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Control in the Textile Industry

SURVEY OF STATISTICAL METHODS AND CONCEPTS TO BE APPLIED IN TEXTILE QUALITY CONTROL [1]

by

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Summary

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Introduction

Quality control in industry leads to tables and numerical data whose figures are not identical but normally present variations independent of any disadjustment of production mechanism. The unavoidable variability of processing can be atributed to multiple factors which should be considered to be of a random nature except when variations can be ascribed to one or more systematic causes.

The characteristics of a product are dependent on a great deal of factors: machinery (tipe, speed, condition) raw material, manpower, general conditions of work, etc. In spite of care to keep these factors uniform, this is only achieved in an imperfect manner. This results in the characteristic of the product presenting deviations with resoect to desired mean values.

A process is under "control" when those deviations, which are random in their nature, fall between set limits and, within this interval, they distribute following a given law. Generally the normal or Gauss's law accounts for these accidental variations between products produced under identical conditions. According to the degree of development of a technique, the relative distribution curve of a character can be more or less wide. When Gaussian, it is defined by the mean (central value) and the amplitude (or range) or the standard deviation (variability index).

In this way an industrialist can guarantee, with a certain degree of certainty, fixed from the properties of statistical laws, that the products from a controlled process lie between given limits. Alternatively, the buyer cannot test each of the items he gets. His problem is to find the number of individuals to be tested in each lot and how to choose them so that he is almost certain not to be sent any lot deviating from set tolerances or alternatively not deviating in a proportion greater than the determined one. Inversely, knowing these reception conditions, the seller can asses the risk of refusal for a certain proportion of the lots he is offering. The seller's risk is at a minimum when the merchandise is perfectly controlled during processing. It is therefore essential, that the control be carried out in a continuous manner, so that any deviation from either standards or specifications can be corrected rapidly.

The main objective of statistical control of processing is, on the one hand, to find to what extent variation can be expected to be normal and to what point it can be considered that variation is not consistent with random causes but, on the contrary, they show the presence of systematic causes, i.e., the presence of something being wrong with processing. On the other hand, statistical control is intended to ensure the agreement of recorded data with "a priori" specifications. In the first instance the control will be acting upon the correct setting of the production mechanism; in the second the agreement between recorded data and specifications is examined.

The production control has two distinct objectives: to secure steadiness of production in the course of time and to limit the proportion of waste from specification deviations. Control is

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carried out on samples from the process flow. The distribution of values of a characteristic studied through a sample of several individuals, will give, for each sample, a statistical image of the distribution, whose stability is required to be kept under control. This picture contains the whole information contributed by the sample on this distribution.

However, it is practically impossible to record the whole of the images that can be obtained in this way to check upon the steadiness of the distribution and, for this reason, the study of the distribution curves of the sample character is replaced by the study of some of its typical measures, which can be considered as sufficiently representative and easy to calculate. These typical measures are those describing the central value and the scatter. The former is specific to "technical quality" of product and the latter to its "statistical quality".

This report will cover the principles of Statistics needed in Quality Control, the techniques of this being outlined. It should be pointed out from the very beginning that Quality Control is not limited by a series of rules based upon Statistical Methods, through the application of which problems can be more or less automatically solved. At present, Quality Control techniques involve not only factors of a mathematical Statistics type, but also technological, psychological which concern both cost and organization; in such a way that the former are practically relegated to the role of a simple tool, certainly a valuable one, to develop certain phases of the whole, whose application, if not accompanied by an adecuate policy is insufficient by it self to get the optimum results that a modern entreprise should aim at.

1. Statistical parameters

1.1 The parameters depicting the statistical distribution of a property can be divided into two kinds: parameters of location or position and parameters of scatter. The former tell us the place the distribution occupies in a numerical field, and the latter are a pointer to greater or smaller amplitude of the distribution.

In Quality Control, all of the location and scatter parameters are not used, but only some of them.

1.2 Measures of location

The main measures of location or averages are the following:

1.2.1 The arithmetic mean

This is the position parameter more widely used and it is the quotient from dividing the sum of the individual values by the number of them. Let x be the variable and n the number of values:

$$\bar{x} = \frac{\sum x}{n}$$

When calculations are made from a frequency distribution

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table, the central values of each class interval must by multiplied by the number of times the class is present. Let x_1 x_2 x_3, the central values of the class intervals and f_1 f_2 f_3 the frecuencies,

$$\bar{x} = \frac{\sum x_1 f_1 + x_2 f_2 + \dots + x_n f_n}{n} = \frac{\sum fx}{n}$$

1.2.2 Median

This is the value of the variable defined by the condition that there should exist an equal number of observations above and below the median. Therefore, it is the value equidistant to the extreme values which have been found or central value of the variable.

When the variable is a continuous one, it divides the variation field into two equal parts.

1.3 Measures of scatter

A statistical set, or sample, is not entirely defined by its mean value, it is only defined when in addition to the mean (parameter of location) the standard deviation is taken into account (scatter parameter). That is to say, to obtain a complete information from a sample it is necessary to know its variability.

The main scatter measures are:

1.3.1 The range

The simplest scatter parameter is the range, which is the difference between the extreme values of the variable in the sample.

The range is given in the same units as the mean.

1.3.2 The standard deviation

The square deviation of a value from an origin is the square root of the sum of the squares of the differences between that value and the origin divided by the number of values. Let A be the arbitrary origin,

$$s = \frac{1}{n} \sum (x - A)^2 \qquad \text{i.e.} \qquad s = \sqrt{\frac{1}{n} \sum (x - A)^2}$$

When the arbitrary origin is the arithmetic mean, the square deviation is referred to as the standard deviation. It is represented by σ :

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$$\sigma = \sqrt{\frac{1}{n} \sum (x - \bar{x})^2} \quad \text{or} \quad \sigma = \sqrt{\frac{1}{n} \sum f (x - \bar{x})^2}$$

expressed in the same units as the mean.

The square of the standard deviation is the variance:

$$\sigma^2 = V = \frac{1}{n} \sum (x - \bar{x})^2$$

When the number of individual in the sample is small ($n < 100$) the sum of the squares is divided by $n-1$ instead of n.

1.3.3 The coefficient of variation

It is sometimes convenient to give the standard deviation as a percentage of the mean. This is the **coefficient of variation**:

$$CV = \frac{\sigma \cdot 100}{\bar{x}}$$

The coefficient of variation is a dimensionless quantity; it is an absolute measure of scatter affording comparisons to be made between different populations.

1.3.4 The Percentage Mean Range

The application of the Statistical techniques of Quality Control has brought about new parameters. A particularly useful one (mainly in spinning control) is the Percentage Mean Range or P.M.R.. It is easy to grasp even by the non-initiated in statistical techniques and it is easy to apply.

For large samples, made of smaller sub-samples, when the range R of the latter is known, the mean range can be calculated. This parameter is related to the standard deviation of the population through the following equation:

$$\bar{R} = \sigma' d_2$$

where d_2 is a constant dependent on the size n of the sub-sample The PMR is defined by:

$$PMR = \frac{\bar{R} \times 100}{\bar{\bar{x}}}$$

where $\bar{\bar{x}}$ is the grand mean (the mean of the means of each sub-sample). Then the coefficient of variation is related to PMR by:

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$$CV = \frac{1}{d_2} \text{ (PMR)}$$

2. Distributions

2.1 The Normal Distribution

When a quantity is under the influence of a number of causes of variation and these are small and independent from each other, it can be shown that the individual values of measu rements follow Gauss's law. This property grants the Normal law a general character.

The main characteristic of this law is well known when the variable is a continuous one. The results cluster about the mean and are symmetrically distributed with a frequency which tails of on boths sides of the mean as values get farther and far ther from the center (Fig. 1).

The Normal Distribution has played a prominent role for a long time because of its successful application to the study of errors of observation and because of the simplicity of the arith- metic involved and the definite character of the parameters on which it is dependent, viz. the mean and the standard deviation.

There is the perjudice of considering that all the dis tributions to be found in industrial practice are Normal or near Normal. For a distribution to be Normal it is sufficient: (1) That the variable be under the effect of different sources of variation which are independent; (2) That the effect of each cause be inde- pendent from the others; (3) That the effect of each cause be small in relation to the sum of the effects. These conditions my lead to normal distributions.

The above conditions are approximately fullfilled in practice. When the mechanism of the observed phenomena is consis- tent with such conditions, the values of any character of a popu- lation may be distributed according to the Normal law only if: (a) The studied character is a physical measurable quantity, (b) if the random mechanism coming into play, directly affects such a quantity, (c) if the numerical data collected can be considered as true measurements of the studied quantity.

The hypothesis of normality cannot be accepted but after the apropriate statistical tests have been carried out.

The aplication of statistical techniques based upon nor- mality to non-gaussian data is liable to lead to higly misleading conclusions.

The normal curve, however, can fit many unimodal distri- butions quite well, affording treatement in an approximate manner of many distributions of this type which otherwise might be dif- ficult to handle.

Normal theory has also been applied to non-normal fit- ting. Finally, non-normal distributions may sometimes be made in to curve approximately normal through a change in the variable.

In the normal curve the arithmetic mean, the median and the mode, or more frequent value of the variable coincide. It is

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fully described when the mean and standard deviation are known.

If values of one, two and three standard deviations are taken on both sides of the mean, on the normal curve, the proportion of observations within the intervals thus limited is as follows:

Interval $\bar{x} \pm \sigma = 68\%$

$\bar{x} \pm 2\sigma = 95\%$

$\bar{x} \pm 3\sigma = 99,8\%$

In other words, if a sample is taken at random from a population following Gauss's law, there is a probability of:

0.68 (68%) that is will not fall outside the limits mean ± 1 S.D.
0.95 (95%) that is will not fall outside the limits mean ± 2 S.D.
0.998 (99,8%) that it will not fall outside the limits mean ± 3 S.D.

Thus, an interval of ± 3 S.D. practically covers the whole distribution.

2.2 Non-Gaussian distributions

2.2.1 The binomial distribution

As known, the probability of an event being a success is equal to the ratio of to the number of times that success is possible to total number of outcomes, if the latter are equally probable. If p is the probability of success and q is the probability of failure, then $p + q = 1$.

Let N the total number of outcomes of an event, the arithmetic mean of the probability distribution p is $m = Np$. The standard deviation is $s = \sqrt{Npq}$. This distribution is referred as the binomial distribution.

2.2.2 The Poisson distribution

Is the limit of the binomial distribution when one of

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the probabilities becomes infinitely small and N is sufficiently large for p.q to be finite. This is the "rare event" distribution and applies to a number of cases in the textile industry. Among these:

1. Number of yarn breaks.
2. Number of neps on a given surface of the card web, or sliver length.
3. Number of fibres in the cross-section of a sliver or yarn.
4. Number of machine breakdowns.

The standard deviation of Poisson's distribution is:

$$s = \sqrt{m}$$

where m is the mean.

This distribution is highly assymmetrical and it becomes more symmetrical as m increases. Its limit is the normal distribution.

2.2.3 The property of the majority of values lying within the interval mean ± 3 S.D. still holds for a great deal of non-gaussian distributions, including the binomial and Posisson's. Therefore the consideration of this interval will also be useful here for the same sort of applications shown for Gauss's law.

3 Sampling distributions. Standard error

3.1 If a number of samples are taken from the population and we calculate a parameter such as the mean or the standard deviation of each sample, different values will be found. If the number of samples is large, these values can be grouped into a frequency distribution which will get closer and closer to an ideal continuous curve as the number of samples increases. This is a "sampling distribution".

The sampling distributions of the mean and standard deviation are Gaussian, but distributions of range and coefficient of variation are assymetrical. However, in practice the whole distribution still lies within the limits mean ± 3 S.D. very approximately.

3.2 The "standard error" is the standard deviation of the sampling distribution. Generally, we can take the interval ± 3 S.E. to find the limits out of which it is not probable that any sample value would lie. It can be used to measure the accuracy of an estimate, or to assess the degree of disagreement between observed and expected values.

The standard error is expressed in the same units as the variable which is being measured.

We shall now show what the standard errors of the main parameters of location and scatter are.

Standard error of the mean

The standard error of the mean is: $s = \frac{\sigma}{\sqrt{n}}$

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This formula is very important in statistics and it is independent from the shape of the frecuency distribution and, therefore, has a general application.

<u>Standard error of scatter measures</u>

The standard error of the standard deviation is: $s_\sigma = \frac{\sigma}{\sqrt{2n}}$

The standard error of the coefficient of variation is:

$$s_V \quad \frac{CV}{2n}\sqrt{1 + \frac{2\ CV^2}{10^4}}$$

4. Statistical Methodology. The principles of statistical methods

4.1 The statistician strives to get conclusions out of a limited number of observations (sample). The general mechanism of the method is as follows: a hypothesis is formulated on the population. This is based on theoretical considerations or, alternatively, it can be suggested by collected data. Then, statistical analysis is used in order to find to what extent the hypothesis is true.

It is obvious that absolute certainty cannot be achieved, since this would imply a knowledge of every single event, an impossible dream no matter how large the sample is. But the degree of certainty of a conclusion can be formulated in terms of probability. It is therefore legitimate [illegible] to consider an [illegible] a very small probability [illegible] one. Conversely, if the probability [illegible] value, [illegible] considered as certain. It [illegible] before [illegible] the degree of certainty should be [illegible] be very little likely to be true if it is not [illegible] re than a 5 per cent of observed data. If the probability [illegible] gher that 5 per cent the hypothesis will be considered as a true one, at least temporarily and with [illegible] further checking. The 5 per cent probability is often taken as a boundary line between true and untrue hypothesis. It is referred as the "5% significance level".

Of course, it is up to [illegible] to decide whether higher or lower levels are to be chosen. In practice the [illegible] per cent and 1 per cent levels are quite common.

Statistical interpolation involves two essential stages: first, the [illegible], to pass from sample to population; second, the [illegible], which brings back the sample with a given probability value, to the group of all possible events that may happen in the random selection from the population. If there are several hypothesis, the choice will be for the one leading, for the sample, to a maximum probability.

The interpretation, of which the principles have just been stated, is carried out trough statistical "tests". The hypothesis to be tested is the "null hypothesis", that is to say, the sample deviations from the population, or of certain experi-

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mental characters from the population, or between several experimental characteristics, can be attributed to sample variation. If the answer from the test to the null hypothesis is contradictory within the given probability level, it will be concluded that the differences are "significant".

When a "test" does not refute the "null hypothesis" there is no reason to asume that there is a disturbing factor. However, although the statistical "tests" can prove, within a degree of probability perfectly stablished, that a sample is heterogeneous or that systematic variation has taken place during its formation, they are unable to show that the contrary hypothesis is true: they only show that the hypothesis is not contrary to facts, which is something different.

In other words, the "tests" can either prove or disprove the existence of non-random a source of variation, but they can never prove its nonexistence. In a set of experiments or observations, a negative answer with respect to the null hypothesis, found from test, is valid whatever the number of contrary answers already recorded. However, if the number of the latter is high, the improbable event (refuting the hypothesis when this is exact), can be found to be realised.

This observation is used to interpret the same series of observations by different tests. From the nature of the formulated hypothesis, the "tests" cannot contradict themselves and any significant effect shown by one of them is an actual proof, although the others should reveal unable to do so. It is obvious that the more the number of observations, the better armed the investigator to refute the null hypothesis, that is to say, to show the effect of the systematic, though little conspicuous sources of variation. That is to say, the larger the amount of information, the larger the field of the hypothesis that one is able to refute and the more limited the field of the acceptable hypothesis and there is a higher probability of finding the true nature of the phenomena.

