Analysing the Shape of an OC Curve for an Acceptance Sampling Plan: A Quality Management Tool

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Abstract: - The paper presented the results of the research of elements determining an operating characteristic (OC) curve of specified acceptance sampling plans and gave the evidence that certain relationships of direct or indirect proportionality among these elements existed. Relationships between sampling risks and other elements inbuilt in a single acceptance sampling plan were considered. Average Quality Level desired by the consumer (AQL), and quality level called Lot Tolerance Percent Defective (LTPD) or the worst level of quality that the consumer may tolerate, were both considered. The producer's risk α was the risk that the sampling plan will fail to verify an acceptable lot's quality set by AQL and, thus, reject it. The probability of acceptance a lot with LTPD quality was expressed as the consumer's risk β. The OC curve pertained to a specific plan, i.e. to a combination of the sample size n and the acceptance criterion or level c. Using ExcelOM2 software, the following findings were found: (1) with c, AQL and LTPD fixed, the increasing sample size n resulted with the risk α increased and the risk β decreased; and (2) with n, AQL and LTPD fixed, the increasing critical value c implicated that the risk α decreased, but the risk β increased; (3) if AQL was increased, with all other components n, c, and LTPD fixed, then producer's risk α would increased, but consumer's risk β would remain the same; and, (4) if LTPD is increased, with all other components n, c and AQL fixed, α would remain the same, while β would decrease. In this paper some previous research results from studying α risk and β risk in audit sampling based on acceptance sampling applications from [1] were shortly presented.

Key-Words: - Acceptance sampling plan, Operations characteristic (OC) curve, Consumer's risk, Producer's risk, Acceptable quality level, Lot tolerance percent defective, Statistical quality control, Quality management.

1 Introduction

Acceptance sampling is an inspecting procedure applied in statistical quality control; see [3] and [6]. It is a method of measuring random samples of populations called "lots" of materials or products against predetermined standards. Acceptance sampling is a part of operations management or of accounting auditing and services quality supervision. It is important for industrial, but also for business purposes helping decision-making process for the purpose of quality management.

Sampling plans are hypothesis tests regarding product that has been submitted for an appraisal and subsequent acceptance or rejection. The products may be grouped into batches or lots or may be single pieces from a continuous operation. A random sample is selected and could be checked for various characteristics. For lots, the entire lot is accepted or rejected in the whole. The decision is based on the pre-specified criteria and the amount of defects or defective units found in the sample. Accepting or rejecting a lot is analogous to not rejecting or rejecting the null hypothesis in a hypothesis test. In the case of continuous production process, a decision may be made to continue sampling or to check subsequent product 100 percent.

The hypotheses for acceptance sampling plan as a kind of statistical test are:

$$H_0 ... \textit{The lot is of acceptable quality} \qquad (1)$$
$$H_1 ... \textit{The lot is not of acceptable quality.}$$

Rejecting the lot is the same as rejecting the null hypotheses H_0.

If the quality controls have broken down, the sampling will prevent defective products from passing any farther. There are a number of different methods widely used for selecting a product for checking various quality characteristics:

a) No checking;
b) 100% checking;
c) Constant percentage sampling;
d) Random spot-checking;
e) Audit sampling (no acceptance and rejection criteria); and
f) Acceptance sampling based on probability.

The approach of no checking may be guaranteed when the process capability is known and the probability of defective product is very small. In some cases, incoming materials from various suppliers may not be inspected because the supplier has demonstrated outstanding quality capabilities. When the process capability and the product quality level are not known, no checking usually results in increased costs for reworking defective product. When defective products are automatically shipped to the next using organization, subsequent operations may have to be stopped to make corrections. When the risks involved are known, this technique will result in significant savings. When the risks are not known, this technique may cause significant losses and problems to the company.

At the opposite extreme, product may be inspected 100%. In certain circumstances, 100% or even more checking may be necessary, particularly where lives are involved. In most routine processes, looking at each item is expensive, not always 100% effective and not necessary to assure product quality. This 100% checking is a sorting operation to separate good product from defective product. In addition, one hundred percent checking cannot be used when a destructive test is made. As the number of quality characteristics being checked increases, the effectiveness of the inspector decreases.

