THE APPLICATION OF STATISTICAL QUALITY CONTROL TO THE DESTRUCTIVE TESTING OF CEMENT IN THE CONTROL LABORATORY

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1960

Submitted to the faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1962

THE APPLICATION OF STATISTICAL QUALITY CONTROL

TO THE DESTRUCTIVE TESTING OF CEMENT

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PREFACE

One problem which constantly confronts industry is control of quality. Management is repeatedly required to make decisions concerning the control of the manufacturing process. As some variable of product quality is measured, someone must decide whether or not this quality is at a satisfactory level.

It must be realized that in many cases the present level of quality is satisfactory and no change is warranted. However, there still exists the problem of maintaining this established level. In other instances, the level may not be satisfactory and change in some control variable is necessary to raise or restore quality to the desired level.

It is the purpose of this thesis to present a complete and useful explanation of Shewhart control charts. When this is completed, it is desired to apply the technique to some phase of cement testing.

I wish to express my gratitude to the Ideal Cement Company, whose research fellowship at Oklahoma State University helped to make this study possible. Many people have contributed to this paper by giving their views and opinions concerning the portland cement industry and statistical quality control. I would like to thank the following men, who are officials of the Ideal Cement Company, for giving me their valuable time during this research: Mr. D. O. Howe, Plant Manager, Ada, Oklahoma; Mr. C. Hargis, Head of Quality Control, Ada, Oklahoma; and Mr. C. J. Noyes, Division Sales Manager, Oklahoma Division.

I am indebted to Dr. Paul E. Torgersen, Oklahoma State University, who has been so helpful during the past semester while acting as my faculty adviser on this project.

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CHAPTER I

INTRODUCTION

In industry, it is either physically impossible or very unprofitable to attempt to consistently produce and dispense a perfect product. As a result of this, the manufacturer is forced to market a certain amount of defective product which inevitably comes back in the form of consumer dissatisfaction. It is largely due to this dissatisfaction that the producer must be concerned with regulating quality.

The purpose of this paper is to present a method which will aid in regulating and controlling quality. The many contributions that have already been made in this area supplied the author with the material necessary to develop an adequate explanation of the method. Once the explanation had been developed, it was applied to the compressive strength requirements for type one cement. The results showed the compressive strength of cement exhibits cyclical tendencies. This made the use of the control charts impossible. In the attempt to uncover the cause for this erradic variation, a correlation analysis was performed. The two variables utilized in this analysis were compressive strength and particle size, which was indicated by a Blaine number. The results were negative. The paper was concluded by recommending further study in this area, in the form of a multicorrelation analysis.

Scope of the Study

The technique of control analysis was applied to the compressive strength of cement. The data required were taken from the Ideal Cement Company, Ada, Oklahoma. It referred to the seven day test results. The information represented a one year period.

It was desired to lay ground work for future expansion of this method to more pertinent areas in the control of cement quality. For this reason the explanation and application were in no way integrated. As a result of this the reader, who is more familiar with the actual operations, is provided with a separate explanation of the technique. Making use of this condensed explanation, he can apply it to more advantageous areas of control.

CHAPTER II

THE HISTORY OF CEMENT

Evidence indicates that the use of cement, in one form or another, is as old as human civilization. Since man first felt the need to build, he has sought a material that would bind stones into a solid mass. The Assyrians and Babylonians, certainly among the first innovators, used clay for this purpose. Later the Egyptians utilized their discovery of lime and gypsum mortar as a cementing material, in the construction of the pyramids. The Greeks made further improvements and finally the Romans developed a cement which resembled the product as it is known today. Their cement had such great durability that some of their buildings, roads, and bridges still exist.

To make cement, the Romans mixed lime to which water had been added (slaked lime) with a volcanic ash from Mount Vesuvius called pozzolana. The ash produced a cement that was capable of hardening under water.

The art of making cement was lost with the fall of the Roman empire, around 400 A.D. It was more than thirteen hundred years later that the secret of making a cement that would harden under water was rediscovered. It was through the scientific spirit of inquiry of a British engineer, John Smeaton, that a "hydraulic" cement was reintroduced to the world.

Repeated structural failure of the Eddystone lighthouse off the coast of Cornwall, England, led Mr. Smeaton to investigate the reactions of various mortars when subjected to both fresh and salt water. These experiments led to his discovery in 1756 that lime extracted from limestone containing a considerable proportion of clay would harden under water.

Discovery of Portland Cement

In 1824, a British bricklayer, named Joseph Aspdin, was granted a patent on a hydraulic cement, which he named "portland" cement because its color resembled that of a natural stone quarried on the Isle of Portland, a penninsula on the southern coast of Great Britain. Aspdin's greatest contribution was his method of production. He found that a cement superior to natural cement could be realized by carefully mixing, grinding, burning, and regrinding certain amounts of limestone and clay.

Before portland cement was discovered and for some years after its discovery, large quantities of natural cement were used. Natural cement was produced by burning the mixture of lime and clay in the state in which they are found in nature. Since the ingredients of natural cement are dependent upon nature's composition, its properties vary as widely as the natural resources from which it comes. Thus the use of natural cement gave way to portland cement, which is a predictable, known product of consistently high quality.

In the beginning, each portland cement manufacturer developed his own formula, until in 1898 ninety-one different formulae were in use. In 1917, the United States Bureau of Standards and the American Society for Testing Materials established a standard formula for portland cement. The Portland Cement Association was formed in 1916 and established research laboratories near Chicago.

The Development of Portland Cement

In 1880, about 42,000 barrels of portland cement were produced in the United States; a decade later the amount had increased to 335,500 barrels; and since that time production has increased steadily until today the United States manufactures and uses more than two and a half times as much portland cement as any other country in the world. Today in this country, 98 per cent of the cement produced is portland cement. This amounts to 50,000,000 tons a year, one fourth of the world's total.[1]

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[1]Sir Charles Davis, Portland Cement, (London, 1934), p. 17.

CHAPTER III

THE MANUFACTURE OF PORTLAND CEMENT

Portland cement, the basic ingredient of concrete, contains about 65 per cent lime, 22 per cent silica, and 6 per cent alumina. Iron oxide and gypsum make up the rest of the materials. The gypsum, which is added in the final grinding process, regulates the setting or hardening time of cement. The lime used to make cement comes from materials such as limestone, oyster shells, chalk, and a type of clay called marl. Shale, clay, silica sand, slate, and blast furnace slag provide silica and alumina. Iron ore supplies the iron oxide.

The materials in the plant go through a closely controlled chemical process that consists of three basic steps: 1. crushing, 2. burning, and 3. fine grinding.

The quarried limestone is dumped into primary crushers. This first crushing smashes the rock into pieces about the size of a softball. Secondary crushers, or hammer mills, then break the rock into pieces about three-fourths of an inch wide.

Next the crushed rock and other raw materials are mixed in the right proportions to make portland cement. This mixture is then ground in rotating ball mills and tube mills.

These mills contain thousands of steel balls that grind the mixture into fine particles as the mills rotate. The materials can be ground by either a wet or dry method. In the wet process, water is added during the grinding until a soupy mixture called "slurry" forms. In the dry process, the materials are ground without water. Otherwise the processes are essentially alike.

After the raw materials have been ground, they are fed into a kiln or calciner, which is a huge cylindrical oven made of steel and lined with firebricks. The cement kiln rotates about 80 revolutions per hour, and is the largest piece of moving machinery used in any industry. It may be more than 12 feet in diameter and 500 feet in length. The kiln is mounted with the axis inclined slightly from the horizontal. The finely ground raw material or the slurry is fed into the higher end, and slides slowly toward the lower end as the kiln revolves. It takes about four hours for the materials to travel through the kiln. Gas is burned at the lower end of the kiln. This produces a roaring blast of flame that heats the materials to about 2,700 degrees Fahrenheit. As the material moves through the kiln, certain combinations of elements are driven off in the form of gases. The remaining elements unite to form a new substance with its own physical and chemical characteristics. The new substance, called "clinker", is formed in pieces about the size of marbles. About 100 pounds of raw material will produce 60 to 65 pounds of clinker.

Large fans cool the clinker after it leaves the kiln. The clinker may be stockpiled for future use, or it may be reground at once in ball or tube mills. A small amount of gypsum is added to the clinker before regrinding. This final grinding produces a powdery portland cement that is so finely ground that more than 90 per cent of it will pass through a screen containing 40,000 openings to the square inch; more than 80 per cent will pass through a screen that has 100,000 openings to the square inch. The cement is stored in silos until it is shipped.

A diagram of a typical cement plant is shown in Figure 1.

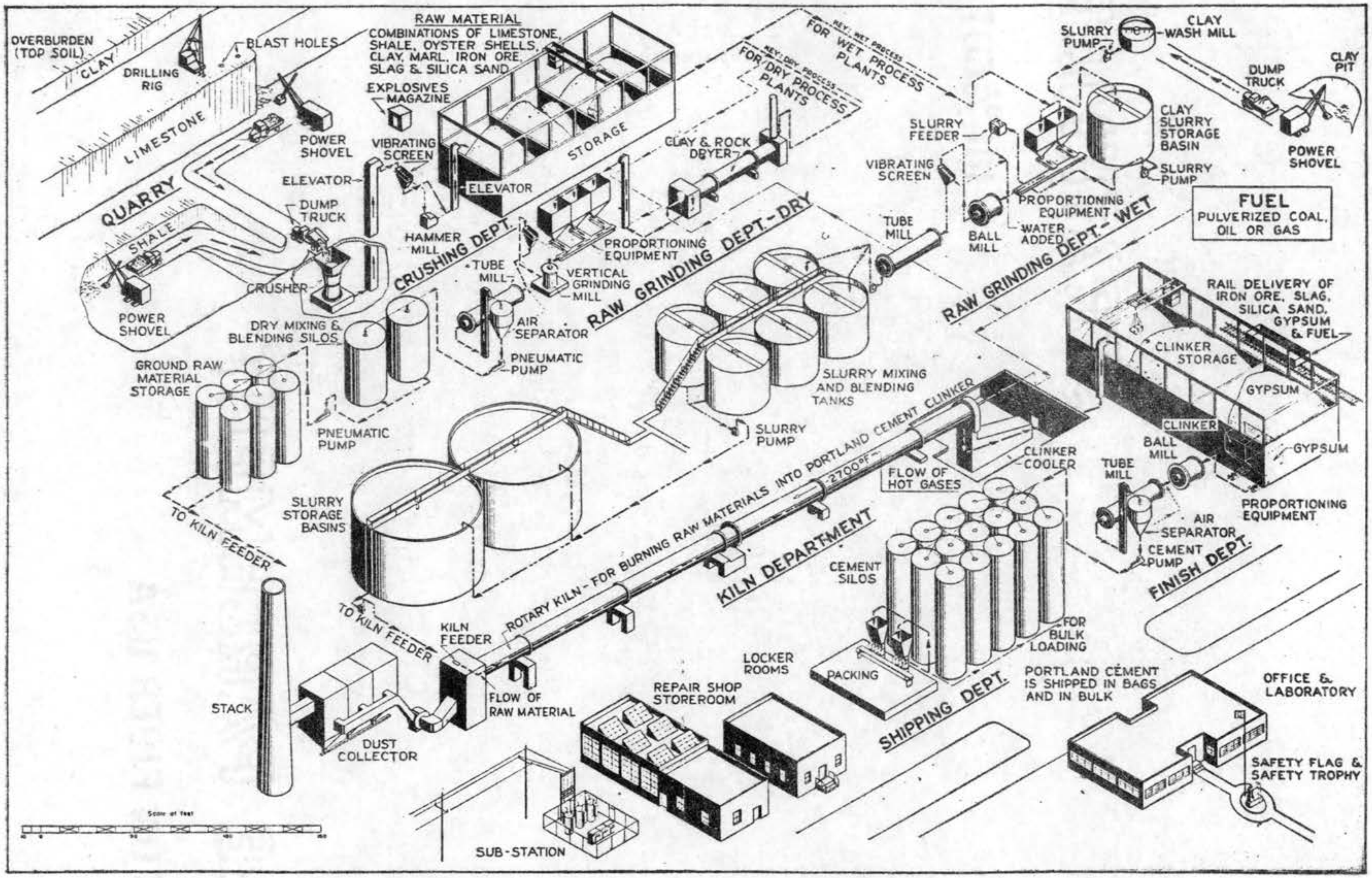

Figure 1. Isometric Flow Chart of the Manufacture of Portland Cement

CHAPTER IV

THE THEORY BEHIND CONTROL CHARTS

Every manufactured product is subject to two types of measured quality variation. The first are chance variations which are inherent in the machine or process. Some stable "system of chance causes" is always inherent in any particular scheme of production and inspection.[1] These chance variations, often referred to as unassignable causes, cannot be controlled or eliminated. This situation is somewhat analogous to the steering of an automobile. To steer the car in a perfect straight line is impossible. The play in the steering mechanism coupled with the constant corrections of the operator cause the vehicle to veer from the desired path. Although this small deviation is evident, it cannot be eliminated from the system. It is to be expected.