On the other hand, the "tests" can be more or less adapted to hypothesis and their power is variable.

The special nature of the statistical tests leads to the idea of "risk". If it is assumed that a given "test" has made us refute the null hypothesis when the hypothesis is true, that is to say, has mislead us into the conclusion of an actual difference when it does not exist, the "test" has made us run on a first kind risk. This risk can be represented by a probability, which varies inversely to probability level and to sample size. If it is desired to limit the risk to a set probability level, the statistical tables give the value to be taken as a function of the number of samples.

A test which tends to decrease the value of the first kind risk as much as possible is an assymetrical test. The conditions to which the application of such a test lead, are subject to a second kind error, which consists in not disproving the null hypothesis when it is actually false, that is to say, to reach the conclusion that the value of the parameter which characterises the population is equal to that of the sample, when there is

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a difference between them.

5. The main comparative tests and their applications

5.1 Comparison of means

The "t", or Student's, test is used here, which is particularly useful for small samples. When an experimental mean $\bar{x}$ is compared with a theoretical mean m,

$$t = \frac{|\bar{x} - m|}{\sigma} \sqrt{V + 1}$$

where V is the number of degrees of freedom, equivalent to n-1 (n = sample size).

When two experimental means $\bar{x}_1$ and $\bar{x}_2$ found from samples of size n_1 and n_2 and standard deviations σ_1 and σ_2 respectively, are to be compared first the pooled standard deviation must be calculated:

$$\sigma = \sqrt{\frac{\sum(x_1 - \bar{x}_1)^2 + \sum(x_2 - \bar{x}_2)^2}{n_1 + n_2 - 2}}$$

and then

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sigma\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

The "t" Tables afford calculation of the probability that an experimental value of t be equalled or exceeded in connection with the random sample variation. Normally the 5 per cent and 1 per cent significance levels are used.

5.2 Comparison of variabilities

Snedecor's F test is used, which affords a comparison between variances:

$$F = \frac{\sigma_1^2}{\sigma_2^2}$$

The significance of F is tabulated as a function of the degrees of freedom $V_1 = n - 1$ and $V_2 = n - 1$ (n_1 and n_2 are the sample size of samples of standard deviations σ_1 and σ_2 res

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pectively). In the calculation of F the larger variance must alway be in the numerator. This criterion can also be applied to compare the variance with a specified value.

5.3 Confidence intervals

The formula for Student's t can be rearranged so that:

$$|\bar{x} - m| = \frac{t\sigma}{\sqrt{V+1}}$$

and

$$m = \bar{x} \pm t \frac{\sigma}{\sqrt{V+1}}$$

i.e., when the mean and standard deviation of a sample of a given size are known, the intervals within which the mean will lie at certain probability levels, can be found.

The principle can be applied to difference between means of two samples:

$$|x_1 - x_2| \pm t\sigma\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

In any case t is the value from the Tables for the corresponding degrees of freedom and the desired significance level.

For samples where $n > 30$ the t values for significance levels of 1 per cent and 5per cent are 1,96 and 2,58 respectively.

Sample size

We may wish to estimate the sample size n with an error for the estimate of the mean not greater than a certain value E per cent. The following expression is used:

$$n = \frac{t^2 CV^2}{E^2}$$

where CV is the coefficient of variation.

If the parameter we may wish to calculate with a given error is a measure of scatter, the sample size is,

$$n = \frac{t^2 CV^2}{2\,E^2}$$

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In these formulas, t is 1,96 or 2,58 depending on whether the probability level is 5 per cent or 1 per cent.

Generally the sample size for a correct estimate the mean is n = 30.

For scatter measures the sample size lies between 30 and 40.

6. The analysis of variance

The methods of variance analysis due to Fisher, afford analyzing the variability of a product when this is not attributable to several causes, each causing a small effect, but it can be ascribed, at least in part, to the intervention of a small number of causes each producing an appreciable effect.

These methods require the observed data to be grouped into sub-samples or homogeneous groups which are characterised by the systematic intervention of one or several factors, of which the influence on the variability of data is to be found.

The analysis of variance affords solving the following problems:

(a) Finding whether a group of samples is homogeneous.
(b) Finding in the variability of a population of measurements, the part due to chance and the one which can be attributed to systematic sources of variation (controlled causes).

It affords separate testing of the influence of the different factors under control and of interactions among those factors. It has a large field of application, since it tends to reach the objective of any investigation, such as the identification of the causes whose effect is being studied.

6.2 In Quality Control it is quite often useful to discriminate the variability from different sources. Shortcut methods based upon the range can be advantageously used instead of the traditional more cumbersome Fisher's techniques.

It will be recalled here that in any process implying several machines at work the total variance and its components "between" and "within" must be considered. These are related by the following expression:

$$V_{\infty} = V_b + V_w$$

where,

V_{∞} = Total variance
V_b = Variance between machines
V_w = Variance within the machine

It can also be written:

$$\sigma_{\infty}^2 = \sigma_b^2 + \sigma_w^2$$

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or, through coefficient of variation :

$$CV_t^2 = CV_b^2 + CV_w^2$$

The calculation of total and within-machine variation can be calculated through the mean range in a two fold way:

1. Based upon the relationship:

$$\sigma = \frac{\bar{R}}{d_2} \quad \text{or} \quad \sigma^2 = \frac{\bar{R}^2}{d_2^2}$$

2. According to relationships:

$$\bar{R}^2 = \frac{\sum R^2}{k} \quad \text{and} \quad \sigma^2 = \frac{\bar{R}^2}{D_2}$$

where k is the number of groups of size n.

D_2 and d_2 are dependent on sample size according to Table :

n	D_2	d_2
2	2,000	1,128
3	3,656	1,693
4	5,014	2,059
5	6,157	2,326
6	7,145	2,534
7	8,014	2,704
8	8,784	2,847
9	9,477	2,970
10	10,109	3,078

The "between" variance can be found by substracting the "within" variance from total variance. An example will be found in Appendix I

7. Regulation control

7.1 Shewhart's control charts

The technique introduced by Shewhart in 1931 takes in to account the mean and either the standard deviation or the range as the only parameters, and it is characterized by an ingenous way of recording statistical data, as they come out as a

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function of time. It is based on the $\pm 2\sigma$ and $\pm 3\sigma$ intervals on both sides of the mean in the normal distribution.

When the investigated character is a measurable one, control begins at a starting point, the observations being recorded either singly or in successive samples of several observations at regular time intervals. The control diagram is found by taking the order figure of the sample on the abcisae and the value of the variable on the ordinate axis. Each sample originates one point (Fig. 2).

The arithmetic mean is used as measure of the central value. The scatter parameter is either the standard deviation or the range. The former is used for large samples ($n > 10$) and the latter for small samples ($n < 10$).

In addition to charts for the mean, others are used for variability or scatter.

Once data from a process has been collected for some time, they are grouped such that their statistical analysis should afford the theoretical distribution ot be found in an approximate manner (this is generally gaussian). Then, the hypothesis of the steadiness of processing is set out. When accepted, it will afford finding the distribution of the properties of future samples of known size, from the theoretical distribution.

If we consider the arithmetic mean as representative of the central value a confidence interval such that there is a sufficiently high a probability of finding within the same the mean of sample, is defined. Practically, the control limits on both sides of the mean correspond to values of the 99.8 per cent probability. Another pair of limits, referred as the "warning" limits", correspond to the 95 per cent probability and they are set on both sides of the mean on ancillary purposes.

If the considered characteristic of a sample falls within the control interval, the result does not contradict the hypothesis of the steadiness of the mean and there is no reason to question the hypothesis (however, the hypothesis could be inexact. Second kind risk). If the caracteristic falls outside the control interval, the hypothesis of steadiness can not be accepted since the probability is very low. Therefore, it is reasonably accepted that there is a disadjustment in processing (however, the hypothesis could be exact. First kind risk). By reason of this fact, as we shall soon show, there are other complementary criterions with the same or better efficiency than the one explained above.

In the absence of any systematic cause, the chart should appear as a series of random points. The plotting of points which appear to be lying in certain privileged areas, the trend toward a certain regularity in their array, are pointers to the hypothesis of disadjustment (or to the existence of a relationship among the samples or pieces drawn). The observation of such irregularities cannot be considered as significant, but in the event they had been previously defined as a criterion for control; "a posteriori" a limited series of points gives, in effect, an impression of internal regularity which would be of significance except if it would eventually appear quite frequently.

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On this line of thought, one of the more important criterions comes from examination of the trend shown by sequences of points. These sequences fall into two categories.

(a) Increasing or decreasing trend: A sequence of points each above (increasing trend) or below the preceding one (decreasing trend).

(b) Trend whereby all points fall below the central value.

The longer a sequence is, the more unlikely of it happenning by chance. Usually, the following rules are considered for the two classes of trends: a sequence of five points is a warning signal (attention to further behaviour); a sequence of six points is an alarm signal (the study of the causes of disadjustment should begin at once); a sequence of seven points shows a disadjustment (stop production).

Sequences can also be controlled on the criterion of the longest sequence observed for a set of points.

Either an increasing or decreasing sequence may be pointers to a long term change.

The above criterions do not take into account the nature of the parameter under control. Generally as we know, control is carried out on a set of two parameters (central value and scatter) whose simultaneous examination contributes extra precision, since the information supplied by each of them restricts the significance of the caracter supplied by the other.

It is advisable not to neglect calculations and to draw the lower limit in the control chart for scatter. This, quite often is not done, on the excuse that a decrease in scatter is associated with an improvement in the "statistical quality of the product", no account being taken of the fact that a temporary improvement in processing, if not attributable to chance, will point to a disturbance of which the source must be looked for.

It follows from the above that a trained statistician should be able to discriminate through simple criterions and before the technician realises it, the existence of any anomaly in processing.

In Appendix two the practical rules for the application of Shewart's control charts are given.

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7.2 Simplification of control charts

The simplification of the control charts is aimed at using the median and range instead of the mean and standard deviation. The range has almost universally been adopted. Clifford proposes control charts where the values of all individuals in the sample are plotted, the median being easy to draw, whereas the range is graphically measured from the distance apart of the most spread out points. This distance is then taken to another frequency distribution diagram, where it is easy, when there are sufficient points, to find the median and the range and to establish the control limits for median and range. This method makes any arithmetic unnecessary. (see 7.3)

Ferrel suggests a procedure which is essentially of the same type, where use is made of the mid range, the median, and the range, as an alternative method to usual charts. The range mid points is the mean of the extreme values in the sample. Although when the process is under control, the method is less efficient than the classical one, this method permits easy detection of disturbance in the process. Calculation is very simple since only extreme values in the sample are used.

Although the method is not as efficient as that of the median and range when the process is under control and for important variations in the processing mean, it presents interesting qualities because of simplicity of application.

The details are given in Appendix III

7.3 Control charts with no calculations

This sort of charts are based upon the technique of control through the median and mid-ranges shown above. Fig. 3 illustrates one such chart, where the points corresponding to individual measurements have been plotted, the points for the median of the sample being signaled differently. When the sample size is an odd number, the point is inmediate and, by reason of this fact, it is convenient for the sample size to be an odd number (in or example n=5). In this way, the position and scatter parameters are included in only one chart, since the range of each sample can easily be found from the distance apart between the extreme values. In the Figure, the values of the median of each sample have been joined by a continuous line and by a pointed line the extreme values, so that the evolution of the range can be seen.

After a number of samples has been selected, 25 in our example, the median of the medians is found (P point) and

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from the frequency distribution of the range, which can be graphically found through adecuate cards, the median of the range can be determined. The only calculation, is that of the control limits on the criterion explained in the preceding section. Where there is a limited number of samples (< 20) it is convenient to estimate the median from the total number of individual results and not to plot the median of the medians. This is easy to find graphically by drawing the frequency distribution of individual results.

To draw the control limits for the individual values, the range of the median will be divided by d_2^M (see Appendix II) and the quotient will be multiplied by 3. In fact R/d_2^M is an estimate of the standard deviation.

This method offers the following advantages:

(a) No data sheet or arithmetic are necessary to calculate the mean and the mean range.

(b) Since out of control observations do not affect to a large extent either $\tilde{X}$ or the $\tilde{R}$ of the medians, repetition of calculations for central line and control limits are practically unnecessary.

(c) The centre line in the chart is the most adequate for counting sequences above and below the median.

(d) When the individual values have been plotted, it is possible to indicate the control and specification or tolerance limits.

(f) Comparisons can easily be made between capacity and actual scatter of process. The graph can easily be summarized.

A similar method uses the mid-range as a measure of the central value (Fig. 4). In this instance only extreme and mean readings will be plotted and the procedure is similar, the centre line in the graph can be estimated on the basis of the median of the mid-ranges. The coefficients to be applied are slightly different, as shown in the previous section. (see Appendix III)

Here, it is not necessary for the sample size to be an odd number as when working with the median, and the graph is very clear. When there are many samples with anomalous ranges, it is better to use the median graph to that of mid-ranges, since the former less affected by what Clifford's "contamination" of the ranges. But for small ranges the mid-range is an efficient measure.

All short cut methods are, as already said, less efficient than those based upon the mean but, industrially, wider control limits can in some instances be an advantage (except for really severe control) because they make adjustments less frequent.

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The simplification of graphs leads in the long run to their supression when they are no longer useful, although it is difficult to determine when this moment comes. However, control through medians lends itself to a procedure without charts and figures concerning control limits for the median and the range being preserved. This would assume that the scatter of the process is practically invariable or that there are especifications establishing a given limiting variability.

7.4 The cumulative sum charts

Some types of production, mainly in continuous processing, require a high degree of continuity in the output quality and, accordingly, the result from one sample is analyzed, no account being taken of earlier samples. Here, a change in processing can be more clearly shown by the cumulative sum method, which is more sensitive than the traditional Shewhart's control charts.

Fig. 5 shows how the mean of a group of I consecutive results is extremely sensitive to variation in processing. The N value for the number of results is taken on the abcissae, and the cumulative sum in the ordinate axis. Let us consider point A for the cumulative sum of I results and point B for the cumulative sum of the N results.

Point A will cover N-r results and the cumulative sum will be $S_N - S_{N-r}$, whereas for B, it will be N and S_N respectively. If the mean were constant all along the N experiments, the slope of line OAB would be 1, that is to say, the θ is 45^{o} and, therefore, any change in the mean, in a cumulative sum graph, such as the one in Fig. 5, will originate a change in the slope line of the chart. Thus, considering the mean of the series of points between A and B, it could be written:

$$\frac{S_N - S_{N-I}}{rw} = tg\ \theta$$

The advantage of this method is that it uses smaller samples than ordinary control charts and affords the same efficiency if the sample size remains invariable; the time taken to detect a change is shorter than for Shewart's charts (almost by a half), which is very important in order to secure stability of the considered parameter.

One way of establishing these charts will be found in Appendix IV. They can also be used for control of faulty pieces and defects per unit

7.5 Trend graphs

This name refers to a short of data plotting which is quite common in France. In addition to playing the role of control chart, it affords observation of result trends, whether on a machine or a group of machines, in connection with the parameter which is being examined.

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This type of chart, when in card form, can be used for machine control or for yarn and fabric characteristics. We will show several examples in Appendix V.

8. Aceptance control

8.1 Specifications and tolerances

The main objective of a specification is to establish certain desirable properties for the material or end product, and to describe an inspection system affording to find whether the material of a given lot has such properties or not. Generally, checking is carried on a sample selected in a definite manner which, after being subjected to certain testing must yield results falling within certain limits ("O.K. limits"). These limits are the most important part in the specification, so that they must be established by taking into account the inherent variability of all materials.

