# QUALITY CONTROL

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## PREFACE

The preferred method of inspection in modern industrial organizations is statistical quality control, such as developed by the Bell Telephone Laboratories and Western Electric. This procedure has contributed to important reductions in costs and to substantial improvements in quality. It is applicable to both large and small operations.

The use of statistical quality control has grown considerably in the last two decades. In spite of this, many plants hesitate to install this method of control possibly because management does not understand the basic principles. The department head in charge of inspection for the factory may desire to introduce quality control but has considered its application impractical after reading numerous books on the subject that were written from the viewpoint of higher mathematics, containing numerous formulas and terminology not generally understood. This paper, then, is for the practical man and for the operating or staff official whose understanding of the problems and the solutions involved will aid management in the over-all aim of quality production at a reduced cost. The author has confined himself to the essential methods and considerations that will be readily understood and useful in establishing and making quality control a working tool of quality production.

The leader in this field in the United States Navy has been and continues to be the Bureau of Ordnance. The author is indebted to J. D. Parry of that bureau for his cooperation in giving his time and advice and making available the information used to research this paper.

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# CHAPTER I

## INTRODUCTION

The goal of competitive industry, as far as product quality is concerned, can be clearly stated as follows: to manufacture a product of quality at the most economical costs that will allow for full customer satisfaction. The system for attaining this goal is the subject of this paper. Quality control may be defined as: "An effective system for coordinating the quality maintenance and quality improvement efforts of the various groups in an organization so as to enable production at the most economical levels which allow for full customer satisfaction."[1]

The accomplishments of American industry during and after World War II are well-known. The quality attained in the manufacture of munitions of all types is familiar history. The efforts to attain and hold this high quality are neither familiar to most of us nor do they present so pretty a picture. Much time and material were lost and continue to be lost due to the poor quality of products found in the manufacturing process. While our quality failures usually are found in the factory and not after shipment, our techniques for doing this are excessively costly and wasteful. These wasteful techniques cannot be tolerated by any industry striving to maintain a competitive position. A new technique, known as statistical quality control, is called for.

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[1]A. V. Feigenbaum, Quality Control, Principles, Practice, and Administration (New York: McGraw-Hill Book Company, Inc., 1951), p. 9.

Statistical quality control is a proven system for maintaining high standards of manufacturing quality at a minimum cost. It has made substantial contributions to manufacturing efficiency, effecting great savings in the cost of production by preventing waste, eliminating rework, and reducing the amount of necessary inspection. By assuring a product of high quality leaving the plant, and by providing a common measure of product quality, statistical quality control assists in the development of understanding between producer and consumer. More and more in both private industry as well as in government circles, statistical quality control is being recognized as the hallmark of efficient management. It has become standard operating procedure in acceptance inspection programs of the Department of Defense.[2] Statistical quality control methods are easy to apply and do not require extensive training or higher mathematics. The routines necessary for effective programs of inspections for process control as well as lot-by-lot inspections are rather simple. Plant equipment in excess of that which is already on hand for the inspections currently being conducted is not normally required.

To the uninitiated, statistical quality control may appear difficult because the mathematical principles are not readily apparent. Once the common sense of these principles is appreciated, management finds widespread application for inspection and process control. This new approach provides a scientific foundation for the correction of many trouble areas. The same men, equipment, and plants in government operations, as well as private industry, have demonstrated time after time that higher production of

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[2]U. S. Department of Defense, Supply and Logistics Handbook, <u>Administration of Sampling Procedures for Acceptance Inspection</u>. INSPECTION H 105 (Washington: 1954), p. 10.

quality products can be obtained at a lower cost by application of these scientific methods.

The remainder of this chapter outlines the principles, in a general way, upon which quality control is based. Those members of the management team concerned with administration and application of quality control may thereby have a general understanding of the subject.

## Variation

The first step necessary to the understanding of quality control is recognition of the variation of pieces produced in the same machine or process. Two machined pieces, such as turned, tapered pins, may look exactly alike, yet will differ slightly in all dimensions. Experienced inspectors and production men are cognizant of small variations between pieces even when the operation involves exceptionally stable manufacturing conditions.