The quota sample seems to be like a logical procedure to many people for checking the quality of a lot. The problem with this method is that the sampling risks involved are not known and that the sample taken from small lots may be too small and the sample taken from large lots may be too large. The inspection accuracy is not achieved for small lots and too much time and effort may be spent on large lots. After a certain point, a larger sample will not give more information. If the sample size is of sufficient size to determine the quality level and a decision can be reached as to accept or reject the lot, then further sampling would not be guaranteed.

So called random spot-checking may sometimes be used when a process is in the status of a statistical control. The random check is used to verify that the process is in control and to report the product quality level. The sampling risks are not known, so this method will not guarantee that the outgoing quality will be at an acceptable level. This type of sampling may be used when a supplier has been certified as providing excellent quality products over some period of time or the process capability is so good that other methods of inspection are not necessary.

Audit sampling is used where the manufacturing quality controls are known to be working correctly. It is kind of sampling that is done on a routine basis, but acceptance criterion is not specified. A quality report is issued and the manufacturing organization will determine what action is to be taken if the material is not acceptable. The process capability must be known and the chance of defective products arriving at the inspection point must be very small.

Acceptance sampling based on probability is the most widely used sampling technique throughout industry. Many sampling plans are tabled and published and can be used with little training. The Dodge-Romig Sampling Inspection Tables are an example of published tables, see [6]. Some applications require special unique sampling plans, so an understanding of how a sampling plan is developed is important. In acceptance sampling, the risks of making a wrong decision are known.

In some previous research findings in [1] from studying an audit sampling based on acceptance sampling applications using other software are showed considering α - the management risk, and β - the risk of audit results users. The paper presents the author's research results achieved using sampling methods and methods of statistical quality control in the analysis of audit risks that are caused by sampling. Using the audit hypothesis testing model and substantive test based on hypothetical examples, the following relationships were recognized: inverse proportionality between the risk α and the risk β; inverse proportionality between β risk and specific audit risks called inherent, control and analytical procedures risks. The sample size was inversely proportionate to: the levels of the risk α and of the acceptable precision (A), and to the size of tolerable misstatement (TM), as well. The value of precision A would increase if the risk β would increase. When analysing OC curves of an acceptance sampling plan selected, the conclusion arose that, with fixed values of other relevant factors (α , AQL and LTPD), an inverse proportionality between the risk of incorrect acceptance of an audit population, which is the risk β of audit results users, and the needed sample size n existed. When changing on low levels the management risk α , which is the risk of incorrect rejection of an audit population, with unchanged values of other relevant factors (β , AQL and LTPD), the needed sample size n does not change visibly.

2 Problem Formulation

2.1 Types of Risks in Acceptance Sampling

Because an entire lot of material is not being inspected, not everything is known, so, sampling will always incur certain risks, see in [7]. Only the sample is known.

This incurs the risk of making two types of errors in «the accept: not accept» decision.

- A lot may be rejected that should be accepted and the risk of doing this is the producer's risk.
- The second error is that a lot may be accepted that should have been rejected and the risk of doing this is called the consumer's risk.

But, it is a good thing that these two risks could be measured.

The Type I Error, called significance level, is preset on with quite low level, most at 5% (or 1% or 10%), to protect of this type of error. It is true that:

$$\alpha = P\{Type\ I\ Error\}$$

$$\alpha = P\{rejected\ H_0 | H_0\ is\ true\}, \quad (2)$$

and

$$\beta = P\{not\ rejected\ H_0 | H_0\ is\ false\}$$

$$\beta = P\{Type\ II\ Error\}. \quad (3)$$

The power of the test is equal to:

$$Power = 1 - \beta = P\{rejected\ H_0 | H_0\ is\ false\} \quad (4)$$

Because the probability of committing a Type I Error (α) and the probability of committing Type II Error (β) have an inverse relationship and the letter is the complement of the power of the test (1- β), then α and the power of the test vary directly. An increase in the value of the level of significance (α) results in and increase in power, and a decrease in α results in a decrease in power. An increase in the size of the sample *n* chosen results in an increase in power and vice versa.

2.2. Designing an Acceptance Sampling Plan

Acceptance sampling is defined as an inspection procedure used to determine whether to accept or reject a specific quantity of goods or materials, compare to [4]. The best sample plan minimizes producer's risk of rejecting an acceptable lot and customer's risk of receiving bad product. There are many possibilities to solve this problem, e.g. see computerized solutions in [5].