The regulation control, affords investigating systematic causes of disturbance, which can eventually be progressively eliminated. This elimination must be pursued until variation is consistent with a system of random causes, over which there is no possible control, that can be considered as a characteristic of the production process under study.

The fact that production should be "statistically controlled" is not sufficient to ensure agreement between specifications and quality product. But, statistical control affords to know at any moment:

(a) Whether the whole, or almost the whole, distribution is within tolerances, whereby the faulty fraction is nil or almost nil. Here, the maintenance of the stability of production process secures agreement with specifications.
(b) On the contrary, if the faulty fraction is high, the adopted processing is not wholly consistent with specifications; machinery is not sufficiently accurate in its work, the quality of the raw material is too low, or the specifications ignore the possibilities and limitations of the technique employed.

The control of processing is a necessary condition for specifications to be fulfilled, but it is not sufficient at all, since it is necessary to understand that if a given production process is not capable of making more than a certain proportion of the production falling within specifications, any control will be powerless to remedy this fact. However on securing stability, a better quality will be obtained.

Therefore, specifications, raise two distinct problems: (a) the regularity in production must be secured through application of regulation control. (b) Setting up a production process

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where its technical capabilities should be consistent with contract specifications.

The specifications that in some instance are imposed upon the products, can be established in writing or by word of mouth contract, and they can refer to quality characteristics of the product, or in addition, to processing. They can, finally, describe the testing to which the products must subject. The concept of "tolerance" inherent to any specification, can either refer to the purely technical aspect of the problem or to commercial aspects. Tolerances can be based upon early practice, experimentation, or, finally, on the bargaining between interested parties. Tolerances can be numerical or not. If not, they are based on the establishment of determined adjectives. When numerical, they can also be unilateral or bilateral, that is to say, only by plus or minus, or both at the same time, in connection with the central specified value.

Figure 6 shows the different cases that a process can present in connection with limits or specification tolerances. The zone between tolerance limits corresponds to acceptable product, whereas that on either left or right of limits, i.e. for articles delivered without the "priori" requisites. Let us considered the different cases:

(a) All the delivered product falls within specifications, the mean of the distribution superimposing the nominal one.
(b) The process falls within specifications, but the mean is slightly deviated, there not being individuals out of limits thanks to small variability.
(c) The whole process is deviated delivering a material which falls below the lower limit. This may originate from (i) an excessive deviation of the mean (although variability is correct) (ii) or the process is centered or almost centered and variability is excessive.
(d) Process delivering rejectable articles, whether on the upper or the lower side, because of excess variability, the mean being centered.
(e) Process which behaves as the previous one, but is deviated with respect to it, so that the rejectable fraction appears on one side only.

Depending on the tolerance range on both sides of the central value, the following cases may happen (Fig. 7).

(a) Tolerances which are narrow as regards the scatter of process. There will always be a fraction lying out of limits.
(b) Very narrow limits; it is difficult to avoid that a fraction of the product should fall out of limits unless there is a very strict centering of processing.
(c) Very wide limits. The central value can oscillate and yet there not being a rejectable fraction.

In Fig. 8 only the lower limit is considered. It is interesting to study the mean to be produced as a function of tolerances and process variability. We cannot go here into details

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concerning this question which has only been pointed out to.

8.2 Sampling plans

Thus, in all processing stages from reception of the raw materials to the inspection of the finished product before delivery to the consumer, there is a need for an acceptance control or conformity of the manufactured product to specifications.

Where a 100 per cent certainty of no faulty items is desired, every single unit should be checked upon. In this way, thanks to rejection of faulty units, these would absent from any delivery. Such a lengthy and costly method is not free from error and, in many instances, it is not necessary. In addition, on many occasions it is impracticable, above all when the test to which the unit is being subjected is of a destructive nature, a very frequent occurrence in textile industry. Furthermore, the cost of 100% control raises the selling cost of product so that it becomes unpayable for, in spite of the high quality level.

Generally, the control of a lot is carried out on the basis of the information from one or several samples. One such information, incumplet in its nature, does not prevent faulty items from included in the lot. The only objective that can reasonably be assigned to control, is that of realizing a better discrimination between lots judged as "good", where the amount of faulty articles is very small, and the "bad" lots where the caracters are reversed, so as to accept the former and reject the latter.

The whole set of agreed rules on which acceptance or rejection of a lot is based depending on the information from the analysis of one or several samples from the lot, is the "sampling scheme". The techniques used in the acceptance control involve sampling and the way samples must be drawn; there are several basic types of acceptance control (single sampling, double and multiple sampling and progressive sampling) which will be applied according to circumstances of inspection and its cost. Statistical methods afford to choose at any time best sampling scheme for the efficiency of control.

8.3 Operating Characteristic Curve.

The control carried out on the basis of a determined sampling can lead to rejection of a good quality lot and to acceptance of a bad lot. Whatever the quality of a lot under control, there is a probability for the lot to be accepted and, another complementary one, of being rejected.

A single sampling scheme involves independent parameters n, N and c, where n is the sample size, N the lot size and c the limiting value of the number of faulty items in the sample, which if surpassed would involve rejection of the lot (acceptable quality level AQL). These three parameters define the scheme without ambiguity.

When the values for parameters N, n and c are known, it is possible to calculate the probability of acceptance, according to the adopted scheme, of a lot whose faulty fraction is p (con-

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taining 100 x p% faulty items). The curve of P as a function of p is the "operating characteristic curve" of the scheme. Probability theory gives the analytical expression as a function of n, N and c. This curve, (Figure 9) does not depend but on the three quoted parameters, which univocally define the sampling scheme. Therefore, it is equivalent to know the sampling plan or the OCC of this later, because the curve describes graphically the statistical properties of the sampling plan. If interpreted in frequency terms it gives, for every eventual quality of the lots, the mean value for the proportion of the lots of this quality, that in the "long run" will be accepted (ordinate nN in the curve) or rejected (complement Mm' of the ordinate).

Comparison of their operating characteristic curves, affords judgement of the respective merits of the sampling plans and their efficiencies to be compared too. A sheme is the more satisfactory the better it affords discrimination of the good from the bad quality lots, that is to say: that it leads to acceptance of a greater proportion of lots subjected to control, for which the faulty fraction is small, and to a smaller proportion of lots for which this fraction is important, that is to say, it will be the more satisfactory when the ordinate $1-\alpha_0$ of any point A of abcissa p_a, close to zero, be near to unity and when the ordinate β_0 of a point B of abcissa p_b, close to unity, be closer to zero.

The first condition is mainly interesting to the "producer". α, the complement of $1-\alpha_0$, is the probability of a lot whose faulty fraction is p_a being rejected, that is to say a good quality lot. It measures therefore the producer's risk at the q quality level; the second conditions is of interest the consumer; β_0 the probability of accepting a lot whose fraction is p_b, that is to say, bad quality, measures the consumer's risk at the p_b quality level.

If it were possible to divide the lots into "good" and "bad", depending on whether the faulty fraction be below or above a clearly defined limit, the ideal operating characteristic curve would be as illustrated in Fig. 10, for which all good lots are accepted and the bad rejected. One such scheme is not stricly accomplishable, although it is possible to get an approximation. In practice, passing from "good" to "bad" lots does not correspond to a given and well determined value of the faulty fraction, but there is a transition covering a zone of "indifferent" qualities. The a and b limits can from reasonable criterions, be ascribed to such a zone by observing that the β_0 risk, corresponding to b quality is the maximum risk of accepting a lot whose quality is worse than that of b (i.e., for which the faulty fraction is greater than b) and that the α_0 risk, corresponding to a quality is the maximum risk of refusing a lot whose quality is better than a. (i.e., of a smaller faulty fraction). If limits a and b are defined, these risk deserve being called "producer's risk" and "consumer's risk" respectively corresponding to the scheme.

The α_0 and β_0 values represent the higher and lower limits, guaranteed by the adopted scheme, of the rejection risks of a satisfactory quality and of acceptance of a faulty quality,

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on both parties.

Once a sampling plan has been adopted, these risks can be found through direct calculation or by simple reading on the operating characteristic curve. Its knowledge cannot replace that of the curve (since it is equivalent to knowledge of only two points A and B on the curve), but it gives information on the a priori ensured guarantees for the acceptance of the scheme. Converseley, if for two a and b qualities the maximum values α_0 and β_0 are established beforehand on the operating characteristic curve should fulfill the condition of passing on the two given points A and B. These conditions are not sufficient to determine this curve which is dependent on three parameters N,n and ce and, therefore, they do not, by themselves, define the sampling scheme. There are, in effect, infinite operating characteristic curves passing on two given points and, therefore, infinite sampling plans securing for the producer and consumer the above guarantees.

To define, without misunderstanding, a sampling plan, such a plan must fulifill a third condition, which can arbitrarily be chosen, whereby the curve corresponding to the plan, fullfilling that condition is selected from among the family of curves passing on A and B.

The acceptance sampling plans can be described, therefore, by the three quantities given above, i.e., N,n and c. Thus one such plan could be the following: N = 50, n = 5 and c = 0. This means: From a lot of 50 individuals, pick up 5 of them at random; if the sample has more than zero defects, reject the lot; if not, accept it.

Figures 11 and 12 show different sampling plans. In industrial practice it is customary to specify the sample at a given percentage of the whole lot, that is to say, 1%, 3%, 5%, etc. This specification is generally based on the wrong idea that the protection from the sampling plans is constant when the relationship sample size/sample lot is constant. By comparison of Figure 11 to Figure 12, we can realise the advantages of using a constant value for n over that of a proportional value.

8.4 Average outgoing quality curve

When a sufficiently hich a number of lots with the same faulty fraction is subjected to control, the mean value π of the faulty fractions which characterise each of these lots after the control respectively is equivalent to P.p; or alternatively, the value of the faulty fraction of the whole bulk obtained by grouping these lots into P.p.

In the curve of π as a function of p, an eventual value p of the quality of a lot subjected to control, corresponds to the mean value of the quality that should be expected for this lot after control.

This curve which binds the mean corrected quality is

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referred to as "average outgoing quality curve" concerning the plan (A.O.Q.C. curve). The maximum of this curve π_c (Fig. 13) is referred as the "average outgoing quality limit" (A.O.Q.L.). If a set of lots of the same quality is subjected to control, this point will be the higher limit for the faulty mean fraction characterizing the set made of these lots after control, whatever their common initial quality. The limit for the average outgoing quality is, therefore, the worst mean quality to which the correcting inspection can lead as a function of the sampling plan adopted, whatever the eventual quality of the lots subjected to control.

The P_a acceptance probability will be:

$$P_a = \frac{\pi_c}{p}$$

One of the conditions that can be set on a sampling plan is that of imposing an anticipated value to this limit, so as to get away from the risk of acceptance of too bad qualities.

8.5 Quality curve for the controlled lots

When consumer's and producer's risk are set beforehand, which must be related to a plan, it is only required that the rules in the latter fulfill certain conditions for a right judgement, leading either to acceptance or rejection of a lot. Therefore, a satisfactory plan is only sought.

But the concrete consequences of the conditions imposed upon the operating characteristic curve cannot fully be appreciated but from the moment when the effective quality of the production under control is known. This quality, can be appreciated from the "procedure curve" or curve of distribution of lots produced according to their faulty fraction. When this curve is known, probability theory affords finding the "outgoing quality curve" of the controlled lots (O.Q.C.) of which the maximum is the "mean outgoing quality level" (Fig. 14). If the control is not a correcting one, passing from one to another curve involves the operating characteristic curve of the plan; if a correcting inspection is being carried out, the so called "efficiency matrix" is involved, or relationship between the quality of a lot before and after control.

If the size of consumer's lots is different to that of the controlled lots, either through subdivision or grouping, probability theory permits constructing the distribution curve of the former as a function of their faulty fraction or "consumer's quality curve". If the size of these lots is a very large multiple of the lots under control, its faulty fraction varies little and it is very close to the mean value of the faulty fraction of the controlled lots. In order to simplify, it is generally accep

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ted that the control lots should be utilised by the consumer as they are. A knowledge of this curve affords, especially, to calculate the fraction of the production received, whose quality falls below some preset standard value. Also, among other conditions to be set for determining a sampling plan, is that in the deliveries of lots whose faulty fraction is above a tolerance limit 1, the mean proportion be at most, equal to a preset value; this latter measures the maximum risk known to the consumer for using lots whose quality is below 1 (a posteriori risk of the consumer).

In a similar manner, in the case of a non correcting control, the producer can demand that, at most, only a given fraction of his production of which the quality is above a given level, should be rejected.

8.6 Single sampling, double, multiple and sequential sampling.

Single sample: By means of this type of sampling, a decision is made on either to accept or reject each lot subjected to control after one single sample has been examined.

Double sample: A second extra sample is taken to better define the quality of a lot, mainly when the lot subjected to control is of a medium quality. If more than two samples are used, we are in the face of multiple sampling (see schemes 15 and 16).

Sequential: In this type of sampling, the items to be examined, are not simultaneously taken into samples of a given size, but by successive random election of separte units or by groups of size n, sampling being interrupted when the collected information affords establishing a significance judgement on the quality of the examined lot. Multiple sampling is but a particular case of sequential sampling.

The sequential plan can be set on a chart as a pair of parallel lines (Figure 17). It is limited by the acceptance line $-h_1 + ms$ and rejection line $h_2 + ms$. The values h_1 and h_2 are calculated from the conditions of the plan. In the graph, we have three zones, viz., acceptance, rejection and indifferent. The mechanism is simple. Items are continually taken in so far as the number of defects falls within the so called indifferent zone. When, on taking a new item, the acceptance line is surpassed, the lot is accepted (case B in the Figure). When on the contrary, on taking a new item the rejection limit a surpassed, the whole lot is rejected (case A Figure 17). It may happen that we should move within the indifferent zone without being able either to accept or reject the lot. In that event, there are special techniques to trunk the test when it is convenient to do so.

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Below are indicated the advantages and inconvenience of each of the sampling methods.

Factor	Single sample	Double sample	Multiple sample
Projection against rejection of good lots and acceptance of bad lots	Practically the same		
Mean number of inspected items per lot	The best	Medium	The least
Variability in the number of items inspected from one to another lot	None	Some	Some
Sampling cost when samples can be taken as needed	The most expensive	Medium	The least expensiv
Estimation of the mean quality of the inspection lot	The most accurate	Medium	The least accurat
Sampling cost when samples are taken all at the same time	The cheapest	The most expensive	Medium
Training of inspectors to use the plan	The easiest	Medium	The most difficul
Psychological: Give the inspection lot more than one chance	The worst	Medium	The best

8.7 Sampling tables: to facilitate application of the sampling methods indicated above, there are special tables by different authors, the most widely used being the U.S. Military Standards, covering single, doble and sequential sampling. Also, the tables of Dodge and Romig for single and double sampling and Columbia University, is which cover all three types: single, double and multiple.

An example of application of a multiple plan in textile quality control is given in Appendix VI, where the mechanism of these plans is explained.

APPENDIX I

Practical application of the analysis of variance through the range.

Example of how the total variance can be split into its components "between" and "within", in the control of count variability in a department of spinning frames.

Table 1 shows the method of calculating the variance within the machine and Table 2 shows how to find the total variance. The working parameters are the mean range $\bar{R}$, the PMR and the coefficient of variation.

