7:M56,4),IF(C60=0. 01,VLOOKUP(F59,K7:M56,3))))),F61) *'This nested IF statements uses the lookup value from cell F59 to find the right table, then right column within the table, then the correct row; returns the acceptance number'*

Cell C66: =IF(G61=FALSE,IF(C59=0.05,IF(C60=0.1,VLOOKUP(F59,B7:F56,4), IF(C60=0.05,VLOOKUP(F59,C7:F56,3),IF(C60=0.01,VLOOKUP(F59,D7:F56,2)))),IF(C60=0.1,VLOOKUP(F59,I7:M56,4),IF(C60=0.05,VLOOKUP(F59,J7:M56,3),IF(C60=0. 01,VLOOKUP(F59,K7:M56,2))))),G61) *'This nested IF statements uses the lookup value from cell F59 to find the right table, then right column within the table, then the correct row; returns* np_1*'*

Cell C67: =ROUNDUP(C66/C61,0) *'Returns the starting sample size by dividing the value in cell C66 by the AQL value; rounds to nearest integer value'*

Cell F61: =IF(C59=0.05,IF(F59<1.521,49,FALSE),IF(F59<1.691,49,FALSE)) *'Returns FALSE if the lookup value exists on the table, if the value is not available on the table returns the starting value of 49'*

Cell G61: =IF(C59=0.05,IF(F59<1.521,38.965,FALSE), IF(F59<1.691,35.032, FALSE)) *'Returns FALSE if the lookup value exists on the table, if the value is not available on the table returns the starting value of 38.965 or 35.032 depending on the appropriate table'*

Macros Used by Worksheet

Toggle Help On/Off Button:

```
'Code for help button on Data Table sheet
Sub ShowDataTableHelp()
  ActiveSheet.TextBoxes("HelpDataTableText").Visible = _
    Not ActiveSheet.TextBoxes("HelpDataTableText").Visible
End Sub
```

Return To Home Sheet Button:

```
'Code for all return to home sheet buttons
Sub ReturnToHomeSheet()
  Worksheets("Sampling Plan").Activate
  Range("A1").Select
End Sub
```