Nowadays, as more companies start to apply quality programs, such as Total Quality Management (TQM) approach, they work closely with suppliers to ensure high levels of quality and the need for acceptance sampling plans is decreasing. The goal is that no defect items should be entered into the production process, passed from a producer to a customer. The customer could be an external or internal customer. In reality many firms must check their materials inputs.

The basic procedure for acceptance sampling is quite simple: (1) A random sample is taken from a large quantity of items and tested or measured relative to the quality characteristic of interest. (2) If the sample passes the test, the entire quantity called a lot of items is accepted. (3) If the sample fails the test, two scenarios are possible: either the entire quantity of items is subjected to 100 percent inspection and all defective items would be repaired or replaced, or the whole quantity is returned to the supplier.

When inspection is performed by attributes, when product is classified as good or defective, different types of acceptance sampling plans may be used, with lot by lot single-sampling plans being the most popular. This is because they are easier to administer and implement than the other plans and they are very effective.

This paper describe the characteristics of basic types of acceptance sampling plans distinguishing between lot by lot single-sampling, double-sampling, and sequential-sampling plans and discusses the decisions involved in setting up the best plan. An operating characteristic curve is developed for a single-sampling plan and the probability of accepting a lot with a given proportion defective is estimated.

Designing an acceptance sampling plan is making a decision about quality and risk. Acceptance sampling involves both the producer or supplier of materials, and the consumer or buyer. Consumers need acceptance sampling to limit the risk of rejecting good-quality materials or accepting bad-quality materials. Consequently, the consumer, sometimes in conjunction with the producer through contract specifications, determines the parameters of the plan. Any firm can be in a production chain, so can be both a producer of goods purchased by another firm and a consumer of goods or raw materials supplied by another firm.

When designing an acceptance sampling plan two levels of quality are considered: first, acceptable quality level, and, second, the unacceptable or worst quality level.

The first is the quality level desired by the consumer and is called the limit quality or the acceptable quality level (AQL). The producer's risk α is the risk that the sampling plan will fail to verify an acceptable lot's quality AQL and, thus, reject it. This kind of risk is also called a Type I Error of the plan. Most often the producer's risk is preset at α =0.05, or 5 percent. Both, producers and consumers also are interested in a low producer's risk, because of the high costs of sending back good materials or products, which could cause interruption and delay of a production process or make poor relations with the partners.

The second, unacceptable level of quality is the worst level of quality that the consumer can tolerate and it is called the lot tolerance proportion (or percent) defective (LTPD). The probability of accepting a lot with LTPD quality is the consumer's risk β , or the Type II Error of the plan. In the praxis a common value for the consumer's risk is set as LTPD=0.10, or 10 percent.

Three often used attribute sampling plans are the single-sampling plan, the double-sampling plan, and the sequential sampling plan. Analogous variable sampling plans also have been devised for variable measures of quality. Different types of acceptance sampling plans are designed to provide a specified producer's and consumer's risk. It is in the consumer's interest to keep the Average Number of Items Inspected (ANI) to a minimum because that keeps the cost of inspection low.

2.2.1 Single-Sampling Plan

The single-sampling plan is a decision rule to accept or reject a lot based on the results of one random sample from the lot. The procedure is to take a random sample of size n and inspect each item. If the number of defects does not exceed a specified acceptance number c, the consumer accepts the entire lot. Any defects found in the sample are either repaired or returned to the producer. If the number of defects in the sample is greater than c, the consumer subjects the entire lot to 100 percent inspection or rejects the entire lot and returns it to the producer.

So called «lot by lot single-sampling plan» could be described in several steps: (1) A lot size (N) of product is delivered to the quality check or inspection position; (2) A sample size n is selected randomly from the lot; (3) If the number of defects or defectives in the sample exceed the acceptance number c, the entire lot would be rejected; (4) If the number of defects or defectives in the sample do not exceed the acceptance number c, the entire lot would be accepted; (5) Rejected lots are usually detailed 100% for the requirements that caused the rejection. In some cases the lot may be scrapped.