This statement may be illustrated by means of a simple experiment: Piece to piece variations follow a definite pattern, as may be shown by testing and sorting a batch of the aforementioned tapered pins. For example, if a box of pins is sorted into separate bins by measurement of their maximum outside diameters [the piece to piece variation here is the difference in the diameters], the pins having the smallest diameters being placed in a bin at one end of the line and progressing up the line with the maximum size at the opposite end, it is observed that the bins in the middle area contain the greatest number of pieces. There appears to be an ever-decreasing number of pins in the bins as one approaches the two ends. If the pattern of variation were to be plotted, the bell shape curve—known as the frequency distribution pattern—would result. Frequency distribution furnishes a measure of the piece to piece variation of machine-made products.

The true bell shape curve results only from plotting the values of a large number of pieces. The frequency distribution of 1000 pins is considerably smoother than that for, say, 100 pins. The tendency of the distribution to become more regular will continue indefinitely. The perfectly symmetrical distribution resulting from measuring an infinite number of pieces is called a normal distribution. In using statistical quality control, this theoretical pattern is of great importance.

In any manufacturing process it can be demonstrated that the variation in the pieces forms a definite pattern. This pattern usually follows the normal curve. Sometimes the curve of the variations will be skewed in one direction or the other. The causes of skewness are readily determined; even here the patterns follow the same general principles. The cause of normal patterns may be shown by mathematical theory. Whenever a large number of chance causes act on a process, a definite pattern of the variations will result.

In any manufacturing process there are always a large number of chance causes at work. These may be the unavoidable play in the bearings, tension on springs, or simply human error in measuring, to name a few. In the pins we have just considered, the variation of the one measurement in question can be caused by any of the above, or even the slight wearing of the grinding wheel. These small chance factors affect each piece independent of each other. In the long run, factors in one direction tend to cancel out the influences in the other, forming a definite pattern as previously mentioned. This pattern always exists in any manufacturing process, and is repeated over and over again as long as the same causes are present.

Since the pattern of variation of the process repeats itself, we can predict the limits of the process for the future as long as there is no

change in the chance causes. As long as the pattern remains the same there is reasonable assurance that no new causes of variation have affected the manufacturing process. This, then, is the scientific basis of statistical quality control. Without the change in chance causes, the process repeats itself hour after hour, and day after day, within the limits predicted. When the pattern falls within the predicted tolerance limits, we may be assured that the population [entire production] is acceptable and there need be no concern over the individual pieces. Quality efficient production results from this and the process is known as being in control.

The detection of something wrong is a simple process, once the limits are established. When there is a departure from the established pattern, there is a sure sign that something is wrong; the product is being affected by something more than the small chance factors. A basic change has occurred in the operation; the cause of the abnormal variation must be tracked down. In addition to the chance factors previously mentioned, other causes of the shift are: inferior material, slippage in the set-up, and changes in temperature.

Employing statistical quality control, the trouble may be spotted almost immediately, and the process may be brought back to control by making necessary correction. Thus, the quality of the product is kept constant, and the amount of scrap is drastically reduced. This obviously could not be done by testing the whole lot after production is completed. Such a procedure would merely eliminate the defective pieces but would not correct the manufacturing process itself.

The objective of statistical quality control is to maintain the quality of the entire lot or population.[3] The method used is scientific

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[3]Feigenbaum, op. cit., p. 15.

sampling. This provides an accurate, early, and economical picture of the population. Sampling frequently provides a more accurate picture of the quality of the whole population than 100% inspection. This is due primarily because more attention is given to the individual units being inspected as well as more refined methods may be used. Many companies now employ a sampling technique to test the accuracy of 100% testing.

In the application of statistical quality control to process control we need only to take periodic measurements of very small samples of three to twenty pieces in order to spot the trouble. The analysis of the results of the sampling will show if the pattern of the process is being maintained or if some force not normal to the operation has suddenly appeared. We are not concerned with the sample pieces themselves but rather what they show about the whole lot.