To find the CV between machines, the total CV is substracted the "within" CV, and taking into account that the coefficients of variation must always be squared for sum or substraction. Thus,

Total CV = 5,4%
CV Within = 4,02

Therefore:

$$\text{CV between} = \sqrt{5{,}4^2 - 4{,}02^2} = 3{,}60\%$$

TABLE I

Calculation of variation within

Data					Total	Mean	Range
	June 1						
Frame No.	43	27	5	16			
	55,5	51,8	56,-	52,-			
	50,2	54,2	57,1	56,1			
	54,8	50,1	55,2	54,1			
	52,1	54,1	51,1	53,-			
Total	212,6	210,2	219,4	215,2	857,4		
Mean	53,2	52,6	54,9	53,8		53,6	
Range	5,3	4,1	6,0	4,1			
	June 2						
Frame No.	8	39	7	12			
	50,3	59,9	55,5	58,8			
	58,8	58,2	50,2	56,1			
	54,-	56,3	51,6	59,2			
	53,8	57,-	54,7	57,1			
Total	216,9	231,4	212,-	231,2	891,5		
Mean	54,2	57,9	53,-	57,8		55,7	
Range	8,5	3,6	5,5	3,1			
	June 3						
Frame No.	21	29	41	32			
	50,4	55,4	58,8	58,6			
	52,1	56,3	57,3	59,2			
	51,6	56,1	56,8	55,7			
	53,5	58,1	53,9	57,1			
Total	207,6	225,9	226,8	230,6	890,9		
Mean	51,9	56,5	56,7	57,7		55,7	
Range	3,1	2,7	4,9	3,5			
Grand Total					2639,8		
Grand mean						55,-	54,2

$\bar{R} = \frac{54,2}{12} = 4,5$; $PMR = \frac{4,5 \times 100}{55} = 8,2$; $\bar{x} = \frac{2639,8}{12 \times 4} = 55$; $CV = \frac{8,2}{2059} = 4,02\ \%$

TABLE II

Calculation of overall variation

Data — June 1

Frame No.	43	27	5	16	Overall range
	55,5	51,8	56,-	52,-	4,2
	50,2	54,2	57,1	56,1	6,9
	54,8	50,1	55,2	54,1	5,1
	52,1	54,1	51,1	53,-	3,-
Total	212,6	210,2	219,4	215,2	
Mean	53,2	52,6	54,9	53,8	
Range	5,3	4,1	6,-	4,1	

June 2

Frame No.	8	39	7	12	Overall range
	50,3	59,9	55,5	58,8	9,6
	58,8	58,2	50,2	56,1	8,6
	54,-	56,3	51,6	59,2	7,6
	53,8	57,-	54,7	57,1	3,3
Total	216,9	231,4	212,-	231,2	
Mean	54,2	57,9	53,-	57,8	
Range	8,5	3,6	5,3	3,1	

June 3

Frame No.	21	29	41	32	Overall range
	50,4	55,4	58,8	58,6	8,4
	52,1	56,3	57,3	59,2	7,1
	51,6	56,1	56,8	55,7	5,2
	53,5	58,1	53,9	57,1	4,6
Total	207,6	225,9	226,8	230,6	
Mean	51,9	56,5	56,7	57,7	
Range	3,1	2,7	4,9	3,5	

Total	73,6
Average overall range	6,1

$$PMR = \frac{6{,}1 \times 100}{55} = 11{,}1 \; ; \qquad CV = \frac{11{,}1}{2.059} = 5{,}4\ \%$$

APPENDIX II

Practical rules for finding Control chart limits

We shall now study the practical manner of finding control limits for different cases in industry.

To simplify, warning limits will not be considered, since they are not always used. The following will be studied:

1. Control of variables. To be applied to processing control.
2. Control of the faulty fraction and defects. For product classification into different qualities and to quality levels, and other aspects which shall later be shown.
3. Control of defects. To be applied to fabric defects, in addition to others.

1. Control of variables

The following cases should be taken into account:

(a) Control of small samples (size $n \leq 10$)

(b) Control of medium samples (size $11 < n < 25$)

(c) Control of large samples (size $n > 25$)

In any of the above cases it may happen that there is or there is not a given specification, whether for the mean or the variability.

In (a) the mean and the range are used, the mean and standard deviation for the others.

The general method is as follows:

(a) Choose the variable to be controlled

(b) Choose the sample size. Let it be n

(c) Make a previous analysis of some 25 to 30 samples, of which the results will be plotted on the mean and range, or standard deviation, depending on sample size n graphs. To plot the points on the mean control chart the mean of each sample of size n will be found. These will be plotted on the chart. Plot for each sample of size n the selected parameter on the variability chart.

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(d) Calculate the mean for the whole 25 or 30 samples. Also, calculate either the mean range or standard deviation depending on sample size.

(e) Find the control limits by means of the formulas in Table 1, according to the concrete case we may be dealing with. The constants in Table 1 are dependent on sample size and they are also tabulated later (Table 2).

(f) Draw the central, upper and lower control lines on the mean and variability charts.

(g) Take action to get process under control.

(h) In future, take corrective action when the control chart suggests to do so, as the different samples are being analyzed, and do not change anything when the graph does not show the existence of any wrong.

(i) Periodically, calculate the mean and the range (or, alternatively, the standard deviation for large samples) and alter limits accordingly. A minimum of from 20 to 30 values is necessary.

Two things may happen on initial testing and first drawing of limits.

1. All points representative of the samples fall within the control limits.

2. Some points fall outside limits.

In the second case, the facts originating points out of control should be analyzed in connection with the sampling method.

When there is a technical explanation for such anomaly, the points should not be taken into account in the calculation of limits if the source of trouble can be eliminated and if, it is sure that future processing will not change after correction.

It may also happen that the initial analysis gives a deviation of the mean from the desired quality (control at a wrong level) or that the variability be excessive. In such events corrective action should be taken, so that processing will be considered under control when a number of from 25 to 30 succesive sample results fall within limits.

When in the periodic revision some points happen to fall outside limits, they will not be taken into account in the calculation of new limits (when circunstances command to do so) if there are known technical causes accounting for such points.

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TABLE I

Measure of scatter	Size of sub-group	Specification	Chart for the means			Chart for scatter		
			Central line	Control limits: Upper	Control limits: Lower	Central line	Control limits: Upper	Control limits: Lower
Standard deviation	>25	with	$\bar{x}$	$\bar{x}+(3/\sqrt{n})\sigma$	$\bar{x}-(3/\sqrt{n})\sigma$	σ	$(1+3/\sqrt{2n})\sigma$	$(1-3/\sqrt{2n})\sigma$
		without	$\bar{\bar{x}}$	$\bar{\bar{x}}+(3/\sqrt{n})\bar{s}$	$\bar{\bar{x}}-(3/\sqrt{n})\bar{s}$	$\bar{s}$	$(1+3/\sqrt{2n})\bar{s}$	$(1-3/\sqrt{2n})\bar{s}$
	11 a 25	with	$\bar{x}$	$\bar{x} + A\sigma$	$\bar{x} - A\sigma$	$C_2\sigma$	$B'_2\sigma$	$B'_1\sigma$
		without	$\bar{\bar{x}}$	$\bar{\bar{x}} + A\bar{s}$	$\bar{\bar{x}} - A\bar{s}$	$C'_2\bar{s}$	$B'_2\bar{s}$	$B'_1\bar{s}$
Range	≤ 10	with	$\bar{x}$	$\bar{x} + A\sigma$	$\bar{x} - A\sigma$	$d_2\sigma$	$D_2\sigma$	$D_1\sigma$
		without	$\bar{\bar{x}}$	$\bar{\bar{x}} + A_2\bar{R}$	$\bar{\bar{x}} - A_2\bar{R}$	$\bar{R}$	$D_4\bar{R}$	$D_3\bar{R}$

When the sample size is not constant, the control limits will vary depending on size, the same formulas applying for calculation.

Action will be taken according to whether the values of the mean and variability are specified or not beforehand.

Example

A spinning frame is producing a nominal 40s count. The data from 30 days on the basis of a daily test, are summarised in Table 3. (for the sake of simplicity, only data of the first two days and the last day are shown). Sample size n = 4 bobbins

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TABLE II

Group size	Factors for the $\bar{x}$ chart		Factors for the R (range) chart					Factors for the s chart (standard deviation)		
n	A	A_2	d_2	D_1	D_2	D_3	D_4	C'_2	B'_1	B'_2
2	2,121	1,880	1,128	0,000	3,686	0,000	3,267	0,798	0,000	2,298
3	1,732	1,023	1,693	0,000	4,358	0,000	2,575	0,886	0,000	2,111
4	1,500	0,729	2,059	0,000	4,698	0,000	2,282	0,921	0,000	1,982
5	1,342	0,577	2,326	0,000	4,918	0,000	2,115	0,940	0,000	1,889
6	1,225	0,483	2,534	0,000	5,078	0,000	2,004	0,951	0,085	1,817
7	1,134	0,419	2,704	0,205	5,203	0,076	1,924	0,960	0,158	1,762
8	1,061	0,373	2,847	0,387	5,307	0,136	1,864	0,965	0,215	1,715
9	1,000	0,337	2,970	0,546	5,394	0,184	1,816	0,969	0,262	1,676
10	0,949	0,308	3,078	0,687	5,469	0,223	1,777	0,973	0,302	1,644
11	0,905							0,976	0,336	1,616
12	0,866							0,977	0,365	1,589
13	0,832							0,980	0,392	1,568
14	0,802							0,981	0,414	1,548
15	0.775							0,982	0,434	1,530
16	0,750							0,984	0,454	1,514
17	0,728							0,984	0,469	1,499
18	0,707							0,986	0,486	1,486
19	0,688							0,986	0,500	1,472
20	0,671							0,987	0,513	1,461
21	0,655							0,988	0,525	1,451
22	0,640							0,988	0,536	1,440
23	0,626							0,989	0,546	1,432
24	0,612							0,989	0,556	1,422
25	0,600							0,990	0,566	1,414
25	$\frac{3}{\sqrt{n}}$								$1 - \frac{3}{\sqrt{2n}}$	$1 + \frac{3}{\sqrt{2n}}$

TABLE III

Bobbins	Days 1	2	3	. . .	30
1	39,85	41,46	40,50		38,93
2	40,49	39,41	39,82		40,50
3	39,41	40,32	41,10		40,62
4	40,05	40,53	38,55		39,17
Means....	39,95	40,43	39,99		39,80
Ranges.......	1,08	2,05	3,55		1,69

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In practice four bobbins will be taken for each test and a 100m skein will be reeled from each. These will be weighed on a quadrant balance. Readings to nearest 0,1 to 0,25 counts are suficient in routines control.

Calculations are as follows:

Grand mean:

$$\bar{\bar{x}} = \frac{39,95 + 40,43 + 39,99 + \dots + 39,80}{30} = 40,64$$

Mean range:

$$\bar{R} = \frac{1,08 + 2,05 + 3,55 + \dots + 1,69}{30} = 2,01$$

P.M.R.:

$$PMR = \frac{2,01 \times 100}{40,64} = 4,92$$

The count deviation from the nominal count is, in our example:

$$\frac{100 \; (40,64 - 40)}{40} = 1,6 \;\%$$

The coefficient of variation can be found from the PMR:

$$CV = \frac{(PMR)}{d_2} = \frac{4,92}{2.059} = 2,44$$

The control limits are found in the following way:

For the mean:

Control limits:

$\bar{\bar{x}} \pm A_2 \; R$ $\qquad$ $\bar{\bar{x}}$ = specified mean count

Warning limits:

$$\bar{\bar{x}} \pm \frac{2 \; \bar{R}}{d_2 \; \sqrt{n}}$$

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For the range:

Upper control limit:

$$D_4 \bar{R}$$

The values of the constants A_2 , d_2 and D_4 will be found in Table II for n = 4.

Therefore: control limits:

$$40 \pm 0{,}73 \bar{R} = 40 \pm 0{,}73 \times 2{,}01 = 40 \pm 1{,}47$$

Warning limits:

$$40 \pm \frac{2 \bar{R}}{d_2 \sqrt{n}} = \frac{2 \times 2{,}01}{2{,}06 \sqrt{4}} = 40 \pm 0{,}98$$

Upper range limits:

$$D_4\bar{R} = 2{,}28 \times 2{,}01 = 4{,}58$$

These are the limits to be drawn on the mean and range charts.

The mean range and the PMR are two random variables fluctuating with time. The statistical significance whether of two mean ranges or two PMR's corresponding to two running periods of a machine can be found.

In the former the parameter F_R is used:

$$F_R = \frac{\left(\frac{\bar{R}_1}{(d'_2)_1}\right)^2}{\left(\frac{\bar{R}_2}{(d'_2)_2}\right)^2}$$

Where $\bar{R}_1$ and $\bar{R}_2$ are the mean ranges corresponding to the two periods and d'_2 the coefficient from Duncan's table. F can be tested by means Snedecor-Fisher F Tables for the degrees of freedom given by Duncan, which are dependent on sample size and the number of groups <u>k</u> of <u>n</u> individuals (generally from 20 to 30).

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For the more usual sizes and the most common number of groups in spinning quality control, Duncan's Tables give the following values:

No. of Groups (k)	n = 4		n = 5		n = 7	
	d.f.	d'2	d.f.	d'2	d.f.	d'2
15	41	2,07	51	2,34	74	2,71
20	55	2,07	73	2,33	106	2,71
25	68	2,07	-	—	—	—

To test the significance of the P.M.R., the author has established the significance limits for the 10 %, 5% and 1% probability levels calculated for k = 25 groups of n = 4 individuals. The values are shown in Table 3

TABLE III

Significance levels

P.M.R.	10%	5%	1%
4	3,4 - 4,7	3,3 - 4,9	3,0 - 5,2
5	4,2 - 5,9	4,1 - 6,1	3,7 - 6,7
6	5,1 - 7,1	4,9 - 7,3	4,5 - 8,0
7	5,9 - 8,3	5,7 - 8,6	5,2 - 9,4
8	6,8 - 9,5	6,5 - 9,8	6,0 -10,8
9	7,7 -10,7	7,4 -11,0	6,7 -12,0
10	8,5 -11,8	8,2 -12,2	7,4 -13,5
11	9,3 -13,0	9,0 -13,5	8,2 -14,8
12	10,1 -14,2	9,8 -14,7	9,0 -16,1

It is advisable to interpret de results in the following way:

(a) The PMR falls within the 10% limits: the difference is non-significant

(b) The PMR falls in the 5% to 10% belts the difference is slightly significant.

(c) The PMR lies in the 5% to 1% belts: the difference is significant.

(d) The PMR falls outside the 1% limits: the difference is highly significant.

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2. Control of attributes

This covers the control of the faulty fraction, number of faulty ones (total and per unit). Poisson's and binomial distributions are used here.

2.1 Faulty fraction (proportion of)

The scheme is as follows:

(a) Draw a list of possible defects.

(b) Group defects into categories (larger, smaller, etc.)

(c) Decide upon wheter all sorts of defects should be controlled by means of a single chart, or different charts should be used.

(d) Choose sample size.

(e) Record data and plot them on the control chart for the faulty fraction. 25 to 30 lots will be taken in the initial calculation.

(f) Calculate $\bar{p}$ (mean faulty fraction) through the formula:

$$\bar{p} = \frac{\sum m}{\sum n} \qquad \frac{\text{sum of faulty individuals}}{\text{total sum of individuals}}$$

(g) Calculation of control limits:

Upper control limit:

$$\bar{p} + 3 \sqrt{\frac{\bar{p}\,(1-\bar{p})}{\bar{n}}} .$$

Lower control limit:

$$\bar{p} - 3 \sqrt{\frac{\bar{p}\,(1-\bar{p})}{\bar{n}}} .$$

$\bar{n}$ is the arithmetic mean of the 25 to 30 considered lots. For $p < 0{,}10$ the above formula can be simplified to:

$$\bar{p} \pm 3\sqrt{\frac{\bar{p}}{n}} .$$

(h) Draw the central and upper and lower control lines.