Accepted lots and screened rejected lots are sent to their destination. The rejected lots may be submitted for repeated inspection.

2.2.2 Double-Sampling Plan

In a double-sampling plan: (1) management specifies two sample sizes (n_1 and n_2) and two acceptance numbers (c_1 and c_2); (2) If the quality of the lot is very good or very bad, the consumer can make a decision to accept or reject the lot on the basis of the first sample, which is smaller than in the single-sampling plan. To use the plan, the consumer takes a random sample of size n_1; (3) If the number of defects is less than or equal to c_1, the consumer accepts the lot; (4) If the number of defects is greater than c_2, the consumer would reject the lot; (5) If the number of defects is between c_1 and c_2, the consumer would take a second sample of size n_2; (6) If the combined number of defects in the two samples is less than or equal to c_2, the consumer would accept the lot. Otherwise, it is rejected. This plan is also called a «lot by lot double-sampling». Rejected lots are detailed or scrapped and accepted lots and detailed rejected lots are sent to their destination.

2.2.3 Sequential Sampling

The sequential sampling plan is a further refinement of the double-sampling and multiple-sampling concept. The inspector will select one part from the lot and check for the specified requirements.

In this plan: (1) The consumer randomly selects items from the lot and inspects them one by one, (2) The part is classified as good or defective. Each time an item is inspected, a decision is made to reject the lot, accept the lot, or continue sampling, based on the cumulative results so far; (3) If the number is greater than another acceptance number c_2, the consumer would reject the lot; (4) If the number of defectives is less than a certain acceptance number c_1, the consumer accepts the lot; (5) If the number is somewhere between the two c_1 and c_2, another item should be inspected. This procedure is done on a lot by lot basis.

The advantage of this type of sampling plan is that a decision could be made based on a relatively small sample.

Rejected lots are detailed 100% (usually by the manufacturing department). If the sample size selected at each stage is greater than one, the process is usually called «group sequential sampling», and if the sample size inspected at each stage is one, the procedure is called «item-by-item sequential sampling».

So called continuous sampling is used where product flow is continuous and not feasible to be formed into lots, as it is described in [7].

2.3 Operating Characteristic (OC) Curve

Analysts create a graphical display of the performance of a sampling plan by plotting the probability of accepting the lot for a range of proportions of defective units. This graph, called an OC curve, describes how well a sampling plan discriminates between good and bad lots.

The OC curve is a picture of a sampling plan. Each sampling plan has a unique OC curve. The sample size n and acceptance number c define the OC curve and determine its shape. The acceptance number c is the maximum allowable defects or defective parts in a sample for the lot to be accepted. The OC curve shows the probability of acceptance for various values of incoming quality. An OC curve is developed by determining the probability of acceptance for several values of incoming quality. An OC curve showing producer's risk α and consumer's risk β is given in Fig.1.

On the vertical axis of the graphical display there is the probability of acceptance and this is the probability that the number of defects or defective units in the sample is equal to or less than the acceptance number c of the sampling plan.

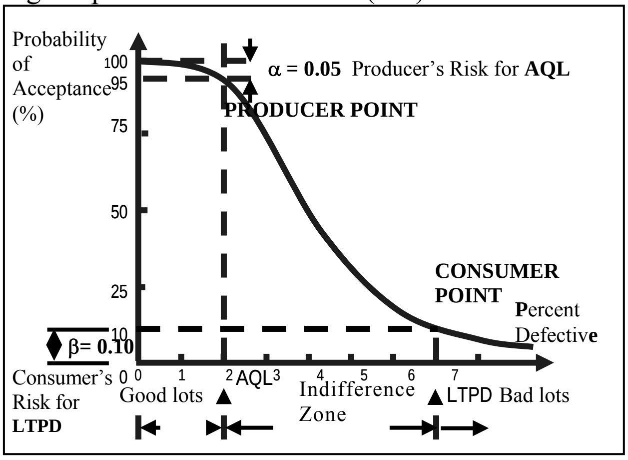
The units on the horizontal axis are in terms of percent defective. The AQL is the acceptable quality level in percentages and the LTPD is lot tolerance percent defective.

A manager usually creates a plan that accepts lots with a quality level better than the AQL 100% of the time and accepts lots with a quality level worse than the AQL zero percent of the time.