The second type of variations are outside this stable pattern. These are variations due to assignable causes. It is these causes that we wish to eliminate from the process. Again the steering of an automobile can be cited as an example. Large deviations, such as radical movements back

[1]E. L. Grant, Statistical Quality Control, (New York, 1952), p. 3.

and forth across the highway center line, can be termed irregular. These could be caused by some failure of the steering apparatus or malfunction of the operator. Whatever the cause or causes, it is desirable that they be stopped.

The control chart provides a useful means of distinguishing between chance variation and assignable causes. It provides the manufacturer with a basis for action. Through it he can determine whether or not the process is operating normally. If it is not, he can determine whether it is deviating sufficiently to justify corrective action.

In reality, a control chart is simply a graphical display of the production process. Its construction merely requires a few elementary mathematical calculations and the capacity to plot these computations graphically.

Types of Control Charts

There are three classifications of control charts as prescribed by Shewhart. The first are control charts for the mean and range, more commonly referred to as $\overline{X}$ and R charts. These are used when some characteristic of quality is measured in terms of variables. When a record is made of an actual measured quality characteristic, such as a dimension expressed in thousandths of an inch, the quality is said to be expressed by variables.[2] The second and third

[2]Ibid., p. 5.

types are the control chart for fraction defective, or the p chart, and the control chart for number of defects per unit, known as the c chart. These are used in the case where the product specifications are written in terms of attributes. When a record shows only the number of articles conforming and the number of articles failing to conform to any specified requirements, it is said to be a record by attributes.[3]

In the testing of cement, the measurement of quality is expressed in specific units, such as pounds per square inch. This makes it necessary to utilize a chart which facilitates the use of measured quality in terms of variables rather than attributes. As a result of this, the control charts for mean and range, $\bar{X}$ and R, will be employed.

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[3]Ibid., p. 5.

CHAPTER V

A BRIEF EXPLANATION OF GENERAL TERMS USED IN QUALITY CONTROL WORK

Before proceeding any further in the explanation of control charts, it is first necessary to consider a few of the statistical principles utilized in their construction and application. For some, this will serve as a brief indoctrination in statistics. However, for the majority it will serve as a means of review.

The Universe

The total or whole of the items, articles, etc., under consideration is called the universe. The hypothetical set of all possible observations of the type which is being investigated is known as the Universe (or Population) of values.[1] Therefore, if vacuum tubes are the criteria of investigation, the universe must be considered as the sum total of all the tubes produced by the system in a specified period of time.

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[1] Owen L. Davies, Statistical Methods in Research and Production, (New York, 1958), p. 11.

Sampling

The first step in the application of any statistical control measure is the collection of data. This data consists of observations or items drawn randomly from the universe. Any finite set of these observations is regarded as a sample. This sample must be large enough to depict a true representation of the universe. As the sample size increases, its properties resemble more and more those of the true population.

Frequency Distribution

Once the data has been accumulated, it must be analyzed. One method is by means of a frequency distribution. The histogram is usually the best method for plotting a frequency distribution. This distribution provides a way of studying the nature of the variation in the body of data. Its construction starts with dividing into equal intervals the numerical values of the measured quality characteristic. These intervals are termed cells, and their numbers are cell values. These numbers are then recorded along the abscissa of a graph. The next operation is to go back through the data and record each measured value in its appropriate cell. When this is done, a diagram resembling the one shown in Figure 2 should result.

There are three important characteristics to be noted in this figure:

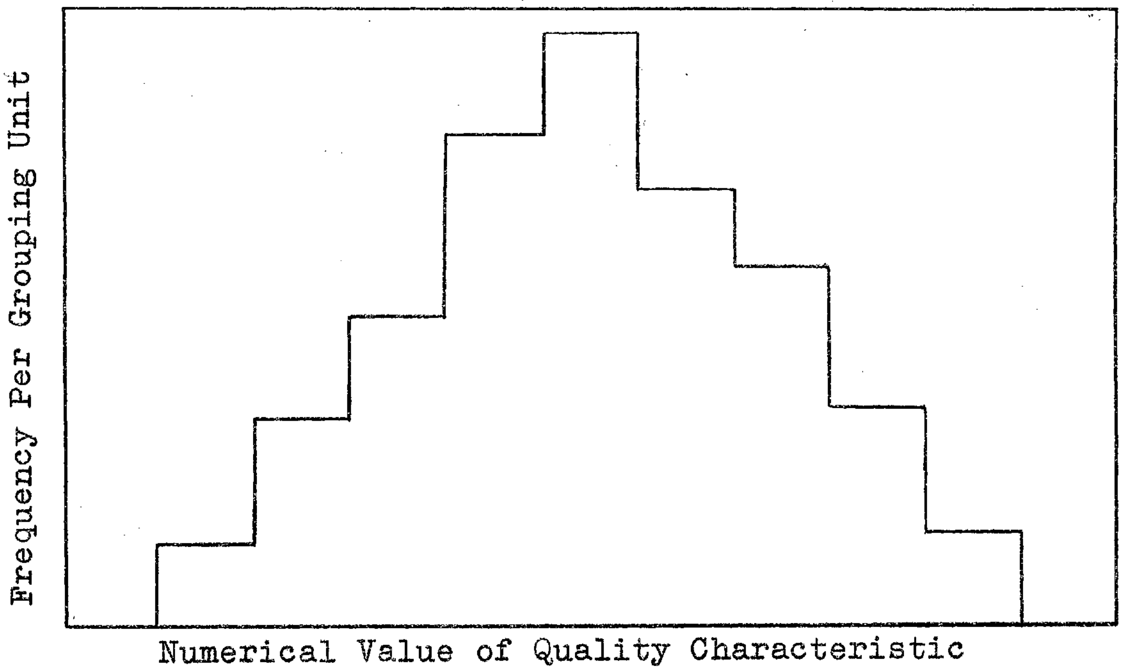


Figure 2. Histogram

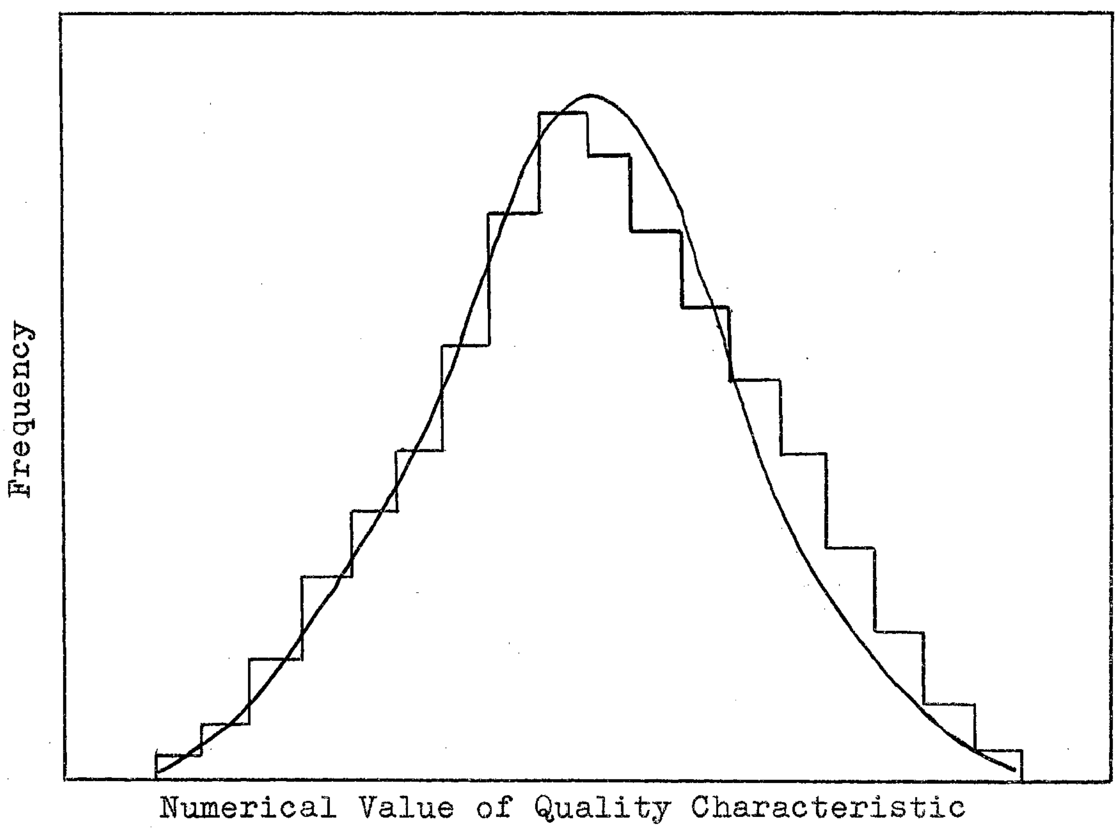


Figure 3. Frequency Curve Superimposed on Histogram

1. The results cluster around a central value.
2. They are spread roughly symmetrically around the central value.
3. Small divergencies from the central value are found more frequently than large divergencies.

Frequency Curve

If the number of observations is greatly increased and the cell intervals made much narrower, it is reasonable to assume a curve, such as the one shown in Figure 3, would result. This smoothed curve is known as a frequency curve. It could be said to describe the true universe. In reality, the size of the sample allows only an approximation to this curve.

The Normal Curve

In actual practice the normal curve is used as a population model in connection with the estimation of the population frequency distribution. A normal distribution is a bell shaped curve as is shown in Figure 4. In other words, there are many cases where the distribution of the true universe closely resembles the normal curve. The reasons for this are beyond the scope of this thesis. It is only necessary to be aware that this situation exists.

Notice that the normal curve is fully defined by two parameters: its arithmetic mean, and its dispersion measured by the standard deviation. By knowing how to calculate and