The sample selection process must be of a random nature, that is, every piece has an equal chance of being selected.[4] Thus, when we survey the sample results we get a true indication of the characteristics of the population itself within the limits of the predicted mathematical accuracy. The risks involved in sampling can be held to whatever limits are established in balancing accuracy and economy, as will be discussed further in Chapter III.

Practically all the individual pieces of a population fall within the limits as shown by its own frequency distribution. It follows, of course, that the units of the sample will also fall within these limits. Since the high and low values of a sample are canceled out in taking an average of this sample, it follows that the average of several samples

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[4] Eugene L. Grant, Statistical Quality Control (New York: McGraw-Hill Book Company, Inc., 1952), p. 389.

will fall within narrower limits. These limits are called control limits with the lower value the lower control limit (LCL), and the upper one the upper control limit (UCL).

Thus it follows that if the sample average does not fall within the control limits it is reasonably certain that the sample did not come from the original population. When this happens, it is a signal that something more than the chance cause has affected the operation causing the whole process to shift, or perhaps to become more variable.

Control charts will be discussed in greater detail in Chapter IV. However, a few salient, introductory comments will be made here. Control charts provide an efficient, simple method of checking continuously whether the process is in control or whether it has changed.

Most control charts are made up of two sections—the upper section portraying the sample averages, and the lower portion the sample ranges. The sample averages provide a sensitive measure of the change of pattern of the individual units. When the sample averages fall between the upper and lower control limits, the process is repeating itself and is in control. The lower part of the chart (where used) measures the difference between the lowest reading and the highest in each sample. This range measurement indicates whether or not the variability of the process is within the control limits.

Any departure from the established pattern will be shown immediately. The incurrence of a faulty batch of material, a shift in tool setting, or wear on some necessary part will show up as the sample average appearing outside the control lines. The process variability may still be within limits but the distribution pattern will have shifted to one side or the

other. Range variability outside the limits imposed may be due to bearing wear, operator carelessness, or other causes. This will be reflected on the lower chart by the appearance of a sample range over the upper limit. Here, again, the sample average may well be within the control limits. The distribution variability chart then gives us an added check at very little extra cost.

The process control chart thus provides us with certain and immediate information about the pattern of the variation expected from the process and gives prompt signals of the trouble or the absence of trouble.

## CHAPTER II

## GENERAL PRINCIPLES OF ORGANIZATIONAL PRACTICES AND METHODS

Before the industrial revolution there was little need for separate organizations for making and inspecting the products produced. Each workman was his own inspector. Each worker made the whole product from start to finish and, thus, inspected it as he went along. In addition, there was no interchangeability of parts to speak of, eliminating the reason for close tolerances. With the coming of the industrial revolution, decline of the individual handicrafts commenced and the emphasis shifted to the use of machines and quantity production. To assure the quality in this production process, inspection as a function commenced. It soon became apparent to the early industralists that a separate inspection group would be the most effective manner of employing this new tool.

In the not too distant past, inspection meant merely rejection of the finished piece. Now the emphasis is on the control of operations within the manufacturing process to assure a quality product at all times during the entire process.

As was previously stated, the most effective organization evolved was that separating the inspectors from the producers. This eliminated bias and pressure to lower standards. Also, as time went on, it became more and more apparent that specialized training and knowledge were the requirements of good inspection. Other factors adding to the necessity for a separate

organization are the size of the companies, the geographical separation of the separate factories, and the necessity for having a common set of rules and standards.

As in all organizational problems, all possible relationships and interplays can not be shown on charts. In addition, the considerations of span of control, line versus staff and communication are present in the organization of the quantity group as well. However, some basic organizations for the inspection or quality control group will be discussed. First of all, it is clear that the quality control group should be separated from the manufacturing division for reasons previously mentioned. Sometimes quality control groups are placed under the engineering department, since standards are tied to the specifications set by this department. They are placed more often, however, in a staff capacity under an official on the same level as the head of the manufacturing function.[5] Both these organizations work well in practice yet each has its advantages and disadvantages. To be successful, however, there must be a spirit of cooperation no matter what organizational procedure is followed.