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(i) Again calculate limits for points close to control line:

$$\bar{p} \pm 3\sqrt{\frac{\bar{p}\ (1-\bar{p})}{n}}$$

(n being in this instance, the size of the sample which is being analyzed) to see whether the points fall within or outside control limits.

(j) Take action to get process under control.

(k) Periodically check upon the mean and control limits and take action if necessary. First checking should be done on the 25 to 30 lots following achievement of correct control to see whether the $\bar{p}$ value can be considered as normal.

As in the control of variables, out of control points in the initial stage, of which the causes is known and can be avoided, will not be taken into account for calculation of limits.

2.2 Faulty (number)

The procedure is the same up to calculation of limits, which will be done in the following way:

$$\bar{p} = \frac{\sum m}{\sum n} = \frac{\text{Sum of faulty individual in the sample}}{\text{Total sum of individual in the samples}}$$

Control limits:

$$n\,\bar{p} \pm 3\sqrt{n\bar{p}\ (1-\bar{p})}.$$

The lower limit will be zero if the formula gives a negative value. If $\bar{p} < 0{,}10$, then:

$$n\bar{p} \pm 3\sqrt{n\bar{p}}$$

the next steps being the same as before.

2.3 Number of defects

The steps are as follows:

(a) Decide what a defect is.
(b) Decide what a sample is.
(c) Record data and plot points (first stage).
(d) Calculate the central line and the control limits:

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$$\bar{c} = \frac{\sum c}{n} = \frac{\text{sum of defect of n samples}}{\text{Number n of samples}}$$

Limits:

$$\bar{c} \pm 3\sqrt{\bar{c}}$$

Using zero as a limit, if the formula gives a negative value. From here onwards the method is the same as before. If the control is for number of defects per unit,

$$\bar{u} = \frac{\sum u}{n} = \frac{\text{total number of defects}}{\text{Total number of tested individuals}}$$

Limit:

$$u \pm 3\sqrt{\frac{\bar{u}}{n}}.$$

If in these cases there is a given specification:

Faulty fraction:

$$p' \pm 3\sqrt{\frac{p' (1 - p')}{n}} \quad ; \quad p' = \text{specified value}$$

Number of faulty ones:

$$p'n \pm 3\sqrt{np' (1-p')} \quad ; \quad p' = \text{specified value}$$

Number of defects:

$$c' \pm 3\sqrt{c'} \quad ; \quad c' = \text{specified value}$$

Defects per unit:

$$u' \pm 3\sqrt{\frac{u'}{n}} \quad ; \quad u' = \text{specified value}$$

The rest of the mechanism is the same as for control of variables.

APPENDIX III

Calculation of limits in the simplified Control charts

Let:

$\breve{X}$ = median.

$\breve{\breve{X}}$ = median of medians.

$\breve{R}$ = median of ranges.

M = mid-range = $\dfrac{x_1 + x_n}{2}$.

$\breve{M}$ = median of mid-ranges.

$\bar{M}$ = mid point of mid ranges.

(a) Where median $\breve{X}$ and range are used.
Control limits for the median:

$$\breve{\breve{X}} + A_4\breve{R}$$

Control limits for the range:

$$\breve{D}_6 \; \breve{R}$$

$$\breve{D}_5 \; \breve{R}$$

(b) Where the mid-range M and the range are used.
Control limit for the mid range:

$$\breve{M} + A_4\breve{R} \; ; \; \bar{M} + A_5\breve{R}$$

The same formulas as before are used for the range.

These modalities for control are well applied when the sample size is not greater than 15 and in Table 1 the coefficients A_4, A_5, D_5 and D_6 are given for sample sizes smaller than 10. In the parameter of location charts, the median of the medians and the centre point of the mid range respectively are used as centre lines. The latter parameter is more efficient than the median for $n < 6$ and less for $n > 6$.

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TABLE I

n	A_4	A_5	D_5	D_6	d''_2
2	2,224	2,121	0	3,865	0,954
3	1,137	1,806	0	2,745	1,588
4	0,828	1,637	0	2,315	1,978
5	0,679	1,532	0	2,179	2,257
6	0,590	1,458	0	2,055	2,472
7	0,530	1,402	0,078	1,967	2,645
8	0,486	1,358	0,139	1,901	2,791
9	0,453	1,322	0,187	1,850	2,916
10	0,427	1,293	0,227	1,809	3,024

APPENDIX IV

Calculation of Cumulative sum Charts

L_A and L_R = average run lengths for the α and β producer and consumer risks

m_A and m_R = process mean for acceptable and rejectable qualities

h = ordinate at the origin for the upper limit line

n = sample size

The fundamental formulas are:

$$L = \frac{1}{\alpha} \quad \text{and} \quad L_R = \frac{1}{1 - \beta}$$

$$h = a \frac{\sigma^2}{n (m_R - m_A)}$$

The following α values are recommended

Control or action limit: α_i = 0,001

Warning limit: α_a = 0,010

and β = 0,5 or β = 0,667 (which corresponds to average run lengths of 2 and 3 respectively). Then, the a coefficients for action and warning are:

		Coefficient a	
β	L_R	a_i	a_a
0,50	2	6,215	3,912
0,667	3	5,808	3,506

If only a small number of values is considered for risks α and β (for instance: α = 0,001 and β = 0,50 and 0,667) the sample size will be given by the formulas:

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$\beta = 0{,}50$ $$n = 5{,}52\left(\frac{\sigma}{m_R - m_A}\right)^2$$

$\beta = 0{,}667$ $$n = 3{,}33\left(\frac{\sigma}{m_R - m_A}\right)^2$$

Example

In a process where 30s counts are being spun, with $\sigma = 0{,}6$, it is desired to establish a cumulative sum control charts in order to realize, whether an average from a second sample, gives a modification of one count (29 or 31).

For $\beta = 0{,}5$, the sample size is:

$$n = 5{,}52\left(\frac{0{,}6}{1}\right)^2 \cong 2$$

Calculation of limits:

Action:

$$h_i = 6{,}215\,\frac{0{,}6^2}{2 \times 1} = 1{,}119$$

Warning:

$$h_a = 3{,}912\,\frac{0{,}6^2}{2 \times 1} = 0{,}704$$

At the beginning of control, if the mean of the first sample (or first samples) falls between $m_0 = \dfrac{m_A + m_R}{2}$, i.e.,

$\dfrac{30 + 29}{2} = 29{,}5$ and $\dfrac{30 + 31}{2} = 30{,}5$ (reference values) no action will be taken and the values will be plotted on the central axis of the chart. When there is a mean value falling out either of the action or warning intervals, the nearest reference value is substracted (29,5 or 30,5) and the result is plotted, on the chart, account being taken of its sign. The means of the next samples are algebraically summed to the preceding ones after substracting the same reference value.

APPENDIX V

Trend Charts
(a) Control of machines

Assume (Fig. 1) a four delivery drawframe in cotton spinning, where it is desired to control sliver hank. The data from a week's work is collected on a control card, which includes the necessary blocks for data from each day to be recorded.

On the basis of the specified mean (290 in our case), the different class intervals, are recorded on the upper part (in thousandths of a count). The interval is 0,002 counts (or 2 thousandths), which is dependent or can be related to quadrant balance readings. Control is carried out by weighing 1,5 m to 10 m lengths of sliver from all the four deliveries of the drawing frame. Let us assume there are four daily controls.

The results from the second control will be recorded in a different colour or in a conventional sign (in our example the cipher from the delivery will be enclosed in a square block □).

The delivery number will be recorded in the square corresponding to the test value. In this way, it will be possible to detect possible wrong trends or anomalies in the machine deliveries. Thus, for instance, on Monday of April 4, the first test from delivery 3 has produced, a normal value, whereas the second value has moved the opposite way and quite far from the mean. A third test, has been carried out (represented by cyphers in a circle ◯) and as can be seen, again delivery 3 was far from them mean and not on the same side as in the previous test. An insufficent pressure was found on the corresponding delivery after machine checking, which caused it to be out of control. After correction, everything went on normally, on the following days.

At the end of the week, the 16% rule is applied to find the standard deviation.

In our example, 52 observations x 16% = 8 values from each of the tails of the distribution. The standard deviation is $\frac{294 - 290}{2} = 2$ and the median, which in this instance is an estimate of the mean) is 292 (i.e. 0,292 hank). The coefficient of variation $\frac{2 \times 100}{292} = 0,7\%$

It is convenient to find the value of the median daily in order to know the general trend of the machine and to be able

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to correct for it if necessary. Control limits are calculated at the end of the week; these are marked on the sheet corresponding to next week. In our example $3\sigma = 3 \times 2 = 6$, i.e., 6 units on each side of the mean (286-298). These limits correspond to individual deliveries.

For the daily means, σ will be divided by $\sqrt{n-1}$, but n varies from 8 to 12, so that in the former case $\frac{2}{\sqrt{7}} = 0,75$ and in the latter $2 / \sqrt{11} = 0,6$. In practice.

$292 \pm 3 \times 0,75 = 294,25$ and $289,75$

$292 \pm 3 \times 0,6 = 293,80$ and $290,40$

i.e., 294 and 290, (it is a coincidence that these values be the same which limit σ in the distribution of the means).

It should be observed in this example, that the control limits have been set from the actual and not from the nominal mean of the process. In this way the stability of processing is secured although it is slightly out of center.

When all the deliveries can be analyzed, the advantage of this system is obvious, since it is easy to see, from the values recorded for each machine, the possible anomalies and to correct them. With a classical control chart the failure of delivery 3 on April 4 would not so easily be detected. If not corrected it would have been going on, originating disturbances which perhaps might have been shown on the long run at the cost of falling out range and, possibly after some useless opinion change harmful to process stability.

(b) Control of properties or parameter

In admission and production control, this method can be used as a substitute for classical Shewhart's control charts. Fig. 2 shows an example of control of a 30s yarn strength for one week at the rate of 25 daily tests. In this instance, the value from each test ar marked by a cross in the blocks of the card. A 5g class interval was chosen.

The final calculations are the same which have been given for processing control.

On the whole, we have 150 tests, of which the 16 per cent is 24. We shall, therefore, take 24 points from each side and the interval $270-235 = 35$ will show the 2σ value. The approximate mean will be $235 + 17,5 = 252,5$ g and the coefficient of variation

$$\frac{17,5 \times 100}{252,2} = 6,9\%.$$

This type of graph has, therefore, many applications as a substitute of Shewhart's.

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APPENDIX VI

Example of application of a Multiple Plan in Textile Control

Quality Control of defects of bobbins

This control is to be applied to bobbins in order to find the proportion and the sort of defects that quite often show up.

The defects are classified into two groups:

Major defects:

Slack bobbin because of an inadequate traveller (at the ring spinning frame)

Large backwards bobbin.
Bad bobbin at start, too low.
Poorly finished bobbin, too high.

Minor defects:

Star wheel too far ahead, giving poorly shaped bobbins (whole doff).
Backwards bobbin.
Bobbin with a poor start, either too high or too low, on the whole doff.

These defects should be added to those inherent to some processes not included in the above classification.

Sampling plan and implementation of control

A sequential multiple sampling plan has been adopted, where an accepted quality level of 5 per cent has been set for the larger defects and of 10 per cent for the smaller defects.

The sampling plan concerns one doff and it is shown on the left top side of the card. It works in the following way:

A first sample of 40 bobbins is taken at random and bobbins are examined one by one, the defects being recorded under "major defects" and " minor defects".

(a) Major defects

If in the whole 40 bobbins there is none to be faulty or only one, the doff will be accepted as good (column A = acceptance, for larger). If on the contrary, the number of faulty bobbins is greater tan 6 (inclusive) the doff will be considered as faulty (column R = rejection for larger). If the number of faulty bobbins is between 1 and 6, a second sample of 10 more bobbins will be taken, and on the whole sample 40 + 10 = 50,

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it will be noted whether there are less than two or more than six faulty bobbins, to acceptor reject to doff. If the number of faulty bobbins is from 2 to 6, a third sample will be taken and so on, up to a fifth sample if necessary, this last being the decisive one.

(b) Minor defects

The procedure is the same to that for larger defects, but with the acceptance and rejection figures shown on the right of the sampling plan.

To count and classify the faulty samples the columns in the lower part of the card will be used. In the example given here, it turns out that of the 40 bobbins taken out of the first sample, (i) there is one slack bobbin, (ii) one large backwards and (iii) a poorly finished one (too high): all said, three bobbins with large defects. The table in the sampling plan shows us that a second sample must be taken, where only a large backward bobbin has turned up. On the whole, there are 4 faulty bobbins out of 50. A third sample must be taken, which has not given any faulty bobbins, but it is still necessary to take 10 bobbins more. Since there are no faulty bobbins in this fourth sample, it will fall into the acceptance number for larger defects. As to the "smaller defects", in the four samples the following in succession have turned up: 2, 1, 1, 1. The total of five smaller defects falls by far in the acceptance number corresponding to the fourth sample for defects of this sort.

Sometimes, the whole doff larger defects (all bobbins are slack) or smaller (star wheel to far forward, bobbins with a poor start or finish because of bad adjustment of the lift at the beginning, or too highly finished). In that event a cross will marked (x) in the corresponding cell and the inspection will be continued in order to detect other possible defects, it being well understood that even if on carrying out this count, the above general defect be overlooked, the final classing will be rejection even if the other defects should be smaller than their corresponding limiting figure.

When there are bobbins with either a poor start or finish, it should be discriminated where the defect is major or minor . Generally, it will be considered as smaller if it affects the whole doff and larger if it only affects a few bobbins because of a bad condition of either spindle or tube.

For slack bobbins it should also be discriminated whether the defect is a general or a particular one, although in this event, the defect will be considered as major .

Backward bobbins can be classified into major and minor according to severity of defect.

Whe a bobbin has two defects it will be classified following the most important of the two.

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DEFECTS IN SPINNING

Faulty bobbins

Sampling plan

Major A	Major R		Sample No.		Minor A	Minor R
1	6	1er	40	(40)	4	9
2	6	2nd	10	(50)	5	10
3	7	3rd	10	(60)	7	12
4	8	4th	10	(70)	8	13
7	8	5th	10	(80)	12	13

Complementary data

Date . . . .

Machine. . . . .

No. . . . .

Batch. . . . .

Breaks: 100 spindle hours. . . .

Saturation . . . .

Control data

Major

	Samples 1er	2nd	3rd	4th	5th	Total
Slack bobbin	1	0	0	0		1
Large backwards	1	1	0	0		2
Poor start (low)	0	0	0	0		-
Poor finish (high)	1	0	0	0		1
	3	1	0	0		4

Minor

	Samples 1er	2nd	3rd	4th	5th	Total
Star wheel too far forward	0	0	0	0	.	-
Little backwards	11	1	1	1		5
Poor start (low)	0	0	0	0		-
Poor finish (high)	0	0	0	0		-
	2	1	1	1		5

Operative. . . . . Qualification .Acceptable . .