The producer's risk α is the probability of rejecting a lot of AQL quality, i.e. Type I Error. This is the probability of rejecting the null-hypothesis H_0 that is true.

The consumer's risk β is the probability of accepting a lot of LTPD quality, i.e. Type II Error. This is the probability of accepting the alternative hypothesis H_1 that is false.

Fig.1 Operation Characteristic (OC) Curve



There are three discrete probability distributions that may be used to find the probability of acceptance: the hypergeometric, the binomial, and the Poisson distribution. The sampling distribution for the single-sampling plan is the binomial distribution because each item inspected is either defective (called also a failure) or not (called a success).

3 Problem Solution

The sampling distribution for the single-sampling plan is the binomial distribution because each item inspected is either defective (a failure) or not (a success). The probability of accepting the lot equals the probability of taking a sample of size n from a lot.

How can management change the sampling plan to reduce the probability of rejecting good lots and accepting bad lots? To answer this question, let us see how n and c affect the shape of the OC curves. A better single-sampling plan would have a lower producer's risk α and a lower consumer's risk β.

Sampling plans may be constructed to meet certain criteria and to insure that the specified outgoing quality levels are met. In the construction of a lot by lot single-sampling plan, four parameters must be determined prior to determining the sample size n and acceptance number c. The parameters are: the acceptable quality level AQL; the producer's risk

α; the lot tolerance percent defective LTPD; and the consumer's risk β.

In most situations the objective is to find a sample size n and acceptance number c whose OC curve meets the above parameters. In this paper, first, the effect of sample size n and then the effect of acceptance number c on the shape of the OC curve will be discussed. After that, the effect of changing AQL and LTPD will be briefly overviewed.

3.1 Sample Size Effect on OC Curve

The question is what would happen if the sample size n would increase with the acceptance number left unchanged at c=1?

Table 1 The Producer's Risk and the Consumer's Risk in OC Curve for Given AQL and LTPD with Fixed c=1 and Changing Sample Size n

	Acceptance level c=1	
Sample Size n	Producer's Risk α for a given AQL=1%	Consumer's Risk β for a given LTPD=5%
30	0,0361	0,5535
40	0,0607	0,3991
50	0,0894	0,2794
60	0,1212	0,1916
70	0,1553	0,1292
80	0,1908	0,0861
90	0,2273	0,0567
100	0,2642	0,0371
110	0,3012	0,0241
120	0,3377	0,0155
130	0,3737	0,0100
140	0,4089	0,0064
150	0,4430	0,0041

Other values of the producer's and consumer's risks are shown in the Table 1, where the results are calculated using the active models based on software ExcelOM2 from [2].

The Table 1 presents an OC curve results for desired values of acceptable quality level AQL, lot tolerance percent defective LTPD, producer's risk α and consumer's risk β. Also, the sample size, n, could be changed, or the acceptance number, c, and it could be seen how the OC curve responds.

Effects of increasing sample size on the OC curve while holding acceptance number c=1 constant could be noticed in Fig.2, Fig.3 and Fig.4. These results, yield the following principle: Increasing n while holding c constant increases the producer's risk α and reduces the consumer's risk β.

Fig.2 OC Curve for n=30, c=1, AQL=1%, LTPD=5%, α=0,0361, β=0,5535, and Probability of Acceptance = (1-α)=0,9639.

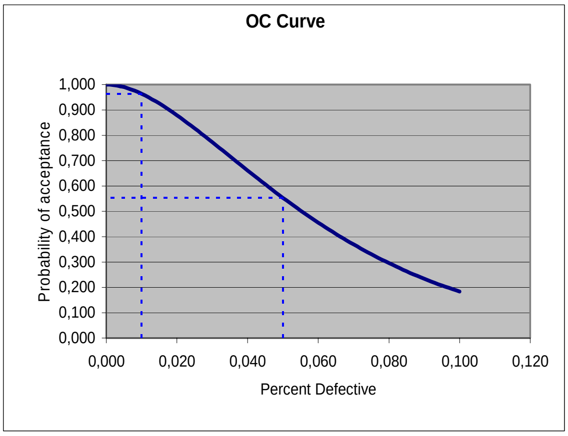


Fig.3 OC Curve for n=80, c=1, AQL=1%, LTPD=5%, α=0,1908, β=0,0861, and Probability of Acceptance =(1-α)=0,8092