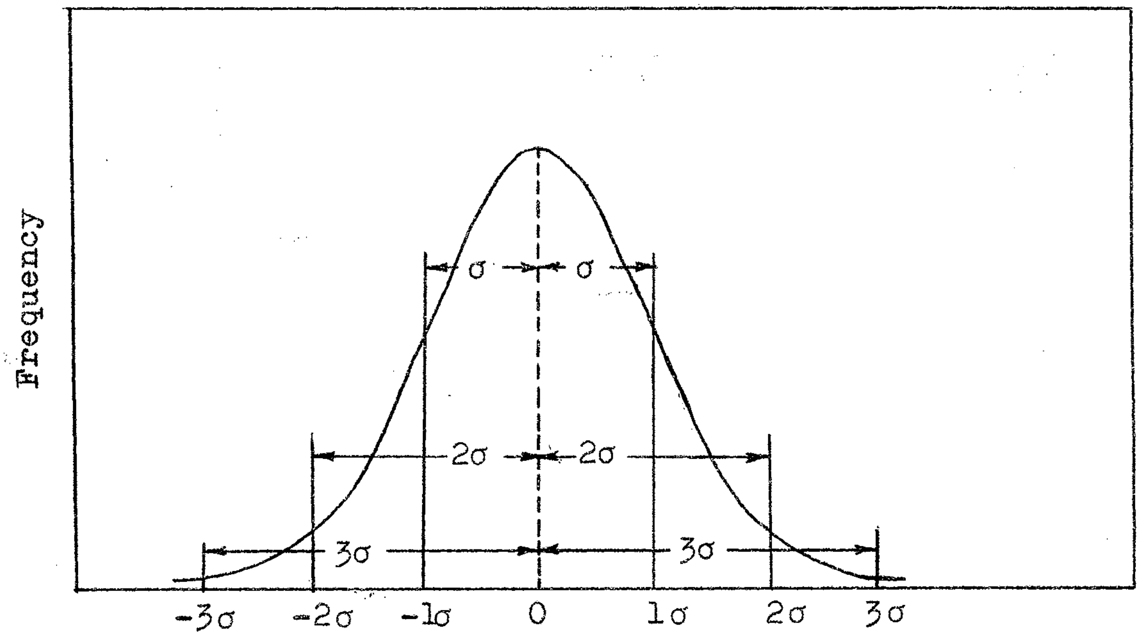


Figure 4. Normal Probability Curve

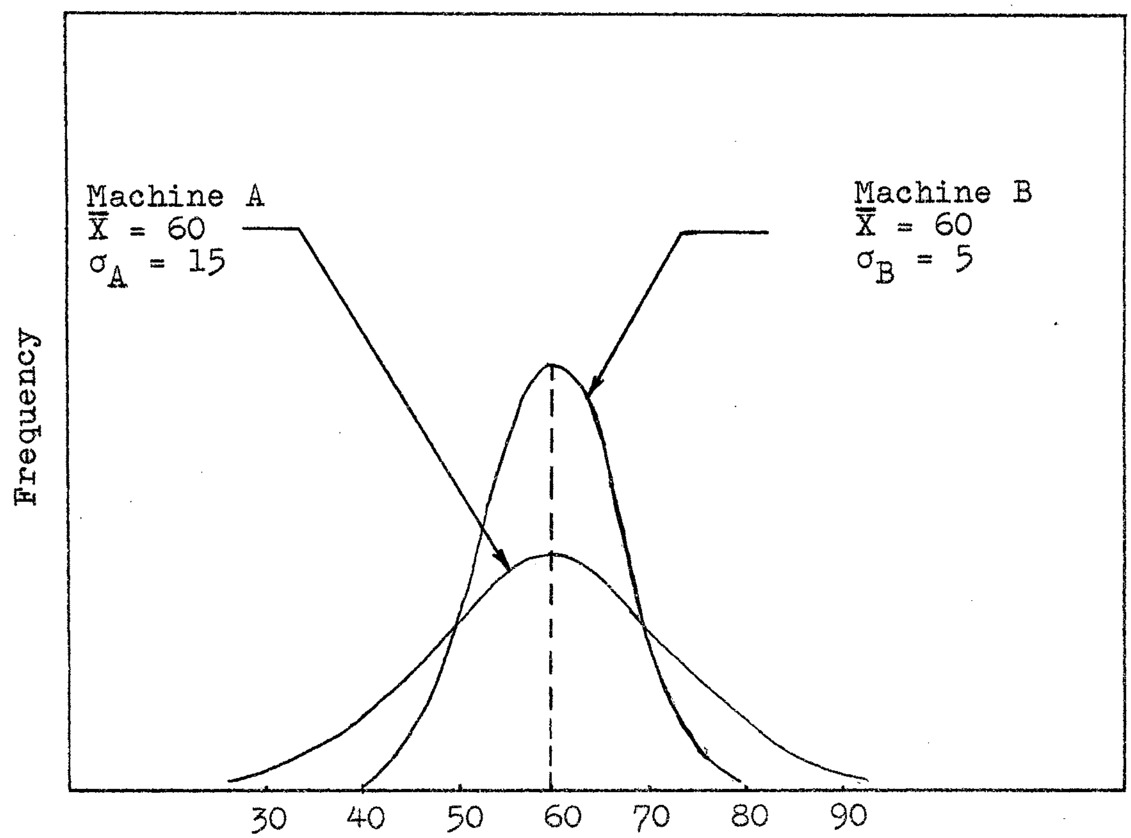


Figure 5. Comparison of Two Different Distributions

apply these two values, it is now possible to describe the distribution. One need not determine all of the many possible irregularities in the exact population frequency distribution. To derive estimates of the two is sufficient.

The Mean

The mean ($\bar{X}$) is one measure of central tendency. The other two, which are not pertinent to this study, are the median and the mode. The mean is calculated by finding the arithmetic sum of the numerical values of all the cases divided by the number of cases. An example will be shown later. As can be seen, the mean characterizes an entire set of data by a single value.

The $\bar{X}$ value, however, does not by any means represent all the pertinent information about a set of data. These two sets of data may have the same mean but very different distributions. Figure 5 illustrates this point. Here are two different distributions that resulted in analyzing two different machines. Machine A shows more variability in the measured characteristic than Machine B. Although both have a mean of 60, it could be said that the performance of B is more homogeneous than A.

The Standard Deviation

There are various statistical indexes that can be used to measure these differences, and they are called measures of variability. One such measure is the standard deviation.

The standard deviation is expressed in terms of the original numerical values of the data, and reflects the variability in the distribution of the cases from the mean. Mathematically, the standard deviation, (σ), is the square root of the average of the squares of the deviations of the individual cases from the mean. Expressed in algebraic terms, that is;

$$\sigma = \sqrt{\frac{\Sigma(X_i - \bar{X})^2}{n}}$$

The Range

In control charts the most widely measure of dispersion is the range. It is denoted by the symbol R. It is simply the difference between the largest and smallest observed value. Take for instance a sample containing measurements or readings of 50, 60, 70, 50, and 80 units. The range would be calculated by subtracting the lowest value from the highest, or 80 minus 50, which would yield a R value of 30. $\bar{R}$ (read R bar or bar R), is the mean value of the ranges and is calculated in the same manner as $\bar{\bar{X}}$.

The Standard Error

It must be remembered that the values of the mean and standard deviation just described are purely estimates of the true mean and standard deviation (signified by $\bar{\bar{X}}'$ and σ') of the universe. They were calculated from a sample which was representative of the population and not exactly like it.

Now suppose that a large number of samples of the same size are drawn from the universe and the average of each sample figured. It would be reasonable to expect the averages to vary somewhat from each other. On the other hand, it would be found that they follow a distribution similar to the normal curve. This distribution of sample averages will obviously have a standard deviation of its own. In order to avoid confusion of terms, it is customary to refer to the standard deviation of sample averages as the standard error of sample averages. Further consideration will show that the standard error of the sample averages is a function of the standard deviation of the universe. The greater the spread in the universe, the greater will be the spread of the averages of samples drawn from it.

By knowing the estimate of the standard deviation of the universe, σ', ($\sigma' = \frac{\bar{\sigma}}{c_2}$, in which $\bar{\sigma}$ is the average observed standard deviation of any given set of samples and c_2 is the tabulated value given in Table B of Appendix III, in Grant's <u>Statistical Quality Control</u>) it is now possible to determine the standard error of the sample averages. The standard error of sample averages is given by the expression;

$$\sigma_{\bar{X}} = \frac{\sigma'}{\sqrt{n}}$$

in which $\sigma_{\bar{X}}$ = the standard error of sample averages,

σ' = the estimated standard deviation of the Universe,

n = sample size.

Control Limits

When an estimate of some quantity has been made, it is desirable to know how precise this estimate is. A convenient way of expressing this precision is to state limits which, with a given probability, include the true value; it is then possible to state, for example, that the true value is unlikely to exceed some upper limit or to be less than a lower limit or to lie outside a pair of limits. They are limits within which it can be stated, with a given degree of confidence, that the true value lies.

In setting control limits, plus or minus one, two, or three standard deviations from the mean can be used. As is noted in Figure 6, two-thirds of the area under the curve falls between plus or minus one standard deviation, 95 per cent between plus or minus two σ, and 99.75 per cent within plus or minus three σ. In actual practice the three sigma limits are the ones most frequently used.

Upper and Lower Control Limits

In control charts, the control limits on the $\bar{\bar{X}}$ chart are the upper control limit for $\bar{X}$, noted $UCL_{\bar{X}}$, and the lower control limit, or $LCL_{\bar{X}}$. They are expressed mathematically in terms of three sigma as;

$$UCL_{\bar{X}} = \bar{\bar{X}} + 3\sigma_{\bar{X}}$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - 3\sigma_{\bar{X}}.$$

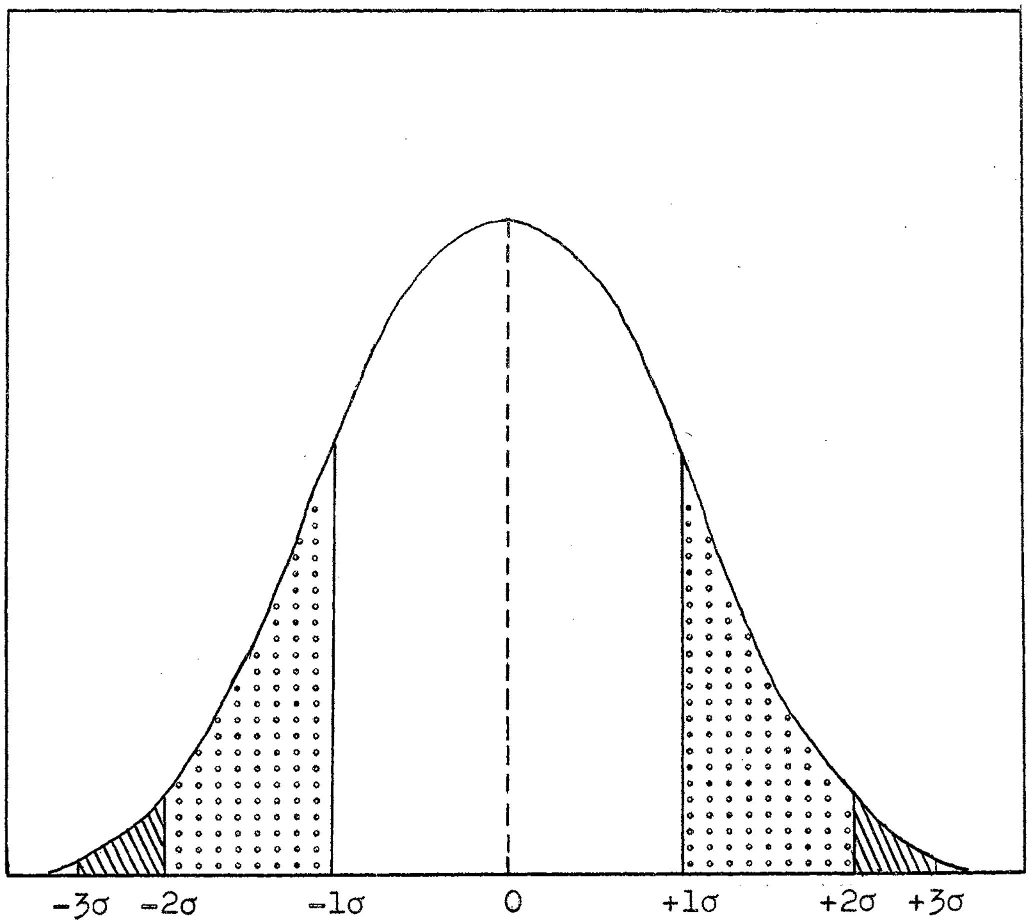
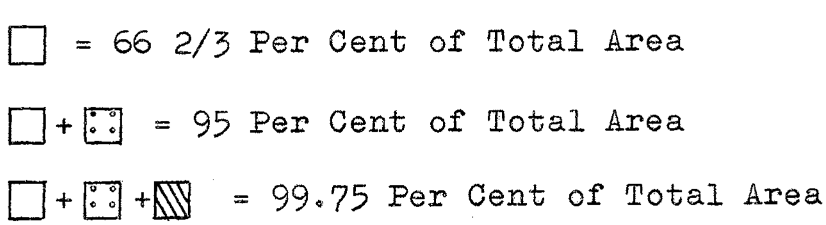


Figure 6. Confidence Limits



The R chart also has upper and lower control limits. These are written as UCL_R and LCL_R. Expressed in equation form, they become;

$$UCL_R = D_4R$$

$$LCL_R = D_3R,$$

D_3 and D_4 being the factors presented in Table C, in Grant's, Statistical Quality Control.

A method of shortening the calculations necessary for control limits is shown in Appendix A.