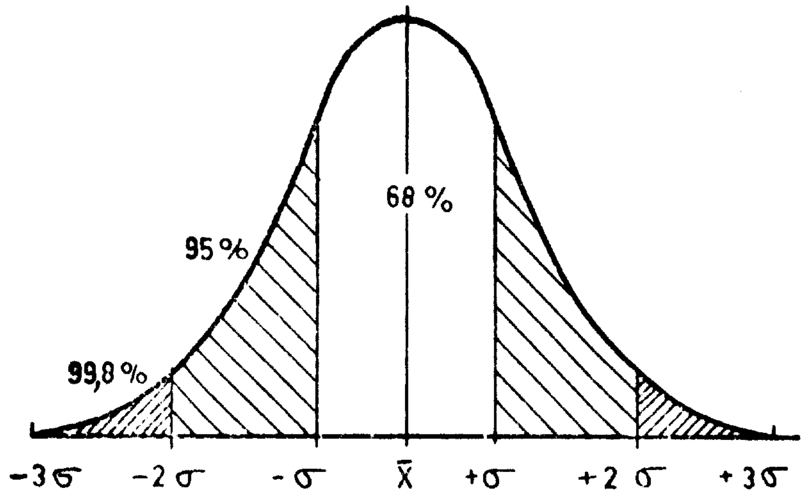
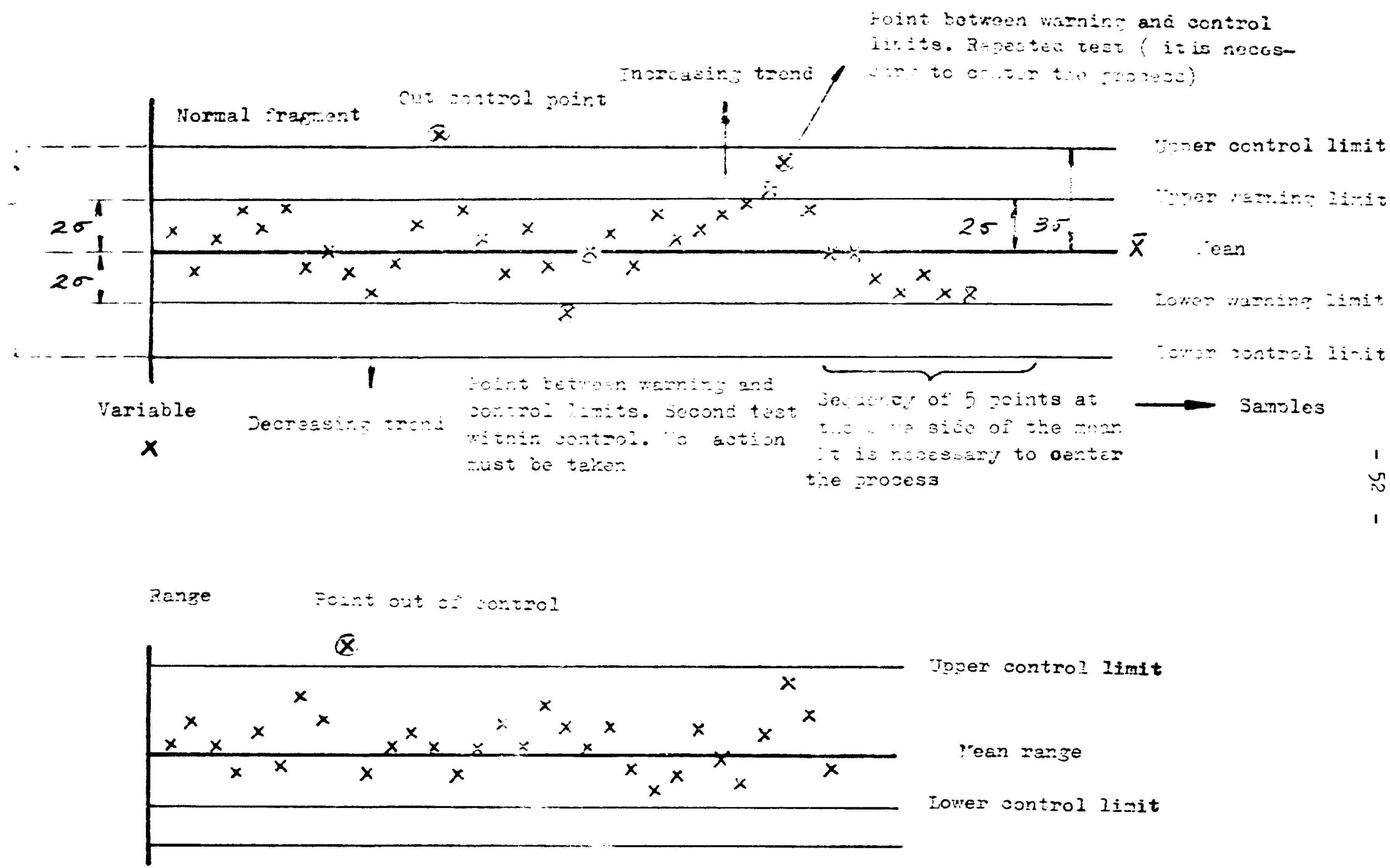


Fig 1.



Point between warning and control limits. Repeated test (it is necessary to center the process)
Increasing trend
Out control point
Normal fragment
Upper control limit
Upper warning limit
2σ
2σ
2σ
3σ
Mean
Lower warning limit
Lower control limit
Variable
Decreasing trend
Point between warning and control limits. Second test within control. No action must be taken
Sequency of 5 points at the same side of the mean It is necessary to center the process
Samples
Range
Point out of control
Upper control limit
Mean range
Lower control limit

Fig 2

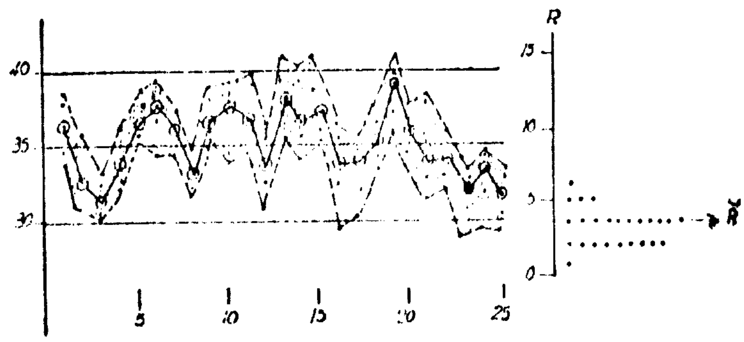


Fig. 3

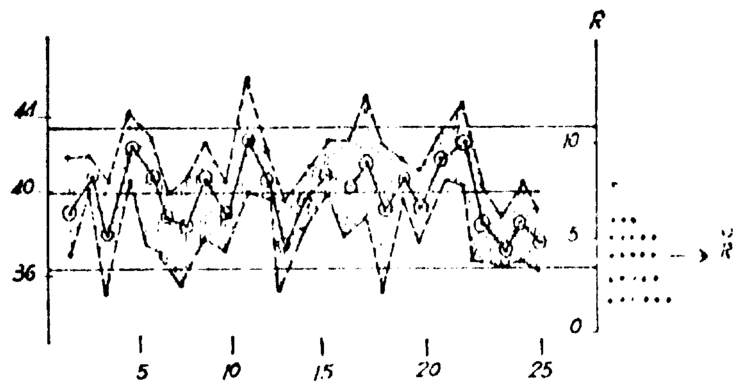


Fig. 4

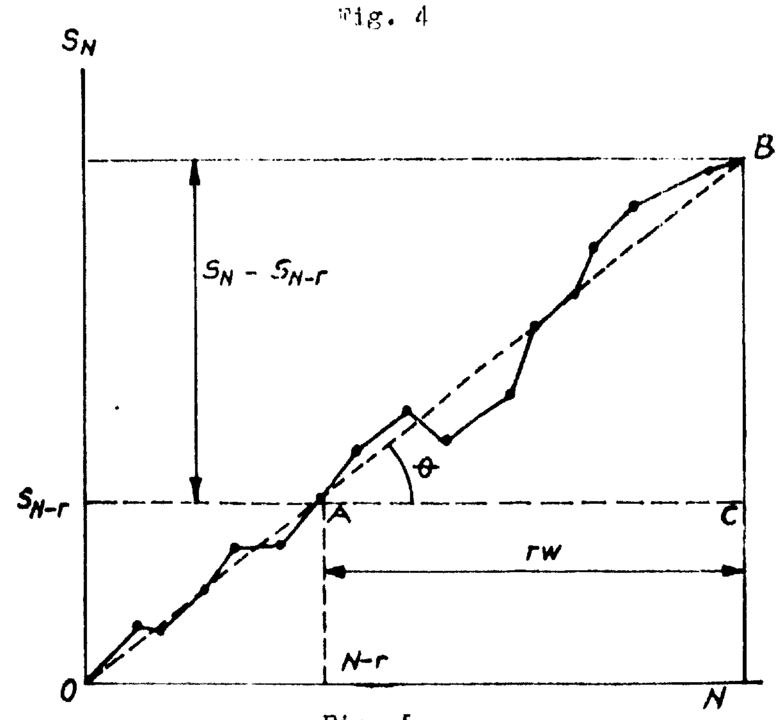
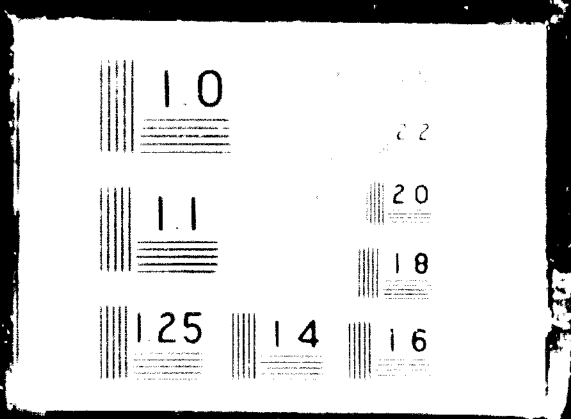


Fig. 5

13.3.74

2 OF 2

DO 0888



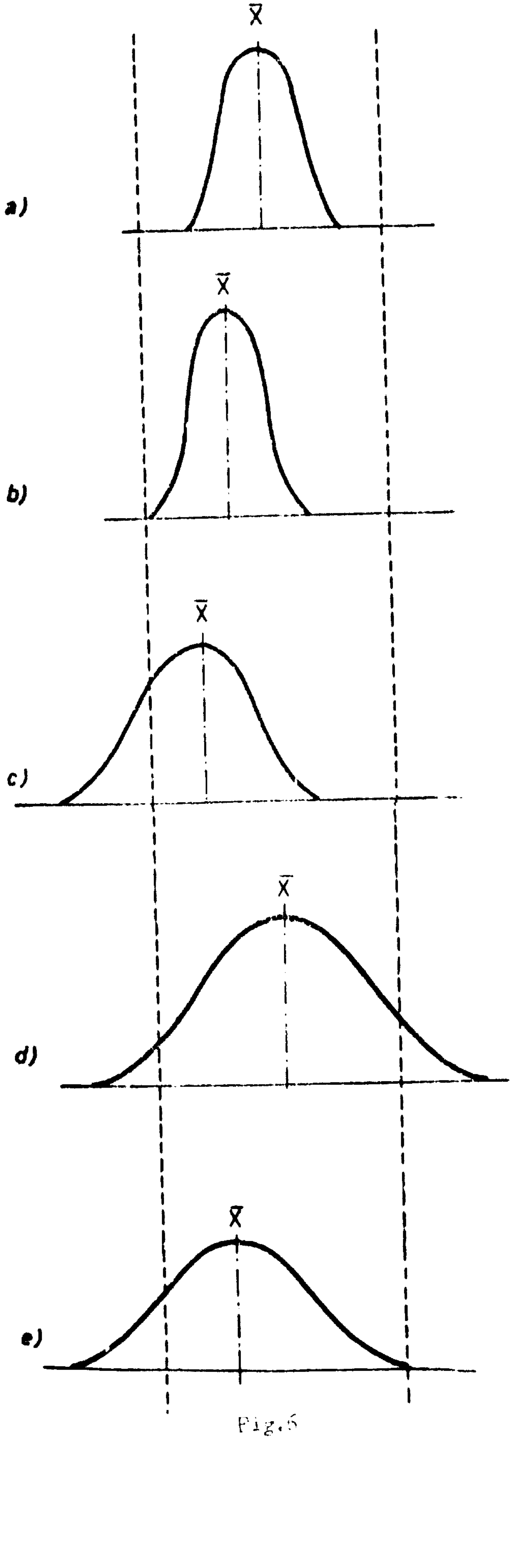
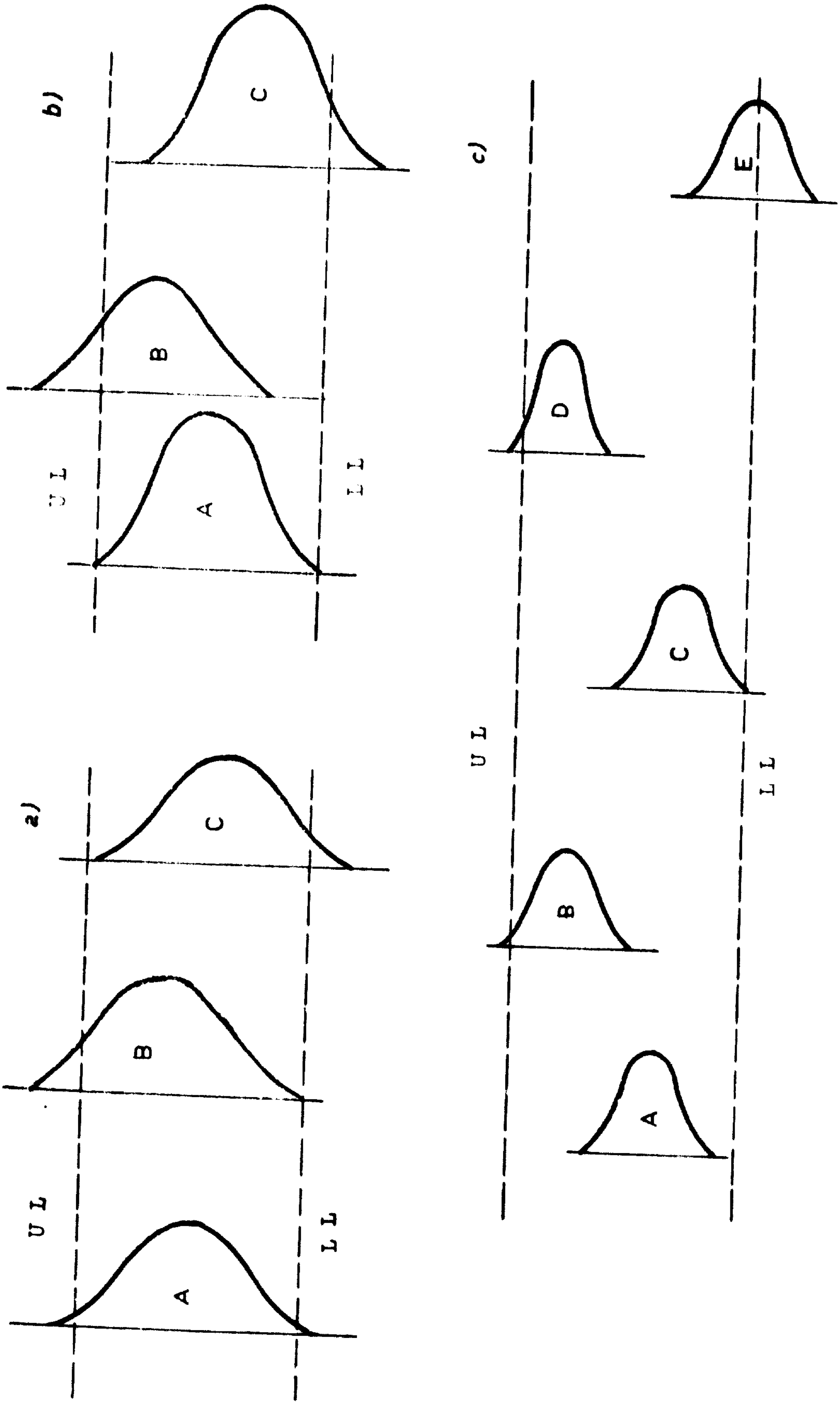