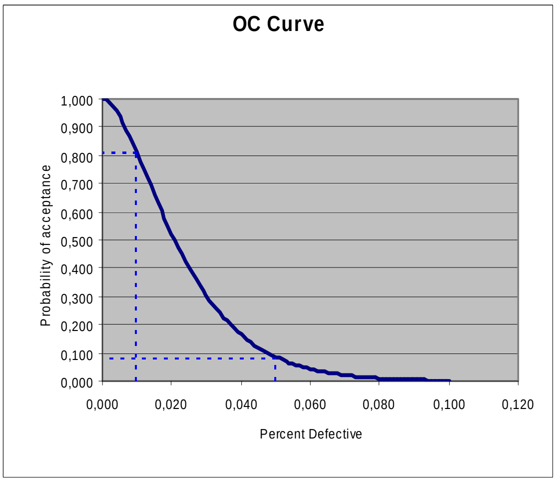
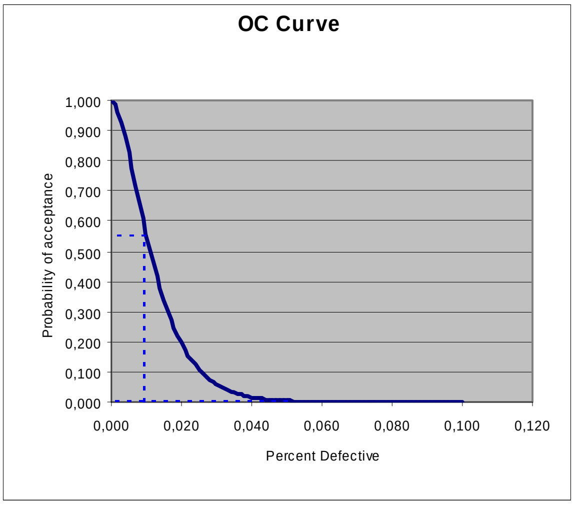


Fig.4 OC Curve for n=150, c=1, AQL=1%, LTPD=5%, α=0,4430, β=0,0041, and Probability of Acceptance =(1-α)=0,5570



Figures 2, 3 and 4 show that increasing the sample size n influences the shape of the OC curve, i.e. the “kurtosis” of the “peak” of the OC curve could be considered as to be sharpened.

3.2 Acceptance Number Effect on OC Curve

The results of increasing acceptance number from c=1 to c=2, while holding sample size n on the same levels as in Table 1, are showed in Table 2.

Table 2 The Producer's Risk and the Consumer's Risk in OC Curve for Given AQL and LTPD with Fixed c=2 and Changing Sample Size n

	Acceptance level c=2	
Sample Size n	Producer's Risk α for a given AQL=1%	Consumer's Risk β for a given LTPD=5%
30	0,0033	0,8122
40	0,0075	0,6767
50	0,0138	0,5405
60	0,0224	0,4740
70	0,0333	0,3137
80	0,0466	0,2306
90	0,0619	0,1664
100	0,0794	0,1183
110	0,0987	0,0829
120	0,1196	0,0575
130	0,1421	0,0395
140	0,1658	0,0269
150	0,1905	0,0182

Increases in the acceptance number from one to two lowers the probability of finding more than two defects and, consequently, lowers the producer’s risk α. However, raising the acceptance number for a given sample size increases the risk of accepting a bad lot β.

An increase in the acceptance number from c=1 to c=2 increases the probability of getting a sample with two or less defects and, therefore, increases the consumer’s risk β. Thus, to improve single-sampling acceptance plan, management should increase the sample size n, which reduces the consumer’s risk β, and increase the acceptance number c, which reduces the producer’s risk α.

The results of acceptance number effect could be noticed when comparing plotting in Fig.2 with Fig.5 (for n=30) and Fig.3 with Fig.6 (for n=80), respectively. Comparison of Fig.2 with Fig.5 and Fig.3 with Fig.6 illustrates the following principle: Increasing the critical value for acceptance number c, while holding the sample size n constant, decreases the producer’s risk α, and increases the consumer’s risk β. The results for risks in Table 1 and Table 2 support the respective images.