CHAPTER VI

DIRECTIONS FOR $\bar{\bar{X}}$ AND R CHARTS

A preliminary consideration in the application of $\bar{\bar{X}}$ and R charts, is the choice of the variable to be analyzed. This variable must be something that can be measured and expressed in numbers, such as a dimension, hardness number, or compressive strength. It is important that the variable chosen depict a pertinent characteristic of the product's quality. For example, to consider weight as the selected variable in cement would be rather useless, as the quality of cement is not necessarily dependent upon weight. A better indication of quality would be compressive strength, elasticity, etc. These measures are more representative in terms of what is desired in the way of quality.

The Subgroup

The key idea in the Shewhart method is the division of observations into what Shewhart called rational subgroups. The success of the Shewhart technique depends in large measure on the discrimination used in the selection of these subgroups.[1] These subgroups should be selected in a way

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[1]E. L. Grant, p. 132-133.

that would afford minimum opportunity for variation <u>within</u> the subgroup, but maximum opportunity for variation <u>between</u> the subgroups.

The size of the subgroup should be small. This is done to keep the variation within each subgroup as low as possible. The two most common sizes are four and five. A size of four makes the computation of the square root of n easier. A subgroup of five simplifies the calculation of the average, which can be obtained by multiplying the sum by two and moving the decimal point one place to the left. The choice between the two is merely a matter of preference.

The Taking of Samples

The frequency with which samples are taken is dependent upon the process under study. In some cases the cost associated with taking and analyzing samples, make a large number impossible. In others, frequent samples are a necessity. This would be applied in the case where the process variability was unusually high. When initially introducing a control chart, it may be necessary to utilize a large number of samples. Later on, when the troubles have been found and corrected, the frequency of sampling can be reduced.

It must be remembered that taking and recording measurements is subject to a certain amount of variation. No two inspectors read or record data exactly the same. What one sees as .002, the other may see as .005. This source of variation must be realized and every possible step taken to reduce it. One such precaution might be to create some means of periodic orientation for inspectors as a group.

Starting the Control Chart

The actual work of the control chart starts with the first measurements. From these measurements a mean is calculated.

$$\bar{X} = \frac{X_1 + X_2 + X_3 + \ldots X_i}{n}$$

Where,

$\bar{X}$ = the mean or average of the subgroup,

X_i = the individual measurements,

n = the total number of measurements.

When this is done, the range of the subgroup is computed.

$$R = R_2 - R_1$$

Where,

R = the range,

R_2 = the largest numerical value in the subgroup,

R_1 = the smallest numerical value in the subgroup.

Next, these points are plotted on their respective graph. The most common graphs consist of eight or ten rulings to the inch.[2] The left side of the vertical scale

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[2] Ibid., p. 136

is used for the $\overline{X}$ and R calculations and the horizontal is used for the various subgroups. Thus, the horizontal scale may be in units of hours, days, or weeks, depending on the frequency of sampling. Each point within the control limits is noted by a dot and each one outside, a cross. The points may or may not be jointed.

The Trial Control Limits

Where past data is available, the trial control limits may be determined from it. However, it is usually a rare case where the records are kept in terms of the desired characteristic.

Where records do not exist, or exist in terms of the wrong characteristic, the subgroups must be allowed to accumulate, in order to compute the trial control limits. On statistical grounds it is desirable that control limits be based on at least twenty-five subgroups.[3] Once these twenty-five subgroups have built up, the trial control limits can be calculated.

First, it is necessary to compute $\overline{R}$, the average range. This is the sum of the separate R's divided by the total number of subgroups.

$$\overline{R} = \frac{R_1 + R_2 + R_3 + \cdots R_i}{n}$$

[3] Ibid., p. 136.

Where,

$\overline{R}$ = the average R,

R_i = the range of subgroup i,

n = the number of subgroups.

Now by using the D_3 and D_4 factors explained in Appendix A, the trial control limits on the R chart can be computed as follows:

$$UCL_R = D_4R$$
$$LCL_R = D_3R \quad .$$

Next, $\overline{\overline{X}}$, or the average of the means, is calculated.

$$\overline{\overline{X}} = \frac{\overline{X}_1 + \overline{X}_2 + \overline{X}_3 + \ldots \overline{X}_i}{N} \quad .$$

Where,

$\overline{\overline{X}}$ = the grand mean,

$\overline{X}_i$ = the average of subgroup i,

N = the number of subgroups.

By utilizing the A_2 factor explained in Appendix A, the trial control limits for the $\overline{X}$ chart become:

$$UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R}$$
$$LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R} \quad .$$

The $\overline{\overline{X}}$ and $\overline{R}$ values are located centrally on the $\overline{X}$ and R chart. They are drawn horizontally as heavy lines. The upper and lower trial control limits for both charts can now be applied. They should be represented by dashed markings. See Figure 7.

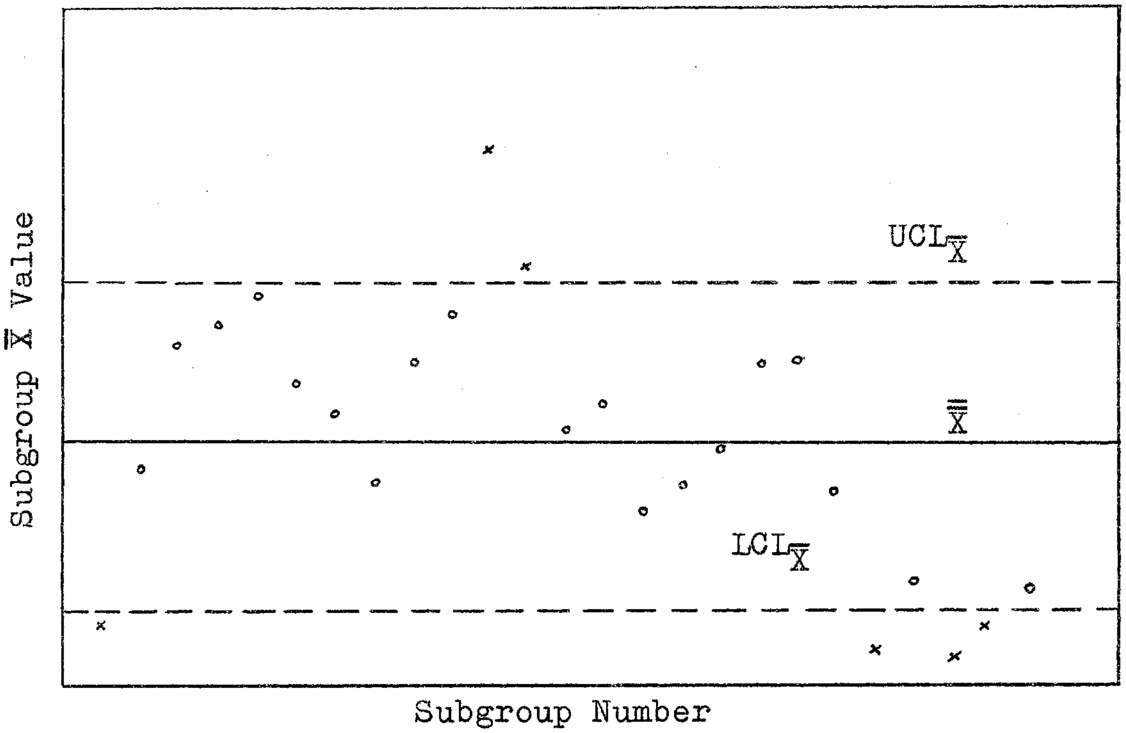

Figure 7a. $\bar{X}$ Chart

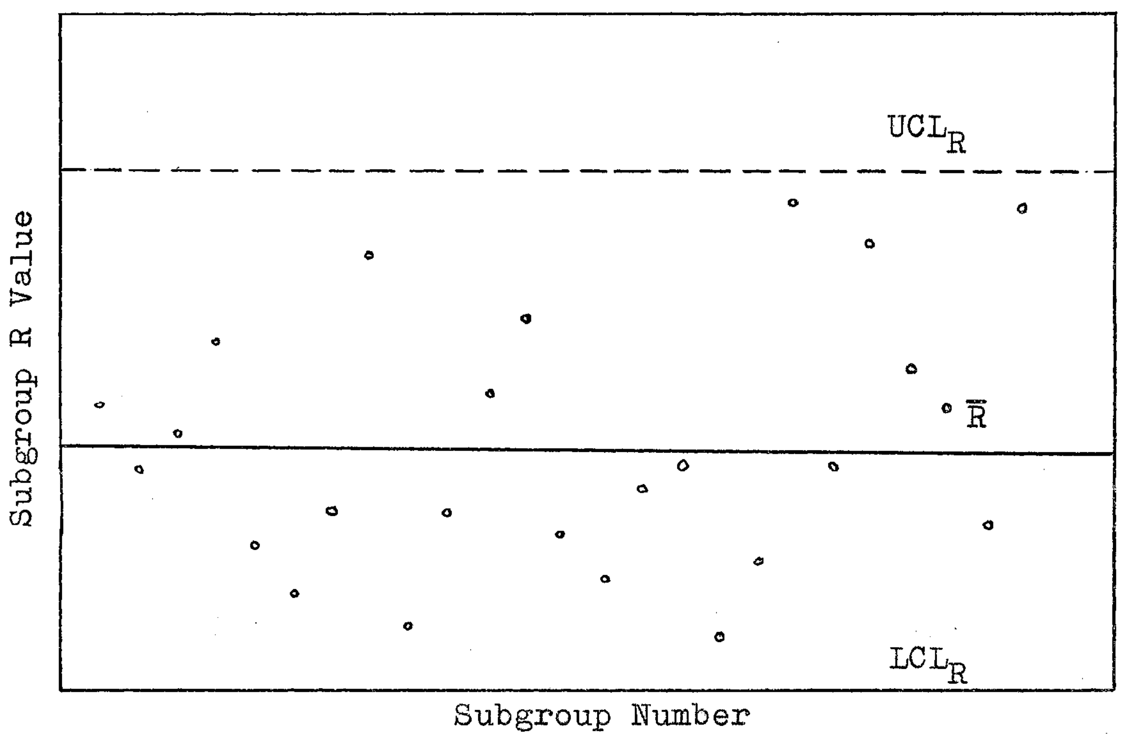

Figure 7b. R Chart

In initially setting up the charts, it may well happen that the plotted points show lack of statistical control for either or both charts; i.e., one or more points outside the trial control limits. This shows that assignable causes of variation have intervened during the acquisition of the initial data. Any subgroup which shows lack of control in relation to subgroup range should be discarded if it is desired to know the inherent variation of the process, and the value of $\bar{R}$ should be recalculated. New trial control limits should be calculated and drawn on the graph. This procedure should be repeated until all the remaining points are within the trial control limits on the R chart. When all the points are within the trial control limits, they become the actual limits used in future application. Whether a subgroup showing an average value out of control with its range in control is discarded or not will depend on the purpose for which the chart is being used. If no specification exists for the process and it is desired to know the best that can be expected, subgroups showing lack of control on subgroup averages would be also discarded. If an average has been specified for the process, the calculated limit lines could be drawn around the specified average without reference to the average $\bar{\bar{X}}$ achieved during the trial period.

In cases where all the plotted points derived in the trial period or from past data are within the trial control limits, the process is said to be in statistical control.

The trial values thus become the actual values used in future application of the charts.

Interpretation of Control Charts

In drawing preliminary conclusions from the charts, it might be appropriate to consider what has happened thus far. First, data was taken from within each subgroup. This was in the form of $\bar{X}$ and R. The $\bar{X}$ and R were next combined into a grand average, $\bar{\bar{X}}$, and an average range, $\bar{R}$. From these $\bar{\bar{X}}$ and $\bar{R}$ values the control limits were determined. These control limits now define the limits for variation among the subgroups. Each $\bar{X}$ and R can be applied to these limits to determine whether their values are probable statistically. A graphic interpretation of this is shown in Figure 8.