Fig.6


a)
U L
L L
A
B
C
b)
U L
L L
A
B
C
c)
U L
L L
A
B
C
D
E

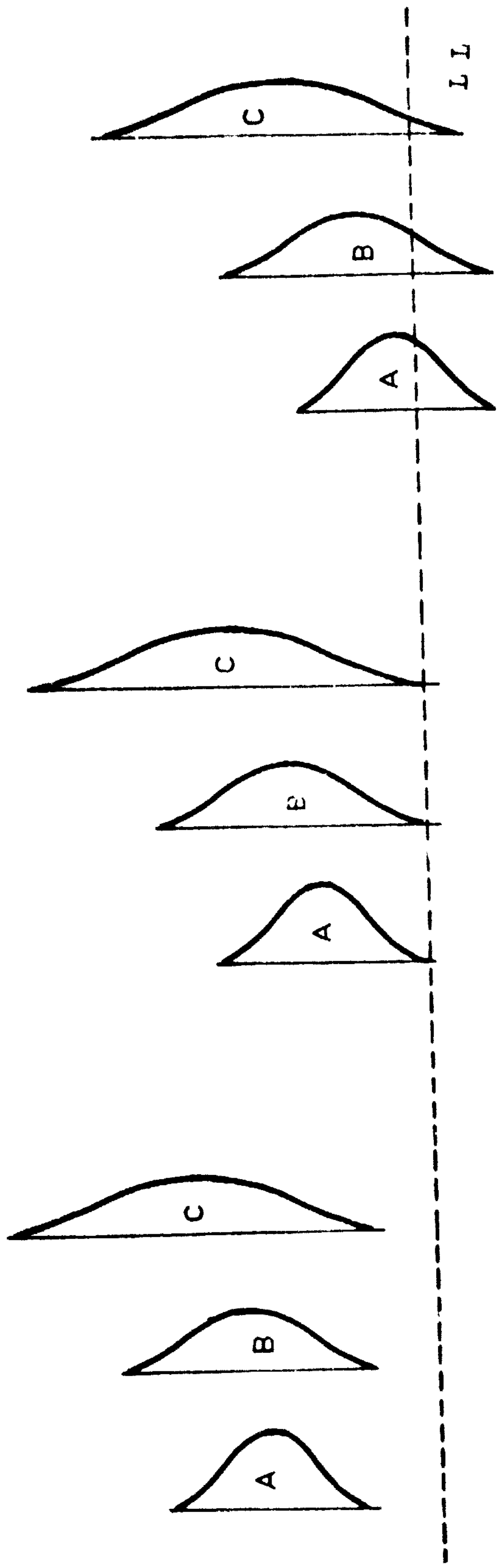
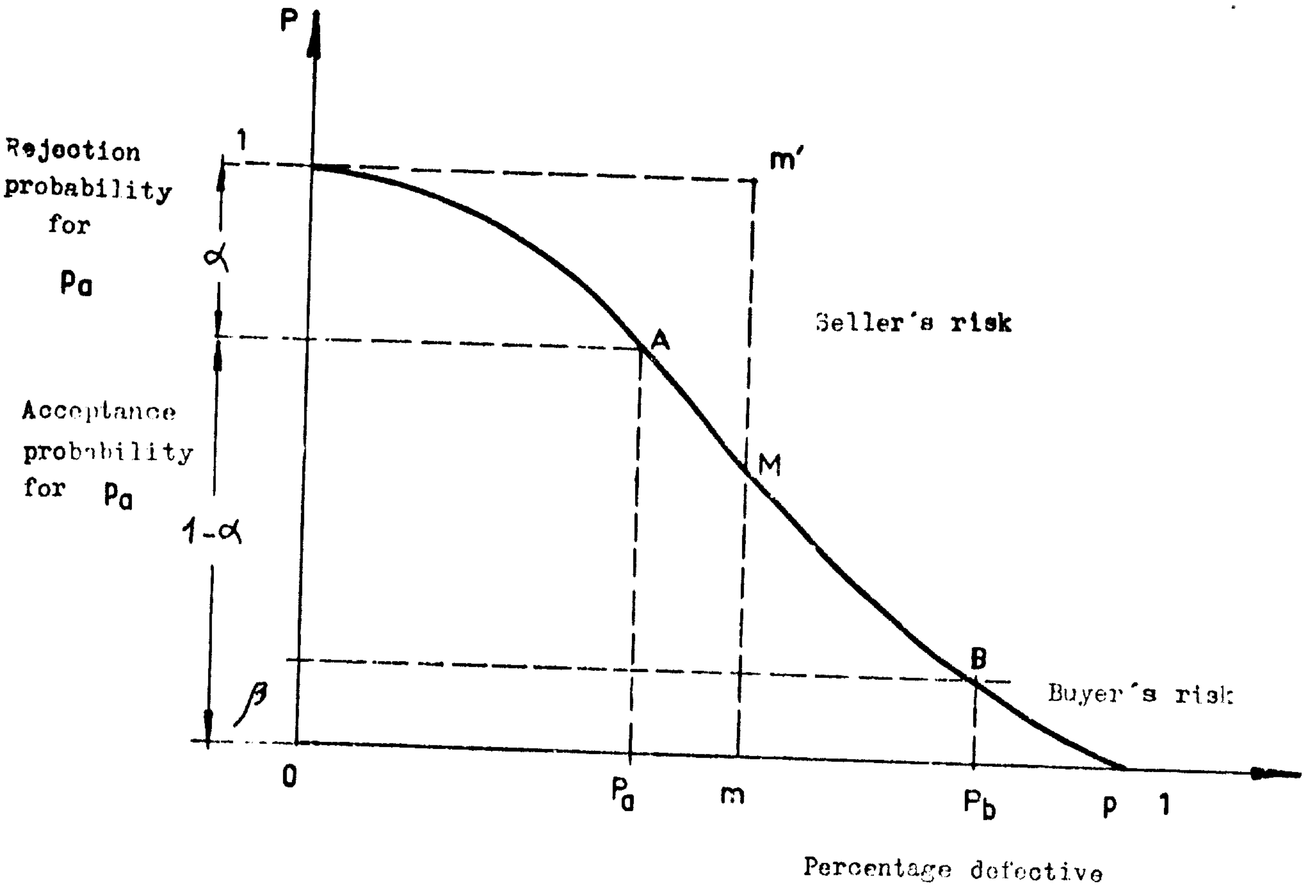


Fig 3


P
Rejection
probability
for
Pa
1
m'
α
Seller's risk
A
Acceptance
probability
for Pa
M
1-α
B
β
Buyer's risk
0
Pa
m
Pb
p
1
Percentage defective

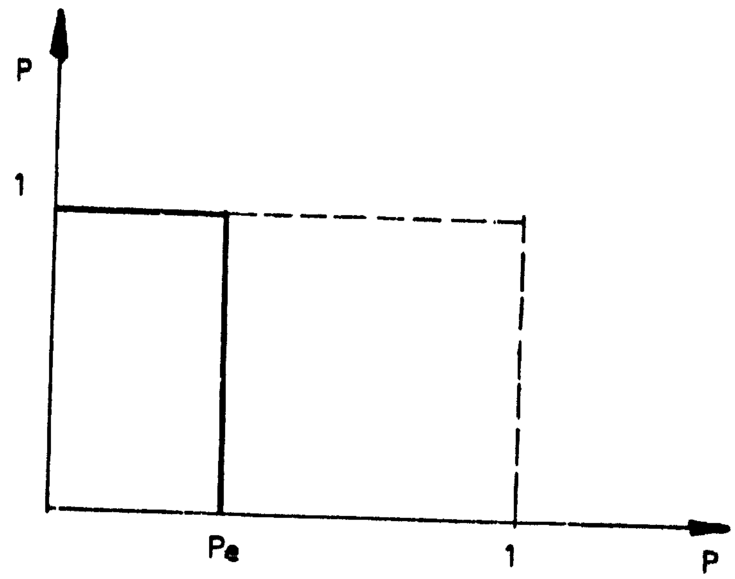
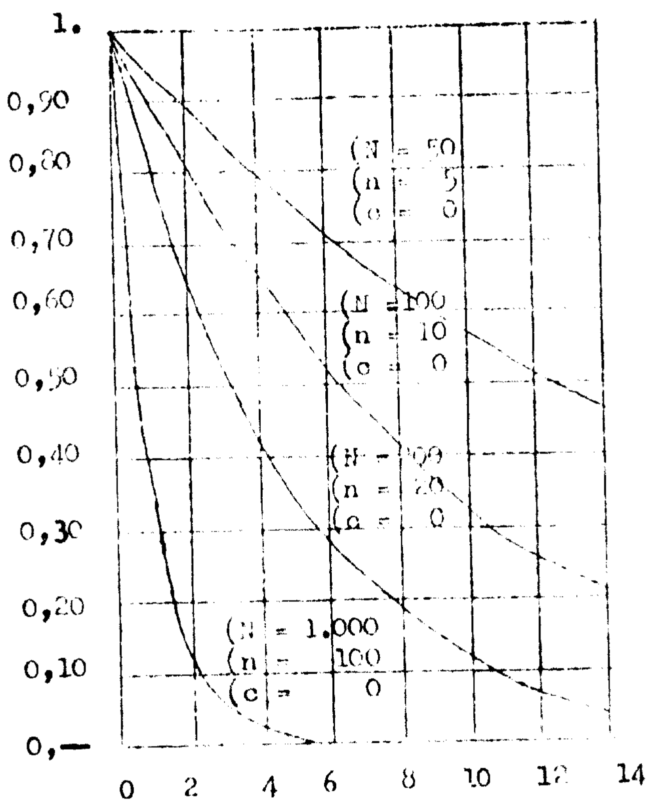
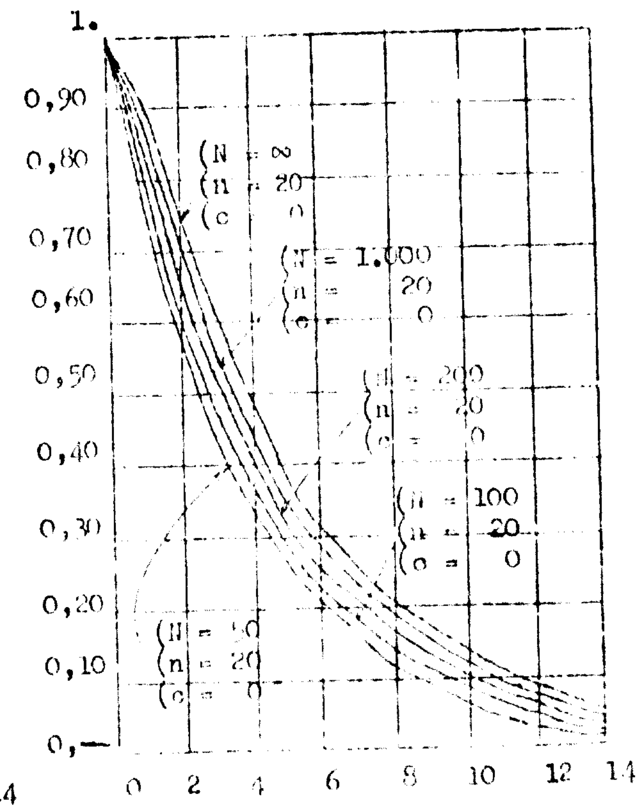