Text Boxes

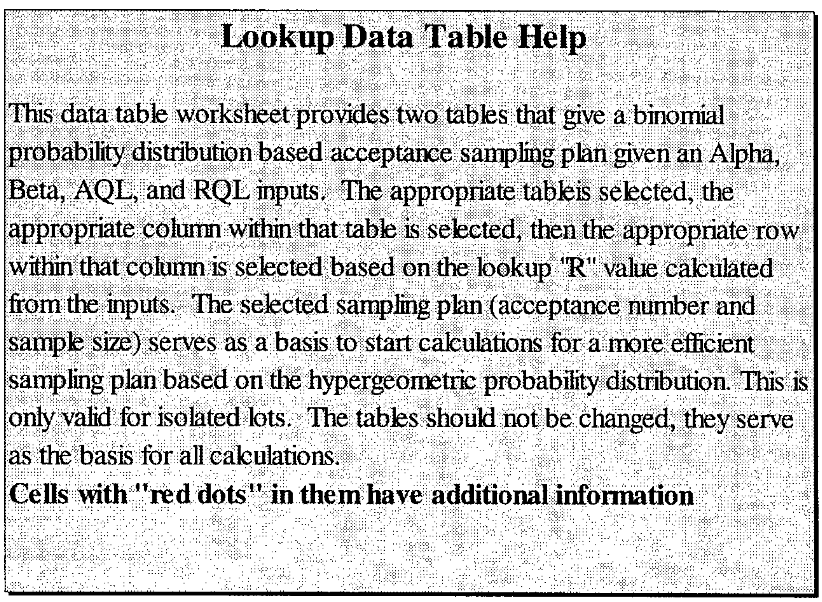


Figure 46. Data Table Worksheet Help Text Box

Variations Worksheet

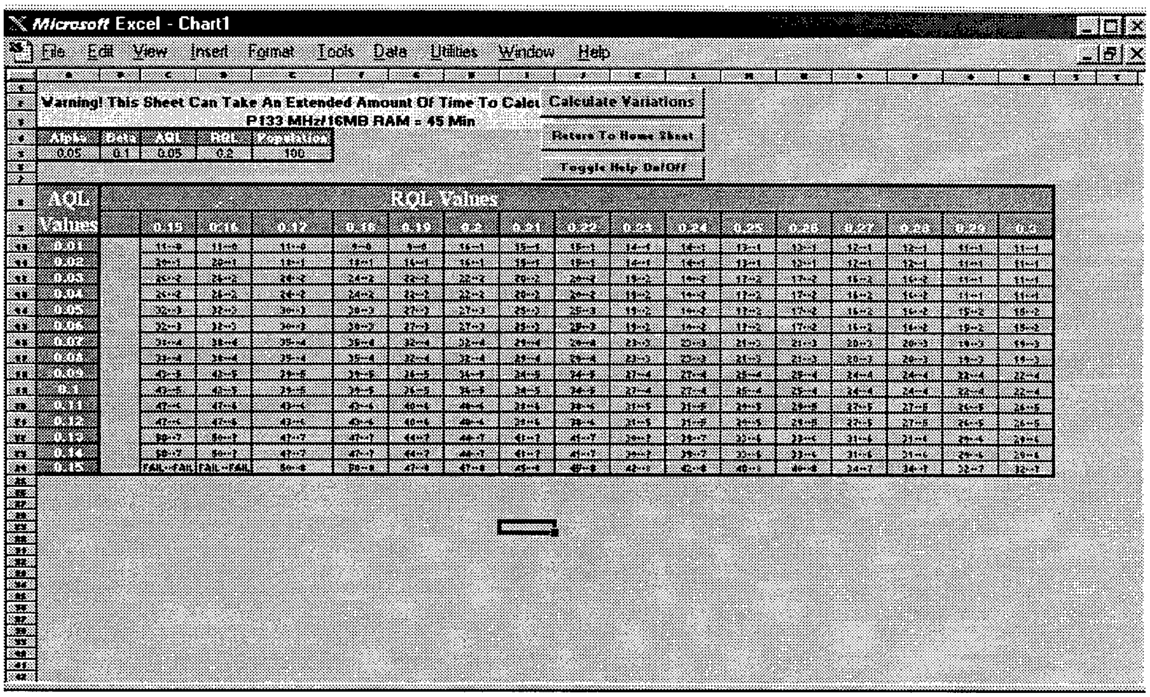


Figure 47. Screen Capture of Variations Worksheet

Cell Formulas

Cell A5: =Single!A2 *'Repeats the alpha risk level'*
Cell B5: =Single!B2 *'Repeats the beta risk level'*
Cell C5: =Single!F2 *'Repeats the AQL value'*
Cell D5: =Single!G2 *'Repeats the RQL value'*
Cell E5: =Single!E2 *'Repeats the population value'*

Macros Used by Worksheet

Calculate Variations Button:

```
'This code runs a loop through all the potential AQL, RQL values and returns the plan
Sub CalculateVariations()
' Loops through the AQL values
  For RowIndex = 10 To 24
  'Loops through the RQL values
    For ColIndex = 1 To 16
      Sheets("Single").Range("F2") = Sheets("Variations").Cells(RowIndex, 1)
      Sheets("Single").Range("G2") = Sheets("Variations").Cells(9, ColIndex + 2)
      SampleNum = Sheets("Single").Range("Q20")
      AcceptanceNum = Sheets("Single").Range("R20")
      Sheets("Variations").Cells(RowIndex, ColIndex + 2) = SampleNum & "--" &
AcceptanceNum
    Next ColIndex
```

```
   Next RowIndex
End Sub
```

Return To Home Sheet Button:

```
'Code for all return to home sheet buttons
Sub ReturnToHomeSheet()
   Worksheets("Sampling Plan").Activate
   Range("A1").Select
End Sub
```

Toggle Help On/Off Button:

```
'Code for detailed help button on Variations Sheet
Sub ShowDetailedVariationsHelp()
   ActiveSheet.TextBoxes("VariationsHelpText").Visible = _
    Not ActiveSheet.TextBoxes("VariationsHelpText").Visible
End Sub
```

Text Boxes

Acceptance Sampling Plan Variations Help

This sheet calculates an array of acceptance sampling plans by varying the AQL and RQL values. The results in each cell are in the format "Sample Number -- Acceptance Number". One plan should be calculated using the start button on the "home Sheet" so the population is set. The cells A5 to E5 just show the inputs based on the dialog box when you hit the "Satart" button. The button "Calculate Variations" located on this sheet runs a macro called CalculateVariations which reruns a calculation of an acceptance plan based on the AQL values in column A and the RQL values located in row 9. The whole process is automatic and no further inputs required once you hit the "Calculate Variations" button. Once started, the macro can take a long time based on the specifications of your system. As a reference, a plan based on a population of 100 took almost 45 minutes on a P133 system with 16 MB of RAM. Once started, you can exit the macro prematurely by hitting the escape key. While the macro is running you will not be able to perform any other tasks. This sheet will allow you to compare various inputs and the corresponding plan in a single glance. Some plans can be the same for close but different quality levels due to rounding, you cannot have 2.45 failures at a given percent defective, only integer values. This can cause two plans with close quality levels to have the same plan. This effect diminishes when population sizes grow.