If points fall outside the limits of probable occurrence, i.e., points above or below the upper or lower control limits on either or both the $\bar{X}$ and R chart, assignable causes of variation are present. In other words, this is not a constant cause system and the process is out of control. It must be remembered, however, that when three sigma limits are employed, a probability of 0.27 per cent exists that the statement that the process is out of control is wrong. This is, of course, assuming that the process distribution resembles the normal. This coupled with the occasional errors in measurement, laboratory variability, etc., usually leads to the adoption of set

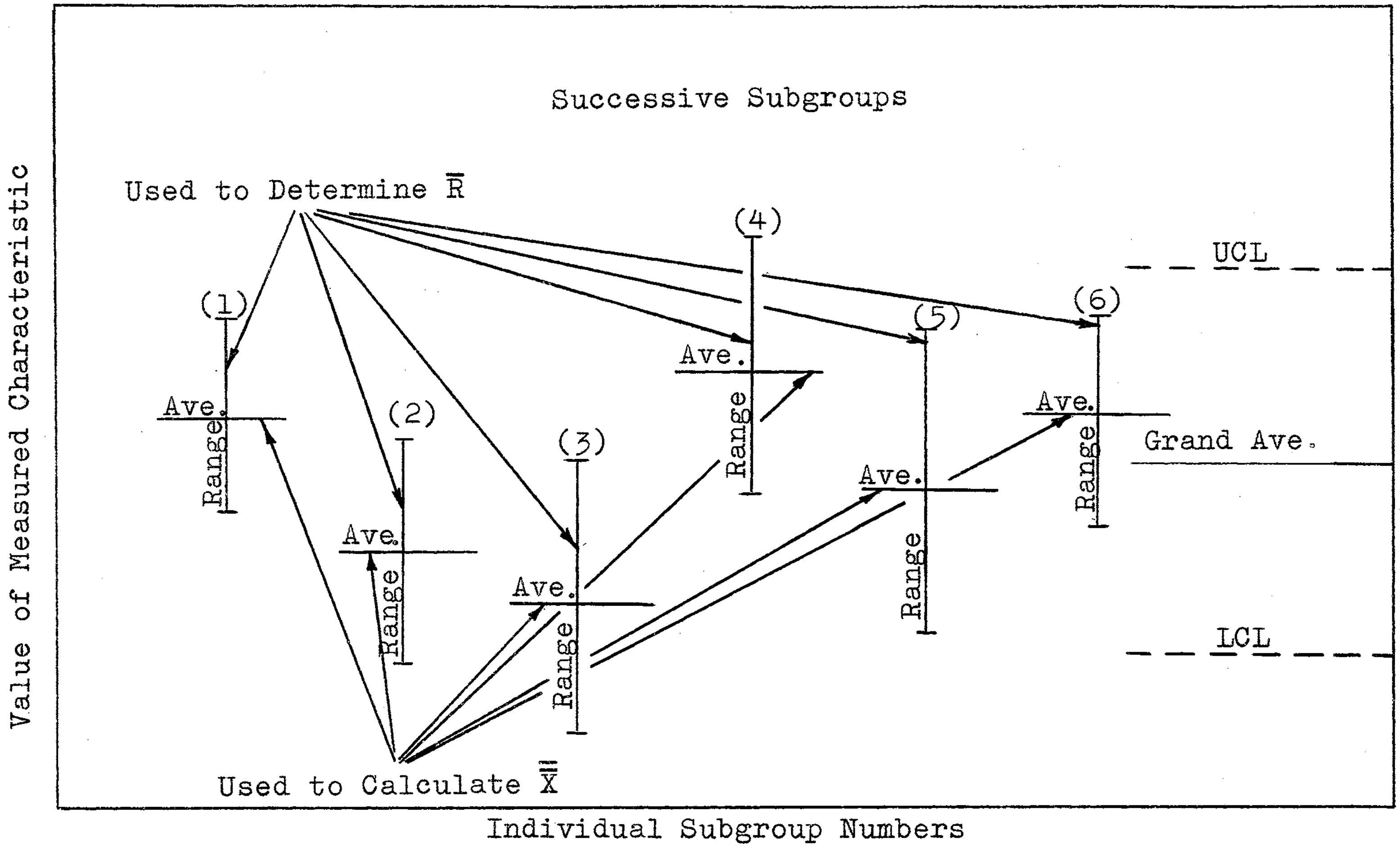

Figure 8. Pictorial Interpretation of the Internal Process of $\bar{\bar{X}}$ and $\bar{R}$ Charts

rules as a guide to future action. One such rule is to consider 0 out of 25 points, not more than one out of 35, or two out of 100 points outside control limits as evidence of excellent control.[4]

When all points fall within the control limits it can be said that there is no reason to believe that the data are not statistically uniform. There is no reason to doubt the presence of a constant cause system. For all practical purposes, the process should be left alone. There are cases, however, where all the points fall within the control limits, and still a lack of control is indicated. This situation is caused by excessive runs above or below the central line.

Lack of Control

Lack of control as shown by either the X or R chart or both can be interpreted by reference to Figures 9 through 11.

Figure 9 shows two distribution curves which have equal standard deviations but different averages. ($\sigma_1 = \sigma_2$; $X_1 \neq X_2$). The shapes are equal, but curve one is to the left of curve two. In this case, the average has shifted. This would exist in control charts where the subgroup average was out of control while the subgroup range was in control. It implies that the system is

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[4] Ibid., p. 138.

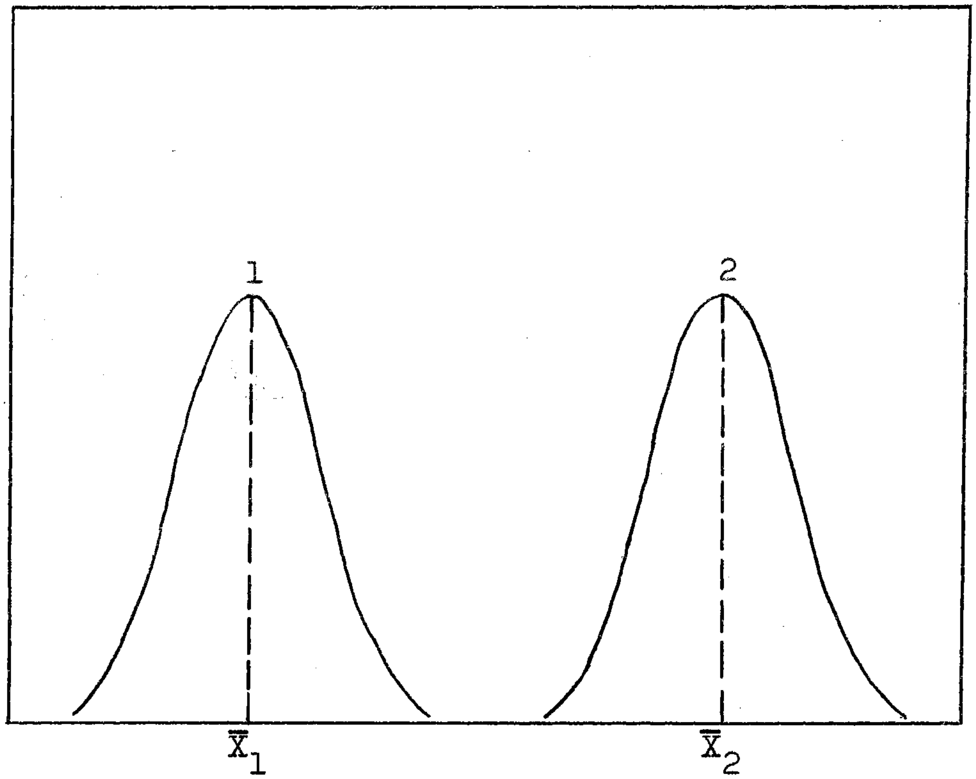

Figure 9. Lack of Control of Averages

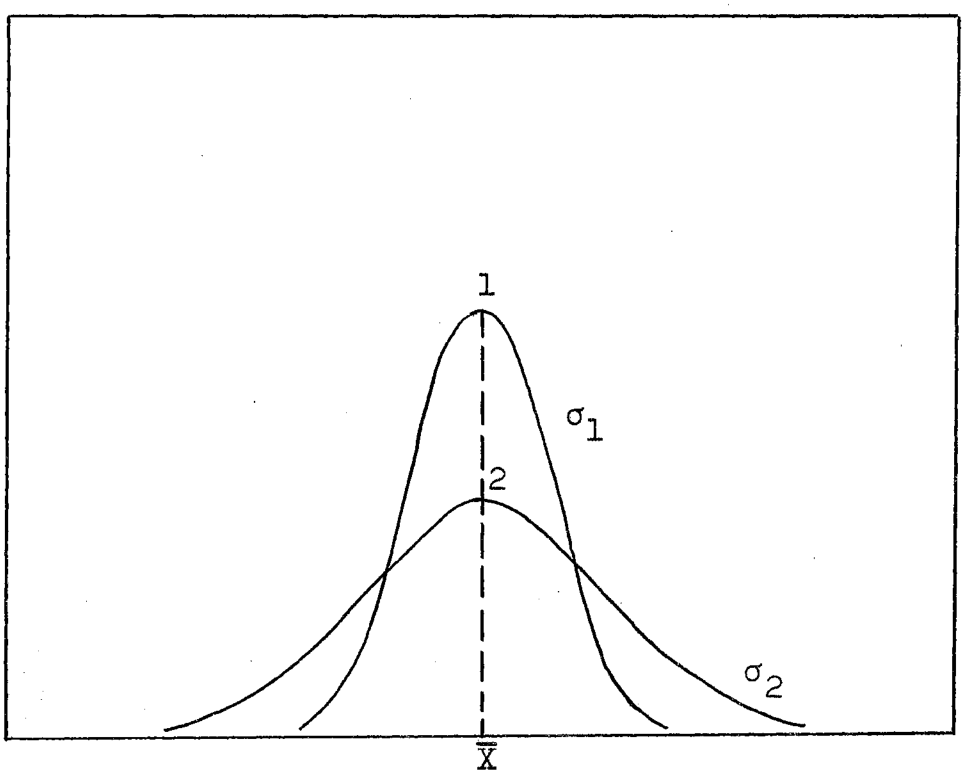

Figure 10. Lack of Control of Ranges

capable of operating under control, but that some factor or factors have caused the average to shift. An example would be a control chart for a weighing machine, where the subgroup average shifted due to material sticking in the pan.

The next case is where there is a lack of control on the chart for ranges while the subgroup averages are under control. It is seen in Figure 10. An example would be worn machine parts in the weighing machine used in the previous example. Because the averages are under control, there can be no material sticking in the pan. This condition certainly suggests that there is something inherently wrong with the system. However, in actual practice the situation suggested in Figure 10 would probably result in a state of affairs present in Figure 11.

In Figure 11, both the subgroup averages and subgroup ranges lack control. This might correspond to both sticking of material and worn machine parts in the above example.

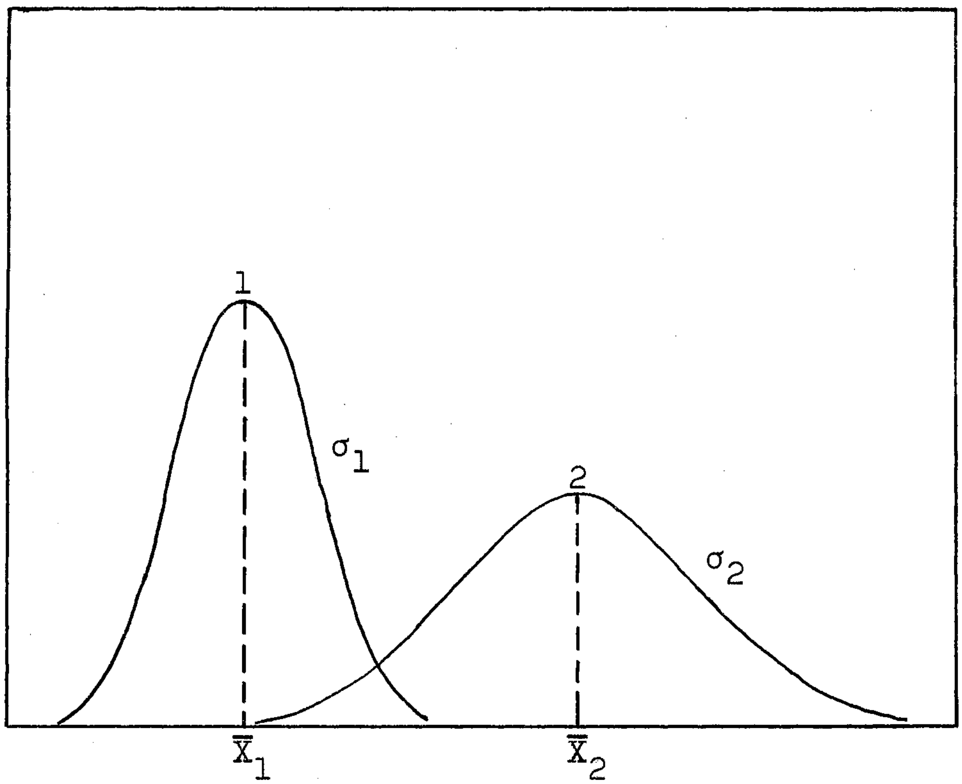

Figure 11. Lack of Control of Averages and Ranges

CHAPTER VII

METHODS USED IN THE COMPRESSIVE TESTING OF CEMENT IN THE CONTROL LABORATORY

The control laboratory at the Ideal Cement Company in Ada, Oklahoma utilizes three shifts. Each shift is composed of eight hours. In one shift eight samples are taken, making a total of twenty-four samples per day. These hourly samples are secured from a continuous sampling machine, located by a conveyor belt leading from the final grinding operation. The sampling mechanism is a homemade apparatus, which continually takes small increments of the product. These small increments are transferred by means of a screw conveyor to a large bucket. Every hour the accumulated product in this bucket is stirred and a sample taken from it. This hourly sample is placed in a container and taken to the control laboratory. When twenty-four samples have been collected, they are placed in a large container and mixed thoroughly. This mixture constitutes the composite sample of product used in performing the various required tests.