Fig.5 OC Curve for n=30, c=2, AQL=1%, LTPD=5%, α=0,0033, β=0,8122, and Probability of Acceptance =(1-α)=0,9967

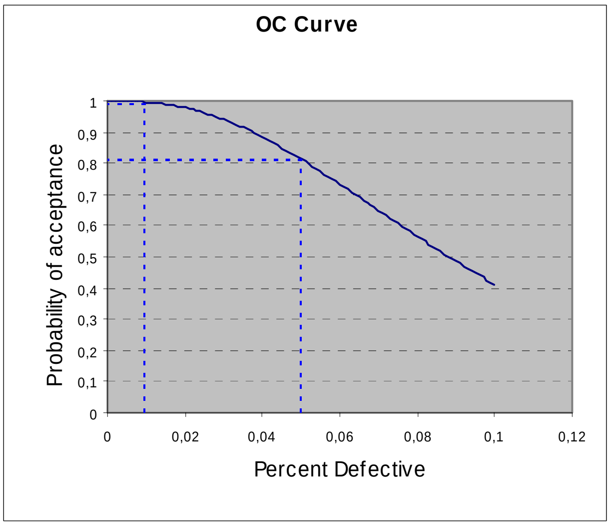
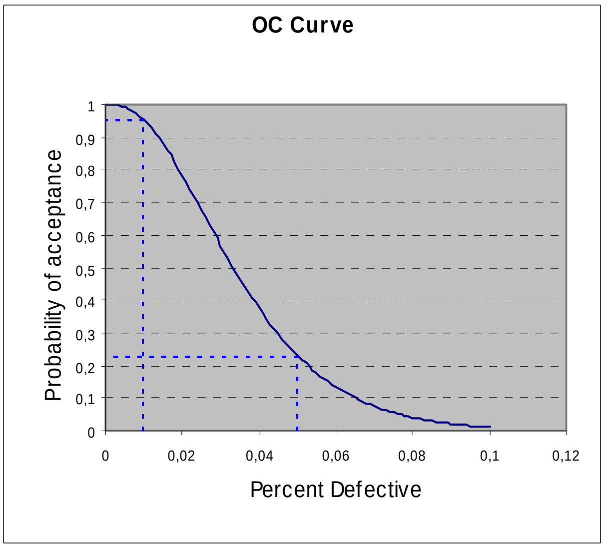


Fig.6 OC Curve for n=80, c=2, AQL=1%, LTPD=5%, α=0,0466, β=0,2306, and Probability of Acceptance =(1-α)=0,9534



3.3 AQL and LTPD Effect on OC Curve

Also, the effects of changing Acceptance Quality Level AQL and Lot Tolerance Percent Defective LTPD on risks α and β when acceptance number c and sample size n are fixed was considered, too.

Fig.7 OC Curve for n=80, c=1, AQL=2%, LTPD=5%, α =0,4770, β =0,0861, and Probability of Acceptance =(1- α)=0,0861

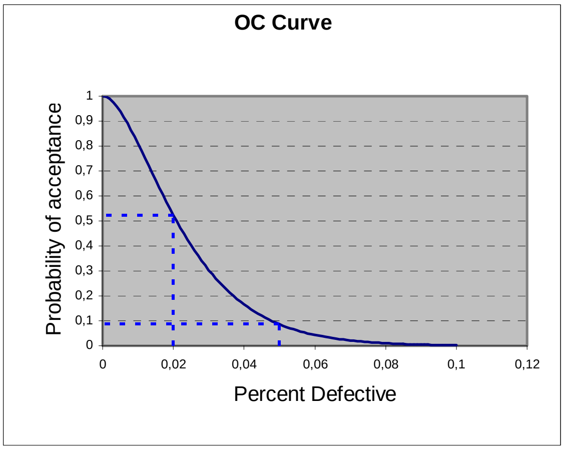


Fig.8 OC Curve for n=80, c=1, AQL=4%, LTPD=5%, α =0,8346, β =0,0861, and Probability of Acceptance=(1- α)=0,1654