Figure 48. Variations Worksheet Help Text Box

Getinfo Dialog Sheet

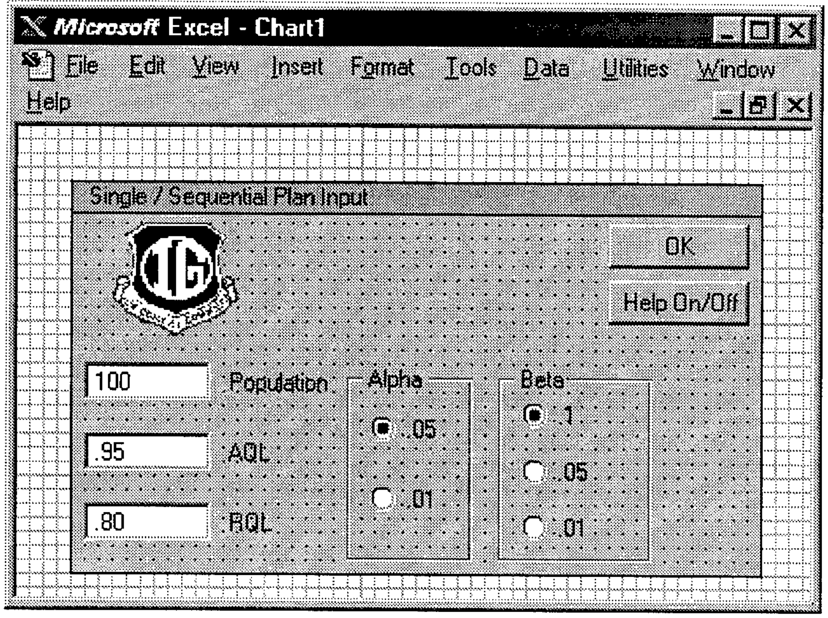


Figure 49. Dialog Box Activated by START Button on Sampling Plan Worksheet

Cell Links

Alpha Radio Buttons are linked to: Single!$A$3
Beta Radio Buttons are linked to: Single!$B$3

Assigned Macros

Help On/Off Button:

```
'Code for help button on Input Box Dialog
Sub ShowInputHelp()
  ActiveSheet.TextBoxes("InputHelp").Visible = _
    Not ActiveSheet.TextBoxes("InputHelp").Visible
End Sub
```

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VITA

Major Troy L. Dixon was born on [redacted] at [redacted]. His family made many moves in the course of his primary education, thirteen different schools in 12 years. He graduated from Northampton High School in 1980 and was appointed to the United States air Force Academy, Colorado Springs, Colorado. He graduated with a Bachelor of Science on 30 May 1984 and received his commission the same day.

His first assignment was Undergraduate Pilot Training at Reese AFB, Lubbock, Texas. In August 1985, he graduated and remained at Reese AFB for two years as an instructor pilot in the Northrop T-38 Talon. Major Dixon was reassigned to Randolph AFB, Texas in March 1988 as a Pilot Instructor Training (PIT) Instructor Pilot and was promoted to Captain in May of the same year. In August 1990, Major Dixon began training in the McDonnell Douglas F-15 Eagle and became operational in the fighter at Eglin AFB, Florida in February 1991. Major Dixon entered the School of Engineering, Air Force Institute of Technology in August 1996.

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Major Timothy S. Madgett was born on [redacted] in [redacted]. He graduated from Novato High School, Novato, California in 1980 and entered the United States Air Force Academy, Colorado. He graduated with a Bachelor of Science degree in International Affairs on 30 May 1984 and received his commission on the same day.

He earned his pilot wings in June of 1985 and has accumulated over 2500 hours in the T-37, F-111F, and F-15E aircraft. While stationed at Mather AFB, California he earned a Master of Business Administration degree from National University. His operational deployments include Operations DESERT SHIELD, DESERT STORM, PROVIDE COMFORT, and DENY FLIGHT. In August 1996, he entered the School of Engineering, Air Force Institute of Technology.

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13. ABSTRACT *(Maximum 200 words)*
A Blue Ribbon Commission report to the Air Force Chief of Staff in February 1997 makes several specific recommendations on the conduct of Operational Readiness Inspections. This thesis develops a solution to one of the recommendations of that report; utilize scientifically based sampling techniques to reduce the footprint of the inspection on an evaluated unit. Acceptance sampling, common in industry, is developed for use in the environment of the Operational Readiness Inspection. The time saved from this more efficient sampling practice reduces Inspector General time at an evaluation, decreases the footprint, and answers the specific recommendations of the Blue Ribbon Commission.

This thesis explains the construction of acceptance sampling plans and procedures. The changes to the Operational Readiness Inspection for effective application of acceptance sampling are defined and the automatic computation of acceptance plans through a computer spreadsheet application is accomplished. A validation is provided with the results from applying these techniques to an actual Operational Readiness Inspection at Cannon AFB, NM. Acceptance sampling has proven itself in the world of industry in international and military standards. This proven practice, simple in concept, can produce more credible and convincing results in any inspected area selected for sampling.

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