One such test, which is pertinent to this study, is the standard method of test for compressive strength of hydraulic cement. The procedure is described in the

American Society for Testing Material's manual, under ASTM Designation: C 109-58.

First one part of cement sample is combined with 2.75 parts of standard sand in a mixing bowl. Standard sand is a natural silica sand produced by a firm in Ottawa, Illinois. Distilled water is then added and the contents of the bowl placed in a mechanical mixer. When the mixing operation is completed, the resulting substance is removed and tamped into three oiled molds. These molds, which contain nine individual 2" by 2" cubes, are allowed to set up for twenty-four hours in a moist closet or room. At the end of the twenty-four hour period, the cubes are removed and submerged in a tray of water. The tray is then placed in a refrigerator. The temperature in this refrigerator is kept at a constant 73.4 plus or minus three degrees Fahrenheit. In three days, the first set of three cubes is removed from the tray and tested. This procedure is repeated at the end of seven days and again at twenty-eight.

The equipment used in the measurement of compressive strength is made by the Baldwin-Southwark Corporation. It has a capacity of 75,000 pounds per square inch. Each cube is placed in the machine and pressure applied until it breaks. The reading in pounds is then recorded. This is repeated until all three cubes have been broken and three breaking poundages recorded. The average of these three readings is figured and the result divided by the cross-sectional area of the cube, or four square inches. These values, which are a measure of the compressive strength in pounds per square inch, are then recorded on a daily tabulation sheet.

CHAPTER VIII

THE APPLICATION OF THE TECHNIQUE TO COMPRESSIVE STRENGTH

A total of 273 measurements were taken from the daily tabulation sheets. The sheets covered the period from January 1, 1960 to December 3, 1960. The measurements were the results of the seven day tests for type one cement. This was done because it was felt that the seven day tests are more pertinent. In the testing of cement, supplementary samples must be sent to a recognized agency. In turn, this agency, must verify the results obtained in the laboratory at Ideal. Only in rare cases will these agencies issue releases for the product on the basis of the three day tests. The product nearly always is released of the strength of the seven day tests.

Beginning the Analysis

The first step in the analysis was to prove that the data were normally distributed. The preliminary procedure in verifying normality is the construction of a histogram. It was decided that the histogram in this case would be composed of forty cells. These cells were in increments of 50 pounds per square inch. They ranged from 2,526 to 4,525 pounds per square inch. In the construction, each of the 273 measurements were recorded in their respective cell. Each value was indicated by an "X". Thus, when the histogram was completed, each cell represented the frequency with which that particular value occurred. The histogram is shown in Table I.

Unexpectedly, what resulted was a bimodal distribution -- a histogram probably composed of at least two separate distributions. This can be seen in the two separate peaks which occur in the area between 3,426 and 3,525, and 3,676 and 3,675. Although pictorially it is somewhat evident that no normality is present, it must be verified mathematically. To accomplish this, a Chi Square Distribution Test was performed. The hypothesis in the Chi Square test is that the data is normally distributed. The mechanics of this test is illustrated in Appendix C and D. As can be seen, the results of this test were not conclusive enough to state strongly that normality existed. To carry the analysis farther, another histogram was needed.

In the second histogram the cell values were shifted over 25 pounds per square inch. This was done to take into account the possibility of the affect of adjacent cells on one another. The histogram that resulted is shown in Table II. This histogram, as in the first case, strongly indicated that the data was not normally distributed. The two separate distributions are even more pronounced than in the previous example. The Chi Square

TABLE I

HISTOGRAM RESULTING IN FIRST ANALYSIS

	2526-2575
	2576-2625
	2626-2675
x	2676-2725
	2726-2775
x	2776-2825
	2826-2875
xx	2876-2925
	2926-2975
xx	2976-3025
xx	3026-3075
xxxxx	3076-3125
xxxxx	3126-3175
xx	3176-3225
xxx	3226-3275
xxxxxxxxx	3276-3325
xxxxxxxxx	3326-3375
xxxxxxxxxxxxxx	3376-3425
xxxxxxxxxxxxxxxxxxxxx	3426-3475
xxxxxxxxxxxxxxxxxxxx	3476-3525
xxxxxxxxxxxxxxxxx	3526-3575
xxxxxxxxxx	3576-3625
xxxxxxxxxxxxx	3626-3675
xxxxxxxxxxxxxxxxxxxxxx	3676-3725
xxxxxxxxxxxxxxxxxxxxx	3726-3775
xxxxxxxxxxxxxxxxxx	3776-3825
xxxxxxxxxxxxxxxxxx	3826-3875
xxxxxxxxx	3876-3925
xxxxxxxxxxxxxxxxx	3926-3975
xxxxx	3976-4025
xxxx	4026-4075
xxxxxxxxx	4076-4125
xxx	4126-4175
xx	4176-4225
xx	4226-4275
x	4276-4325
xx	4326-4375
xx	4376-4425
x	4426-4475
x	4476-4525

TABLE II

HISTOGRAM RESULTING IN SECOND ANALYSIS

```
                         _2501-2550
                         _2551-2600
                         _2601-2650
                         _2651-2700
                        x_2701-2750
                         _2751-2800
                        x_2801-2850
                        x_2851-2900
                        x_2901-2950
                       xx_2951-3000
                        x_3001-3050
                     xxxx_3051-3100
                      xxx_3101-3150
                     xxxx_3151-3200
                       xx_3201-3250
                xxxxxxxxx_3251-3300
               xxxxxxxxxx_3301-3350
                      xxx_3351-3400
xxxxxxxxxxxxxxxxxxxxxxxxx_3401-3450
      xxxxxxxxxxxxxxxxxxx_3451-3500
        xxxxxxxxxxxxxxxxx_3501-3550
        xxxxxxxxxxxxxxxxx_3551-3600
                xxxxxxxxx_3601-3650
      xxxxxxxxxxxxxxxxxxx_3651-3700
      xxxxxxxxxxxxxxxxxxx_3701-3750
xxxxxxxxxxxxxxxxxxxxxxxxx_3751-3800
         xxxxxxxxxxxxxxxx_3801-3850
           xxxxxxxxxxxxxx_3851-3900
               xxxxxxxxxx_3901-3950
            xxxxxxxxxxxxx_3951-4000
                       xx_4001-4050
                 xxxxxxxx_4051-4100
                    xxxxx_4101-4150
                      xxx_4151-4200
                        x_4201-4250
                      xxx_4251-4300
                        x_4301-4350
                      xxx_4351-4400
                         _4401-4450
                       xx_4451-4500
```

Distribution Test firmly rejected the hypothesis that the data were normal. This can be considered very conclusive on the basis of the magnitude by which the hypothesis was discredited. Notice that in the first case the hypothesis was barely accepted by $31.31 < 32.70$. However, in the second analysis it was strongly rejected by $41.17 > 31.40$. It will be remembered that normality is the necessary prerequisite to control chart application. Under the present conditions they cannot be successfully employed.

Interpretation of Existing Conditions

This state of affairs certainly must be interpreted as process out of control. Some variable or variables are intervening and causing erratic changes in the process. In order to better visualize these fluctuations, the data were put in graphical form. See Figure 12. As can be seen, the graph shows that the process runs in a cycle. The dotted line is superimposed to emphasize the existing cycle.

Having verified the fact that the process exhibits cyclical characteristics, it was next necessary to attempt to determine the cause. To do this a number of suspected variables were required. These variables for the most part were the result of the writer's conversations with respected authorities in the field of cement. Although the consensus was that there were many variables that might possibly have an effect on compressive strength, the ones mentioned most frequently were particle size, raw material variability,

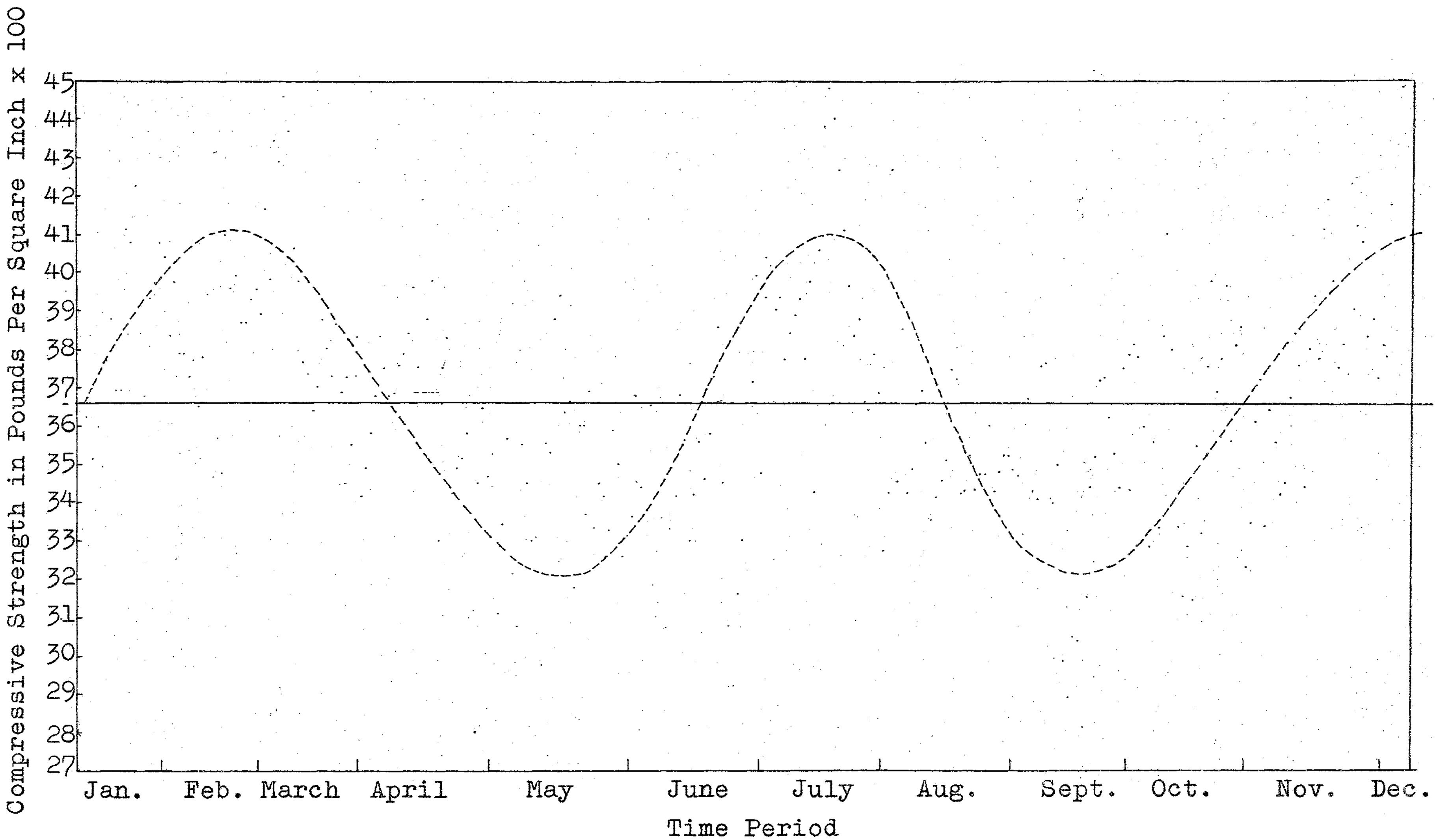

Figure 12. Graphical Representation of Data for One Year

kiln temperature differential, tricalcium sulfide content, and the effect of humidity.