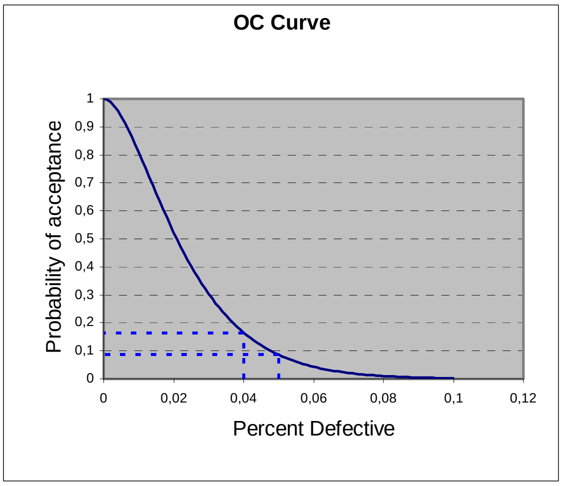


Fig.9 OC Curve for n=80, c=1, AQL=1%, LTPD=6%, α =0,1908, β =0,0433, and Probability of Acceptance = (1- α)= 0,8092

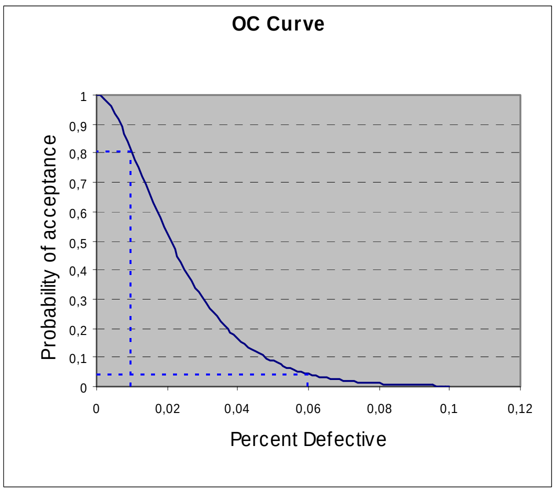
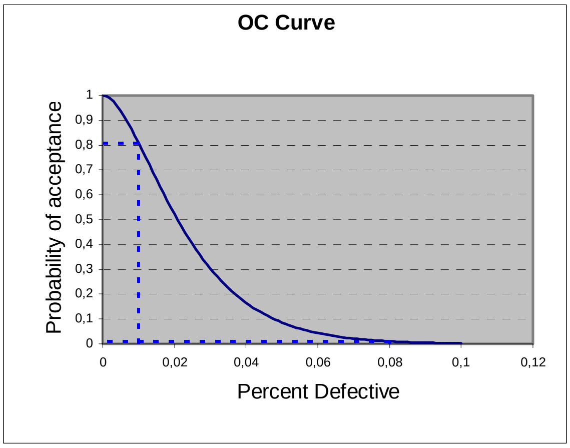


Fig.10 OC Curve for n=80, c=1, AQL=1%, LTPD=8%, α =0,1908, β =0,0101, and Probability of Acceptance = (1- α)=0,8092



With changing AQL the effects on risk α and risk β could be noticed when comparing Fig.3 with Fig.7 and Fig.8 (all for fixed sample size n=80, and acceptance number c=1).

With changing LTPD, the effects on the risks α and β could be noticed when comparing Fig.3 with Fig.9 and Fig.10 (all for fixed sample size n=80, and acceptance number c=1).

Creating graphical displays using software ExcelOM2 from [2], the following findings were found: (1) If AQL is increased, with n and c fixed, the risk of incorrect rejection, i.e. producer's risk α would increase, but risk of incorrect accepting, i.e. consumer's risk β would remain the same. (2) If LTPD is increased, with all other components n and c fixed, α would remain the same, and β would decrease.

4 Conclusion

Management may select the best acceptance sampling plan (choosing sample size n and acceptance number c) by using an operating characteristic (OC) curve. If the sample size n is increased, with c, AQL and LTPD fixed, the OC curve would change so that the producer's risk α increases while consumer's risk β decreases. Further, with increasing the critical value c, and with n, AQL and LTPD fixed, the probability being the risk α would decrease, but the probability for the risk β would increase. If AQL is increased, with all other components n, c, and LTPD fixed, the risk α would increase, but the risk β would remain the same. If LTPD is increased, with all other components unchanged, the risk α would remain the same, while the risk β would decrease.

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