P
1
Pe
1
P

Fig. 10



Abs: Percentage defective (100 p)
Ord: Acceptance probability P

Fig. 11



Abs: Percentage defective (100 p)
Ord: Acceptance probability P

Fig. 12

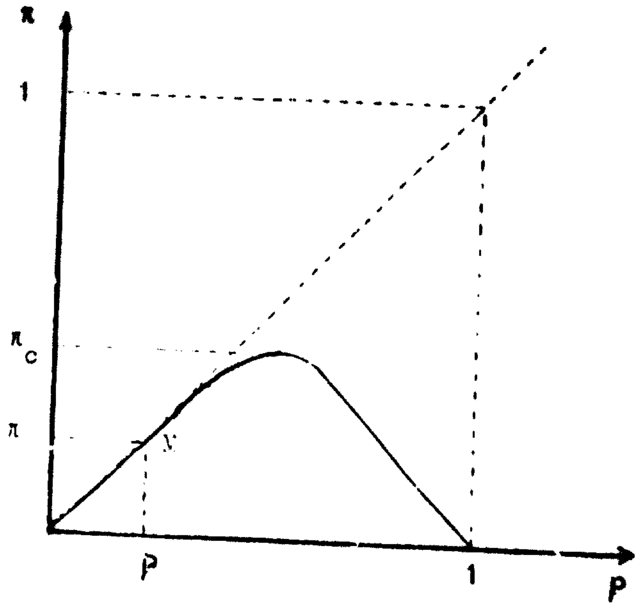

π
1
π_c
π
P
1
P

Fig. 13

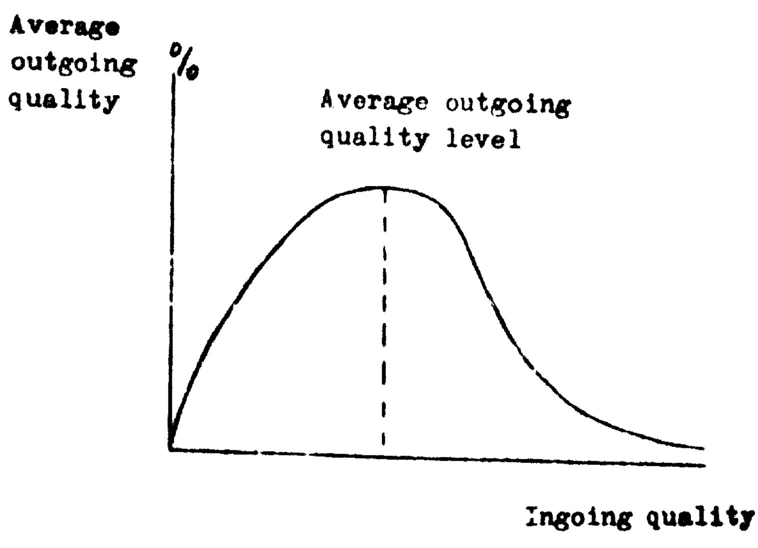

Average
outgoing
quality
%
Average outgoing
quality level
Ingoing quality

Fig. 14

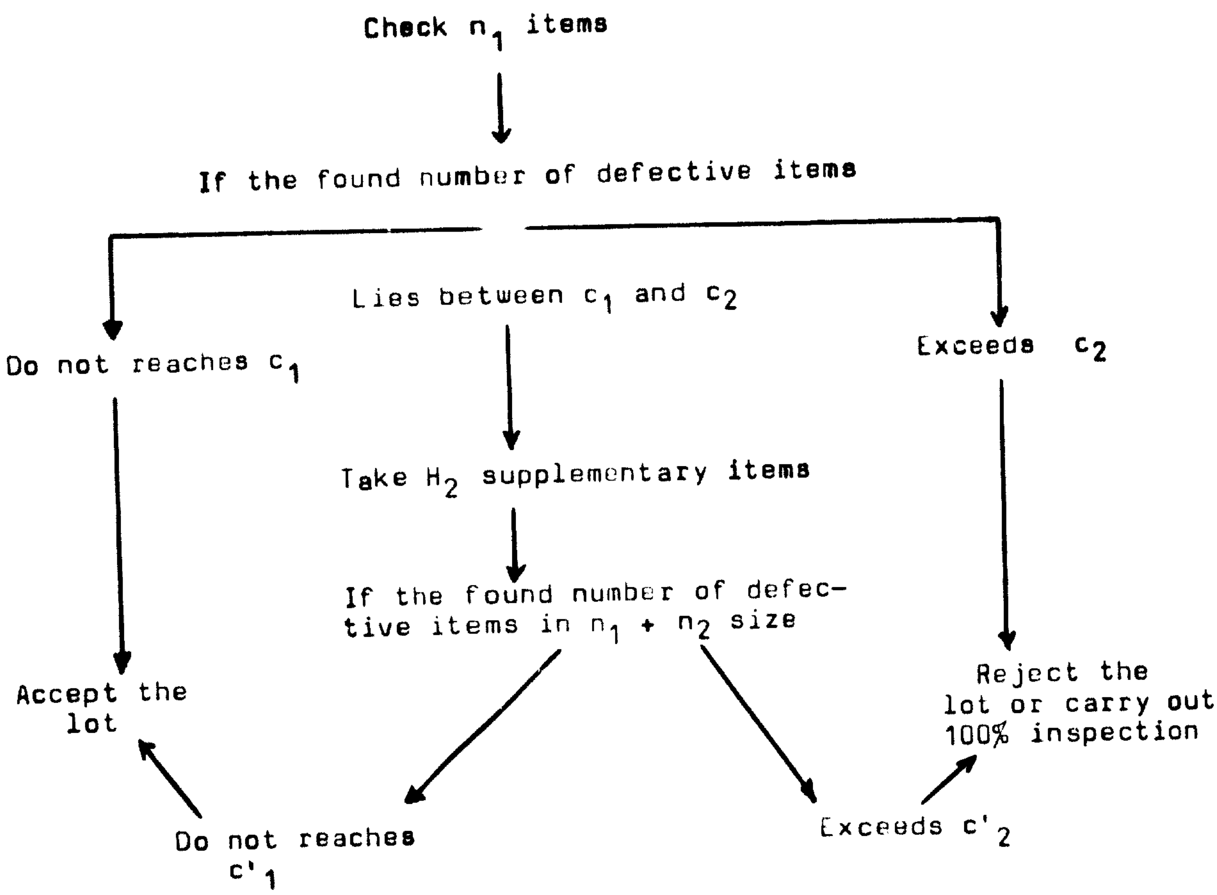

Check n_1 items
If the found number of defective items
Lies between c_1 and c_2
Do not reaches c_1
Exceeds c_2
Take H_2 supplementary items
If the found number of defec-
tive items in $n_1 + n_2$ size
Accept the
lot
Reject the
lot or carry out
100% inspection
Do not reaches
c'_1
Exceeds c'_2

Fig. 15

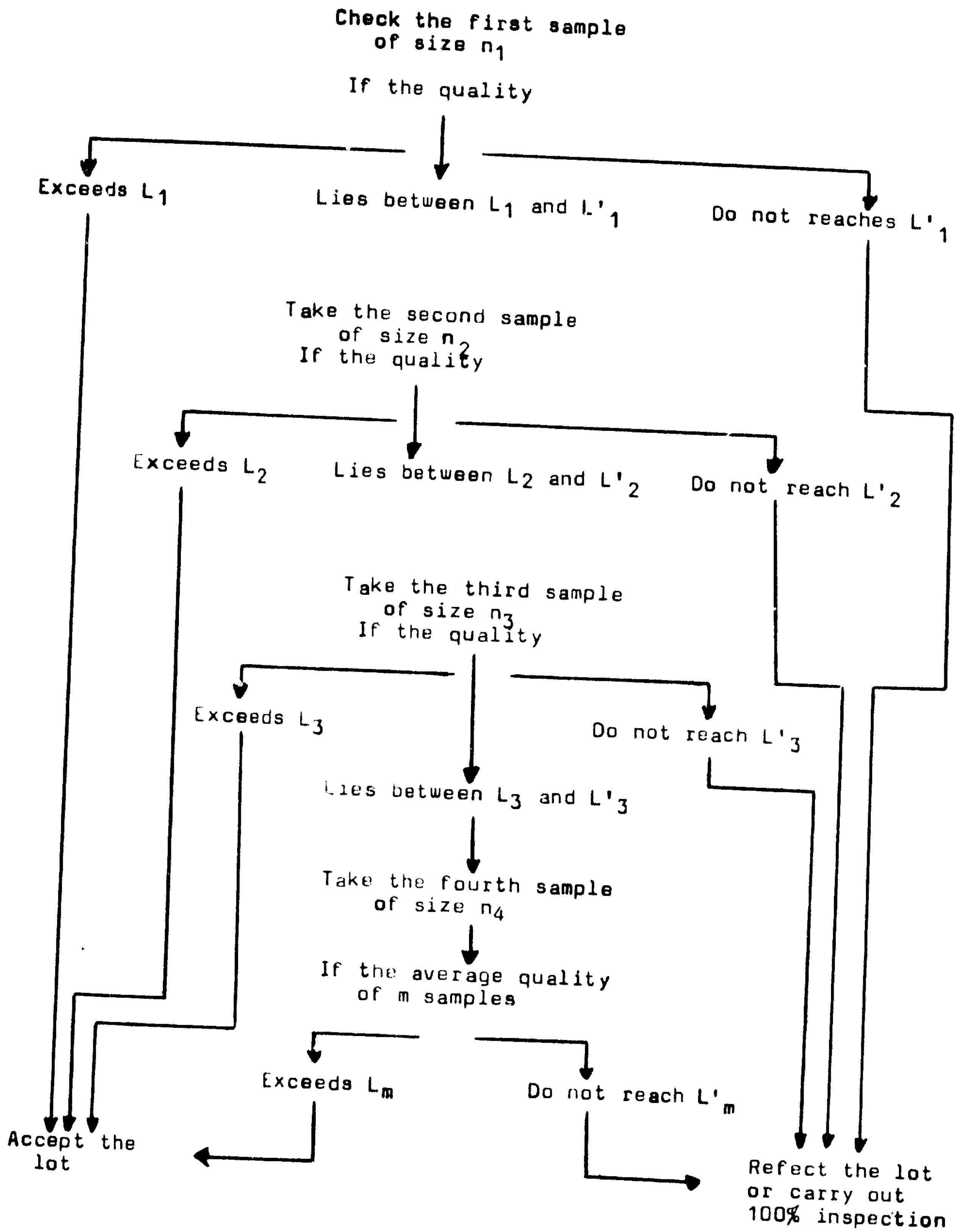

Check the first sample
of size n_1
If the quality
Exceeds L_1
Lies between L_1 and L'_1
Do not reaches L'_1
Take the second sample
of size n_2
If the quality
Exceeds L_2
Lies between L_2 and L'_2
Do not reach L'_2
Take the third sample
of size n_3
If the quality
Exceeds L_3
Do not reach L'_3
Lies between L_3 and L'_3
Take the fourth sample
of size n_4
If the average quality
of m samples
Exceeds L_m
Do not reach L'_m
Accept the lot
Refect the lot
or carry out
100% inspection

Fig. 16

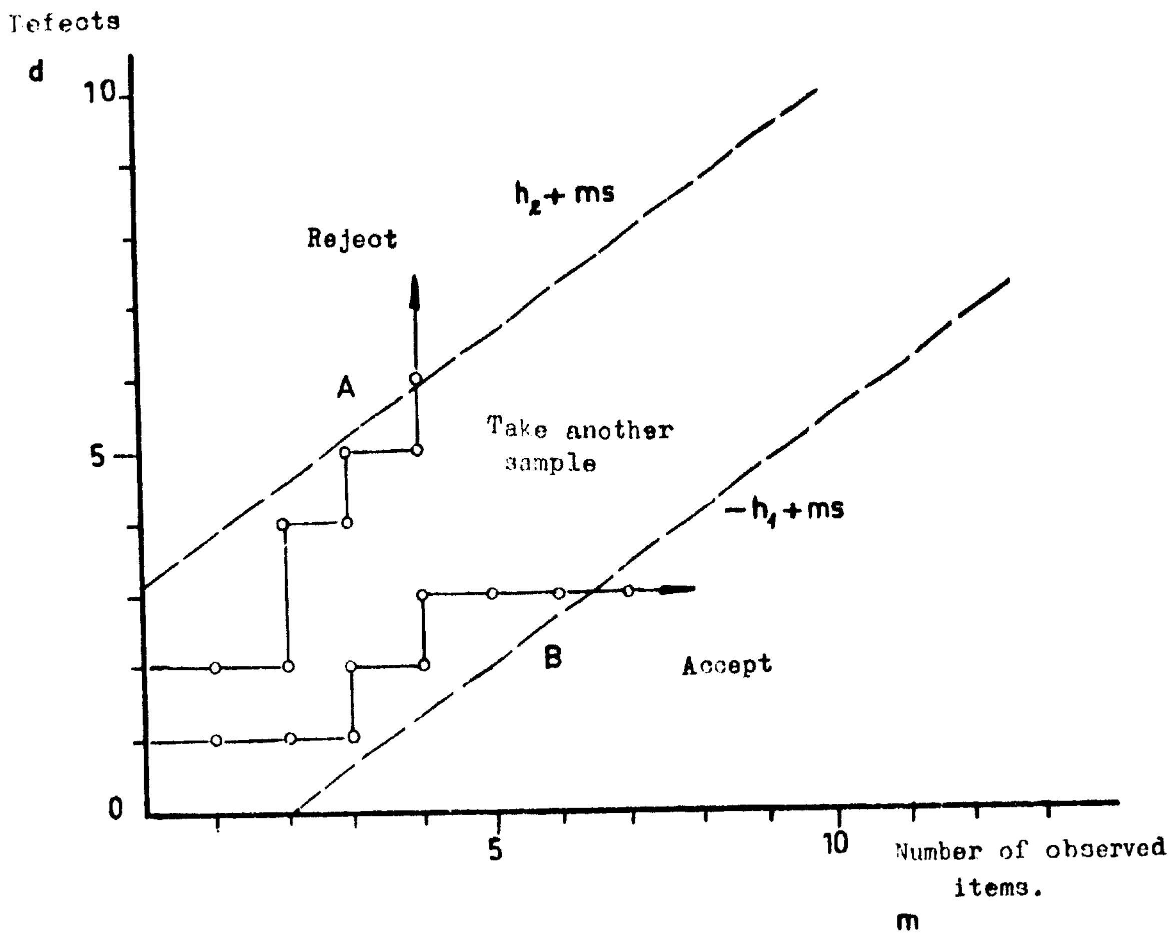
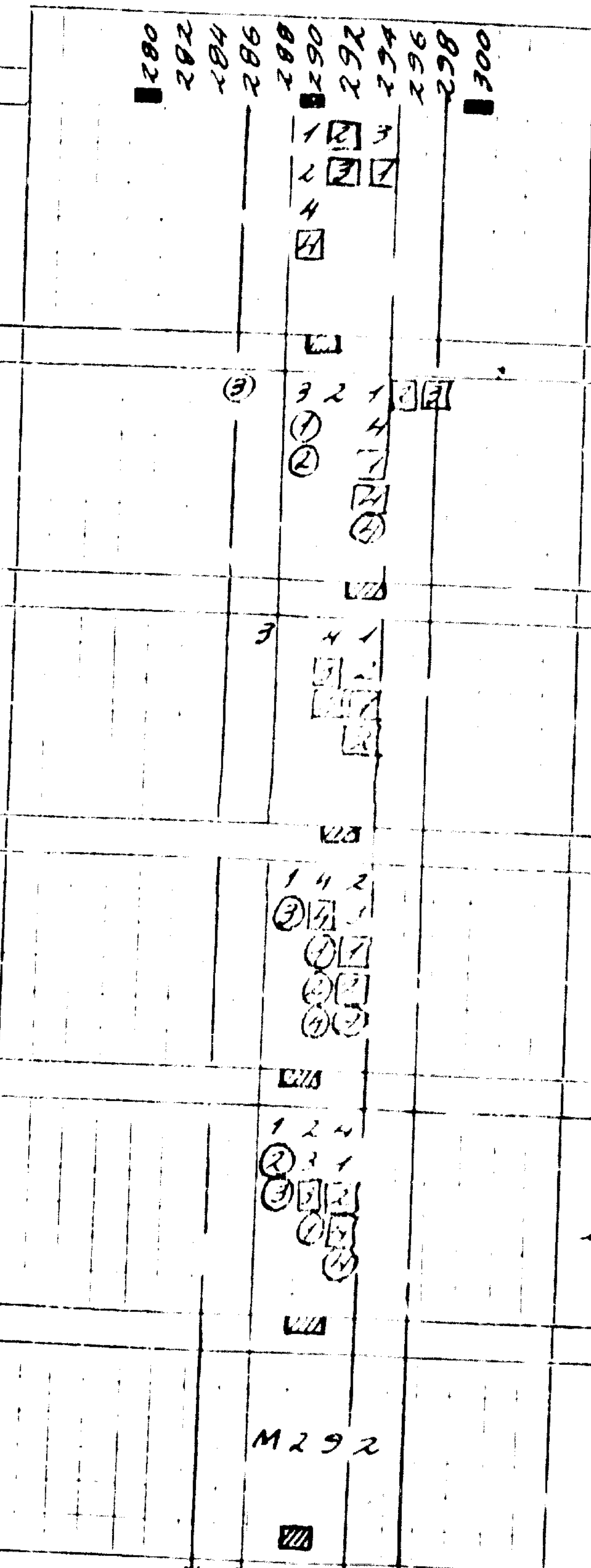

Tefects
d
10
5
0
Reject
$h_2 + ms$
A
Take another sample
$-h_1 + ms$
B
Accept
5
10
Number of observed items.
m

Fig. 17

RAW MATERIAL: American cotton X 10-20
COUNT: 0.29 (metric)
PARAMETER : Sliver count.

MACHINE: Draw frame.
DATE : 12 - 17 January 1970.



Day	Tests	Remarks
Monday 12th January	8	
Mean		
Tuesday 13th January	12	Lack of pressure head 3
Mean		
Wednesday 15th January	8	
Mean		
Thursday 15th January	12	
Mean		
Friday 16th January	12	
Mean		
Mean		
Total	52	16 ... 8

[illegible] : 294 - 290 2 [illegible] 2 x 100:97.

1

RAW MATERIAL : Cotton.
COUNT: 30.
PARAMETER : Single yarn strength

MACHINE: Spinning ring.
DATE 12 - 17 January 1970.

Day	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	Sum	Remarks
12 January			X		XXX	X	XX	XXX	XXXX	XX	XXX	XXX		XX		X		25	
13 January			X	XX	X	XX	XXX	XXXX	XXX	X	X	XXX	XX	X		X		25	
14 January			X		X	XXX	X	XXX	XXXX	XX		XX	XXX	X	XX	X	X	25	
15 January		X	X			X	XX	XX	XXXXXX	XXX	XXX		X		XX	XXX		25	
16 January		X	XX		XXXX	XX	XXXXX	XXXX	XX	XXX		X		X				25	
17 January			X		X	XXX	XX	X	X	XXXXX	XX	XX		XX	XX	X	X	25	
																	Total	150	16 24

σ σ

13.3.74