Blaine Number and Compressive Strength

The one variable that the writer felt had the greatest impact was particle size. This particle size is recorded in the daily tabulation sheets as a Blaine number. This number is in units of square centimeter per gram. Once these numbers had been matched with the respective compressive strength, a correlation analysis was performed. First, the data was combined in terms of a graph. It was desired that a scatter diagram would result. As can be seen in Figure 13, this did not occur. The mathematical correlation analysis, shown in Appendix E, positively substantiated the fact that no correlation exists between particle size and compressive strength of cement.

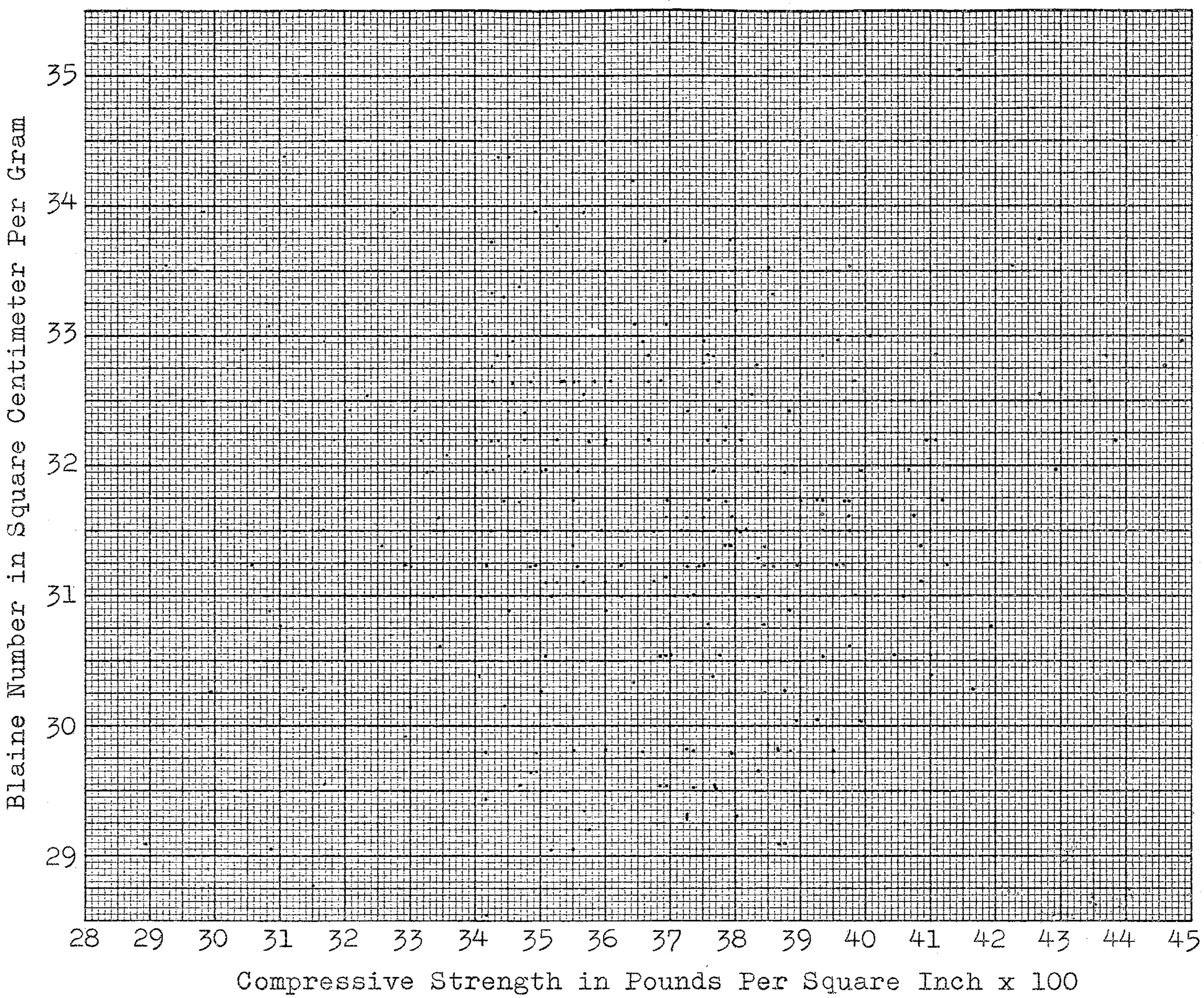

Figure 13. Scatter Diagram

CHAPTER IX

SUMMARY AND CONCLUSIONS

One aspect of quality control work which most frequently is misinterpreted and misused is specifications and the relationship of these specifications to control limits. Many times specifications are set without taking into account the process capabilities. For instance, take the compressive strength requirements specified by the American Society for the Testing of Materials. A comparison of this specification with the data taken over a year's period, quickly reveals not one measurement as low as that specified by ASTM. This indicates that the specifications are outdated and revision upward is necessary.

It is also necessary to comment on the specifications issued by the main control laboratory of Ideal Cement Company in Denver, Colorado. This laboratory specifies that compressive strength should be maintained somewhere between 3,400 and 4,200 pounds per square inch. In reality, the larger number is completely arbitrary and the lower figure should be interpreted as a minimum specification requirement. An analysis of the data shows that under existing conditions compressive strength cannot be maintained above this minimum level. If no solution can be found, assuming an investigation is undertaken for the causes for the present fluctuating performance, then a revision should be required. There is a need to change the required limit so as to conform to production capabilities.

In considering control limits, it must be remembered that they are formulated mathematically. To use them validly, the process must be capable of operating in a stable pattern. As can be seen under present conditions, no normality exists.

Another factor which seemed abnormal to the author was the procedures used in sampling. The constant mixing of the sampled product could possibly contribute to a misrepresentation of existing quality. Consider the effect on the mean of two samples taken at a high and low quality level of production. For example, say the two measurements were numbers of 5,000 units, representing the high, and 1,000 units, the low, and it was desired to maintain a quality level of 3,000 units. Notice that when these two samples are combined or mixed they yield a mean or average value of 3,000. This certainly meets the requirements of 3,000. However, when they are considered separately, they tell a completely different story. Theoretically, one half of the time the process was operating far below the desired level. This is a far truer picture of the existing process.

The breaking of three cubes in each of the three, seven, and 28 day tests is another procedure which should be terminated. The variability which exists between the three cubes rarely exceeds ten pounds per square inch. This is not enough to be significant.

Recommendations

A plan which the writer feels would be more adequate and, in part, solve the mixing and excessive cube breaking problems is as follows. First, only three samples would be taken in a 24 hour period. These three samples would be taken in increments of eight hours and in no way mixed. From each sample one cube would be made for each of the three, seven, and 28 day tests. In this way there would still be three cubes to be analyzed. However, each would represent an entirely different time period. It is felt that this procedure would depict more clearly the true operating characteristics of the process.

The most prominent problem exposed by this paper, was the fact that the compressive strength measurements show cyclical tendencies. It would be advantageous to uncover the cause or causes for this erratic fluctuation. To do this, a carefully controlled experiment would be necessary. The first step in such an analysis would be to list every possible variable. The difficulty will be in attempting to assign a numerical index to those variables which at present have none. An example of this is raw material variability. There is at present no measurement of the characteristics of the materials when they are entering the plant. An attempt to do this would definitely have to be considered from the economic standpoint. However, it would be necessary for a complete and comprehensive analysis.

Having done this, it would next be necessary to apply a multiple correlation analysis to the collected data. The results of this type correlation would determine whether the cause was contained in the list of predetermined variables. If the results show the cause is not contained in the list of predetermined variables, then further analysis is necessary. Assuming that the cause or causes were contained in the listed variables, it would then be a process of elimination. Each variable would be analyzed in the manner described previously, when an attempt was made to correlate compressive strength and Blaine number or particle size.

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A P P E N D I X E S

APPENDIX A

A METHOD OF SHORTENING CONTROL LIMIT CALCULATIONS

Because;

$$3\sigma_{\bar{X}} = 3\frac{\sigma'}{\sqrt{n}} \quad \text{and} \quad \sigma' = \frac{\bar{R}}{d_2} \quad ,$$

(d_2 as given in Table B, Grant's, _Statistical Quality Control_, p. 512) it is possible to reduce $3\sigma_{\bar{X}}$ to the following:

$$3\sigma_{\bar{X}} = \frac{3\bar{R}}{d_2\sqrt{n}} \quad .$$

This allows the control limits for $\bar{X}$ to be calculated from $\bar{R}$ and also allows the use of the tabulated values of the factor $\frac{3}{d_2\sqrt{n}}$, noted as A_2 in Table C. The new expressions thus become:

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R}$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R}.$$

APPENDIX B

LIST OF SYMBOLS

N	Number of subgroups
n	Sample size
R	Range
$\bar{R}$	Average range
X_i	Individual item
$\bar{X}$	Mean or average
$\bar{\bar{X}}$	Grand mean
$\bar{X}'$	True mean of the universe
σ	Standard deviation
σ'	True standard deviation of the universe
$\bar{\sigma}$	Average observed standard deviation of a given set of subgroups
$\sigma_{\bar{X}}$	Standard error of sample averages
$UCL_{\bar{X}}$	Upper control limit on X chart
$LCL_{\bar{X}}$	Lower control limit on X chart
UCL_R	Upper control limit on R chart
LCL_R	Lower control limit on R chart
r	Correlation coefficient

APPENDIX C

THE CHI SQUARE DISTRIBUTION TEST

FOR ANALYSIS ONE

Upper Limit of Class	(Z) $\frac{(X-\bar{X})}{\sigma}$	P(X<Z)	Prob X Within Class	(f) Theor. Freq.	(F) Act. Freq.	$\frac{(F-f)^2}{f}$
4525.5	2.863	0.9979	0.0069	1.88	4	2.388
4375.5	2.368	0.9910	0.0215	5.87	5	0.129
4225.5	1.873	0.9695	0.0309	8.44	5	1.402
4125.5	1.543	0.9386	0.0227	6.20	9	1.265
4075.5	1.378	0.9159	0.0286	7.81	4	1.859
4025.5	1.213	0.8873	0.0347	9.47	5	2.110
3975.5	1.048	0.8526	0.0412	11.25	17	2.939
3925.5	0.883	0.8114	0.0478	13.05	9	1.257
3875.5	0.718	0.7636	0.0537	14.66	18	0.761
3825.5	0.553	0.7099	0.0589	16.08	18	0.229
3775.5	0.388	0.6510	0.0627	17.12	21	0.879
3725.5	0.223	0.5883	0.0652	17.80	22	0.991
3675.5	0.058	0.5231	0.0657	17.94	13	1.360
3625.5	-0.107	0.4574	0.0646	17.64	10	3.309
3575.5	-0.272	0.3928	0.0617	16.84	17	0.002
3525.5	-0.437	0.3311	0.0575	15.70	20	1.177
3475.5	-0.602	0.2736	0.0520	14.20	21	3.244
3425.5	-0.767	0.2216	0.0459	12.53	14	0.172
3375.5	-0.932	0.1757	0.0393	10.73	9	0.280
3325.5	-1.097	0.1364	0.0330	9.01	9	0.000
3275.5	-1.262	0.1034	0.0477	13.02	5	4.940
3175.5	-1.592	0.0557	0.0163	4.45	5	0.068
3125.5	-1.758	0.0394	0.0210	5.73	7	0.281
3025.5	-2.088	0.0184	0.0178	4.86	6	0.267
						31.309

$$X^2 = \frac{\Sigma(F_i - f_i)^2}{f_i} = 31.309$$

Because 31.309 < 32.700 (value taken from Table C in Duncan's, <u>Quality Control and Industrial Statistics</u>, Revised Edition, p. 871), the hypothesis must be accepted.

APPENDIX D

THE CHI SQUARE DISTRIBUTION TEST FOR ANALYSIS TWO

Upper Limit of Class	(Z) $\frac{(X-\bar{X})}{\sigma}$	$P(X<Z)$	Prob. X Within Class	(f) Theor. Freq.	(F) Act. Freq.	$\frac{(F-f)^2}{f}$
4500.5	2.781	0.9973	0.0084	2.29	5	3.205
4350.5	2.285	0.9889	0.0142	3.88	4	0.004
4250.5	1.955	0.9747	0.0268	7.32	4	1.505
4150.5	1.625	0.9479	0.0200	5.46	5	0.039
4100.5	1.460	0.9279	0.0571	15.59	10	2.005
4000.5	1.130	0.8708	0.0380	10.37	13	0.667
3950.5	0.965	0.8328	0.0447	12.20	10	0.397
3900.5	0.800	0.7881	0.0508	19.06	14	1.343
3850.5	0.635	0.7373	0.0565	20.61	16	0.840
3800.5	0.470	0.6808	0.0610	21.84	25	0.457
3750.5	0.305	0.6198	0.0641	22.69	19	0.600
3700.5	0.140	0.5557	0.0657	23.12	19	0.734
3650.5	-0.025	0.4900	0.0653	23.01	9	8.530
3600.5	-0.190	0.4247	0.0634	22.50	17	1.344
3550.5	-0.355	0.3613	0.0598	21.51	17	0.946
3500.5	-0.520	0.3015	0.0548	20.15	19	0.066
3450.5	-0.685	0.2467	0.0490	13.38	25	10.091
3400.5	-0.850	0.1977	0.0415	11.33	3	6.124
3350.5	-1.010	0.1562	0.0372	10.16	10	0.003
3300.5	-1.180	0.1190	0.0535	14.60	11	0.706
3200.5	-1.510	0.0655	0.0326	8.90	7	0.405
3100.5	-1.840	0.0329	0.0179	4.89	5	0.002
3000.5	-2.170	0.0150	0.0142	3.88	6	1.157
						41.170

Because 41.170 > 31.400 (value taken from Table C in Duncan's, <u>Quality Control and Industrial Statistics</u>, Revised Edition, p. 871), the hypothesis, that the data is normally distributed, must be rejected.

APPENDIX E

COMPUTATION OF CORRELATION COEFFICIENT

The correlation coefficient is computed by utilizing the following equation:

$$r = \frac{n\Sigma xy - \Sigma x \Sigma y}{\sqrt{n\Sigma x^2 - (\Sigma x)^2} \quad \sqrt{n\Sigma y^2 - (\Sigma y)^2}}$$

where,

n = number of individual observations (273)

x = one variable

y = second variable.

The computations were performed on a table calculator with the following results:

Σy = 863,463

Σy^2 = 2,739,029,675

Σx = 998,680

Σx^2 = 3,678,057,028

Σxy = 3,158,623,624

These values, when substituted in the above formula, result in a r value of -.0049.

TABLE III

DATA ON COMPRESSION STRENGTH FOR MONTHS OF JANUARY THROUGH DECEMBER

JANUARY

1	3027 - 3133*
2	3150 - 3333
3	3100 - 3625
4	2904 - 3517
5	2981 - 3600
6	2965 - 3492
7	No production
8	No production
9	2954 - 3767
10	3027 - 3875
11	3100 - 3692
12	No production
13	No production
14	No production
15	No production
16	No production
17	3173 - 3695
18	3173 - 4117
19	3161 - 4075
20	No production
21	No production
22	No production
23	No production
24	No production
25	No production
26	3354 - 4225
27	3077 - 3842
28	2954 - 3683
29	3150 - 3933
30	3123 - 3967
31	3111 - 4083

FEBRUARY

1	3054 - 4092
2	2965 - 3833
3	3061 - 3975
4	2981 - 3792
5	3161 - 3792
6	2931 - 3725
7	2954 - 3767
8	No production
9	No production
10	3100 - 3650
11	3173 - 3783
12	3163 - 3933
13	2953 - 3467
14	2935 - 3567
15	2965 - 3483
16	No production
17	No production
18	No production
19	No production
20	3054 - 4100
21	2965 - 3950
22	3004 - 3992
23	No production
24	2981 - 3867
25	2981 - 3867
26	3004 - 3925
27	2981 - 3950

* The numbers in the first column represent the Blaine number (square centimeter per gram). The second column is the compressive strength in pounds per square inch.

TABLE III (Continued)

MARCH	
1	No production
2	No production
3	No production
4	3004 - 3892
5	3027 - 4167
6	No production
7	No production
8	No production
9	No production
10	No production
11	3265 - 3983
12	3265 - 4342
13	3196 - 4292
14	3277 - 4458
15	3285 - 4367
16	No production
17	No production
18	3099 - 4058
19	3100 - 3983
20	3038 - 3767
21	2981 - 3732
22	3038 - 3642
23	3054 - 3700
24	2908 - 3875
25	2931 - 3800
26	2931 - 3725
27	2908 - 3867
28	2954 - 3692
29	2981 - 3725
30	2904 - 3550
31	2953 - 3733

APRIL	
1	2981 - 3417
2	2981 - 3492
3	2920 - 3575
4	3054 - 3683
5	3100 - 3833
6	3277 - 3750
7	3111 - 3675
8	3054 - 3692
9	3077 - 3758
10	3138 - 3792
11	3123 - 3842
12	3123 - 3958
13	3150 - 3750
14	No production
15	No production
16	3077 - 4192
17	2981 - 3883
18	3161 - 3975
19	3123 - 3300
20	3123 - 3750
21	3254 - 3825
22	3330 - 3425
23	3123 - 3492
24	3111 - 3508
25	3219 - 3575
26	3546 - 2725
27	No production
28	3438 - 3450
29	3650 - 3642
30	3338 - 3467

TABLE III (Continued)

MAY

1	3385 - 3525
2	3438 - 3108
3	3450 - 3342
4	3396 - 3567
5	3242 - 3208
6	2904 - 3083
7	3138 - 3550
8	3438 - 3450
9	3461 - 3300
10	No production
11	No production
12	3242 - 3308
13	3396 - 2983
14	3265 - 3550
15	3265 - 3533
16	3088 - 3883
17	3054 - 3933
18	3150 - 3633
19	3219 - 3183
20	3219 - 3183
21	3219 - 3600
22	3271 - 3600
23	3161 - 3692
24	3196 - 3333
25	3088 - 3450
26	3123 - 3417
27	3196 - 3325
28	3150 - 3592
29	3196 - 3500
30	3138 - 3258
31	3038 - 3408

JUNE

1	3208 - 3358
2	3173 - 3550
3	3265 - 3533
4	3504 - 4142
5	3161 - 3750
6	3077 - 3100
7	3296 - 3458
8	3088 - 3083
9	3196 - 3427
10	3196 - 3507
11	3265 - 3683
12	3111 - 3567
13	3015 - 3300
14	2854 - 3417
15	3196 - 3558
16	3265 - 3458
17	3265 - 3583
18	3242 - 3725
19	3123 - 3858
20	3242 - 3450
21	3308 - 3083
22	3354 - 2025
23	3296 - 3167
24	3138 - 3300
25	3296 - 3658
26	3100 - 3708
27	3196 - 3992
28	No production
29	No production
30	No production

TABLE III (Continued)

Day	JULY	Day	AUGUST
1	3123 - 3483	1	3396 - 3275
2	3173 - 3933	2	3265 - 3425
3	3300 - 4008	3	No production
4	3173 - 3900	4	No production
5	No production	5	3373 - 4267
6	3285 - 3933	6	3285 - 3450
7	3242 - 3775	7	3353 - 3850
8	3027 - 3842	8	3372 - 3425
9	3123 - 3892	9	3150 - 3568
10	3173 - 3925	10	2980 - 3658
11	3054 - 3775	11	No production
12	3173 - 2975	12	No production
13	3219 - 3433	13	3114 - 3692
14	3196 - 4067	14	3213 - 3558
15	3219 - 4383	15	2981 - 3358
16	3296 - 4483	16	3942 - 3417
17	3265 - 4400	17	3173 - 3467
18	3254 - 4267	18	3054 - 3508
19	3285 - 4108	19	3123 - 3742
20	3173 - 3967	20	3123 - 3725
21	3277 - 3833	21	3150 - 3425
22	3242 - 3883	22	3433 - 3433
23	3285 - 3667	23	3219 - 3525
24	3429 - 3642	24	3285 - 3433
25	No production	25	3196 - 3475
26	No production	26	3219 - 3475
27	No production	27	3088 - 3600
28	No production	28	3277 - 3425
29	No production	29	3265 - 3483
30	3373 - 3792	30	3300 - 3525
31	3373 - 3692	31	3300 - 3525

TABLE III (Continued)

SEPTEMBER

1	3396 - 3491
2	3242 - 3475
3	3219 - 3317
4	3219 - 3667
5	3219 - 3425
6	3100 - 3408
7	3173 - 3759
8	No production
9	3285 - 3767
10	3219 - 3400
11	3027 - 3500
12	3027 - 2992
13	2907 - 2892
14	3123 - 3058
15	3290 - 3042
16	3150 - 2817
17	No production
18	No production
19	No production
20	2954 - 3167
21	3025 - 3442
22	3100 - 3517
23	3150 - 3717
24	3150 - 3725
25	3123 - 3625
26	3111 - 3525
27	3173 - 3442
28	No production
29	No production
30	3219 - 3758

OCTOBER

1	3161 - 3792
2	3150 - 3808
3	3231 - 3783
4	3111 - 3600
5	3123 - 3292
6	3265 - 3558
7	3100 - 3333
8	3128 - 3833
9	3038 - 4100
10	3150 - 3800
11	No production
12	3061 - 3342
13	3150 - 3167
14	2992 - 3292
15	2877 - 3150
16	2981 - 3550
17	3138 - 3783
18	3285 - 3758
19	3354 - 3975
20	3308 - 3672
21	3265 - 3775
22	3296 - 3958
23	No production
24	3265 - 3558
25	3219 - 3808
26	No production
27	No production
28	3331 - 3858
29	No production
30	No production
31	No production

TABLE III (Continued)

NOVEMBER

1	No production
2	No production
3	3254 - 3233
4	3150 - 3350
5	3265 - 3608
6	3161 - 3725
7	3161 - 3342
8	3308 - 3642
9	3254 - 3567
10	3196 - 3417
11	3207 - 3450
12	3150 - 3675
13	3138 - 3842
14	3196 - 3767
15	3331 - 3442
16	3319 - 3800
17	3173 - 3933
18	3219 - 3783
19	3219 - 4108
20	3219 - 4092
21	3150 - 3975
22	3296 - 3750
23	3150 - 3808
24	3100 - 3733
25	3173 - 3900
26	3123 - 4125
27	3138 - 4083
28	3196 - 3833
29	3196 - 3875
30	3100 - 3725

DECEMBER

1	3138 - 3808
2	3265 - 3783
3	3173 - 4175

VITA

John B. Reinhart

Candidate for the Degree of

Master of Science

Thesis: THE APPLICATION OF STATISTICAL QUALITY CONTROL TO THE DESTRUCTIVE TESTING OF CEMENT IN THE CONTROL LABORATORY

Major Field: Industrial Engineering and Management

Biographical:

Personal Data: Born in Oklahoma City, Oklahoma, December 27, 1936, the son of John A. and Betty Reinhart.

Education: Attended elementary and junior high school in Oklahoma City, Oklahoma; graduated from McGinness High School, Oklahoma City, Oklahoma in May, 1955; received the Bachelor of Science degree from the University of Oklahoma, Norman, Oklahoma with a major in Industrial Management Engineering in May, 1960; completed requirements for a Master of Science degree in May, 1962.

Professional experience: Worked at American Potash and Chemical Corporation located in Trona, California during the summers of 1956 and 1957 as an industrial engineering trainee; worked at Warner Oil Company located in Oklahoma City, Oklahoma during the summer of 1958 and 1960 as an engineering trainee.

College Activities: Served as treasurer of Sigma Nu social fraternity; student member of the American Society of Automotive Engineers; member of the Society of Industrial Management Engineers at the University of Oklahoma. Student member of the American Institute of Industrial Engineers and Sigma Nu social fraternity at Oklahoma State University.