Where the branches of the corporation are physically separated, a central office for quality control coordination is recommended. This coordination involves establishment of consistent standards, furnishes a single point for settling disputes, and generally promotes unity of purpose.

Frequently the inspection groups will be broken down into units, which may be organized into raw materials, process, and finished products groups. They may also subdivide further into groups by products or detailed parts and assemblies.

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[5]Feigenbaum, op. cit., p. 71.

All organizational problems have one common quality—that is, human nature. All problems of organization must be solved by considering good practices as well as the ability of the individual.

As with installation of any new system, we always have to ask, How much can we afford? Specifically, how much quality control is economical? We know that if machines and men consistently produce products that do not vary in quality, obviously, there would be no need for quality inspection. A good quality control department minimizes manufacturing costs and customer complaints. Yet the amount of time and effort applied to inspection must not be increased to a point where increased costs do not compensate for the smaller increase in quality, or the savings in the reduction of scrap. A further detailed examination of a specific example will be shown in Chapter III.

The quality of the product must be controlled in order to maintain its reputation as well as that of the company. This, along with safety, is an intangible but must be considered in judging how much quality control may be justified.

A cost-conscious attitude must be established in the quality organization for attaining the most economical quality control. There usually is an avoidance of this subject by the inspection group on the basis that an emphasis on this will cause a reduction in the quality desired. Actually, the two subjects are closely allied and the emphasis on costs—or at least the awareness of them—should result in greater efficiency through attention to details.

The ratio of inspectors to production workers, or to products manufactured, is arrived at as the result of experience. Future

requirements are based on these historical values also. In light of improved methods, new tools of inspection, improved personnel, and improved technology on the production line, these ratios should be periodically reviewed to assure economical quality control.

The awareness of the importance of the control of costs in the quality department is usually absent. However, adequate cost control leads to economical inspection. Very little work has been done in this field. One of the major reasons is the very small savings to be realized as compared to processes in manufacturing itself. Also, the work itself does not lend itself as well to efficiency studies as do the various machine operations. In the latter, time and motion studies may be used to great advantage but not so the details of making a good inspection. In addition, an installed piece-work system for the quality department might have a tendency to shade the quality of the material in the interest of higher wages.

The following six items affect the costs of the inspection group:

1. Type of product
2. Manufacturing department attitude
3. Quality standards
4. Tools and equipment
5. Procedures and methods
6. Effective utilization of labor.[6]

The first two items are not controllable by the quality department. However, the attitude of the manufacturing department can be influenced by the manner in which the inspection personnel at all levels deal with the producers. Tact and diplomacy—rather than the negative attitude typified by the rejecting only manner of many inspectors—must be practiced. A

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[6]John G. Rutherford, Quality Control in Industry, Methods and Systems (New York: Pitman Publishing Corporation, 1948), p. 26.

cooperative attitude, coupled with cost consciousness, will be reflected in a quality product that requires very little checking.

Establishment of quality standards should be a coordinated effort of the engineering department in cooperation with the inspectors as well as the manufacturing division. Obviously, there are times when rigid standards imposed by the engineers just are not attainable in practice or are not practical with the machinery presently installed. The inspection group can and does give good service in providing liaison for establishing reasonable, economically-attainable standards.

Costs are reduced and uniformity is maintained through use of procedure manuals, which serve as general guides for all inspectors and include items such as the use of rejection and rework tags, records to be maintained, and use of inspection stamps. These manuals do not give detailed procedures for the inspection of any one item.

Procedures specifying details of the individual inspection are given in another source that may be termed procedure or method cards. These cards follow the part or assembly along the line in the factory, and thus assure uniform checks by all the individuals involved. In writing these cards, the sequence of the job, trouble spots, methods of performing the work, and tools to be used should be shown. As in all written instructions and record keeping, the costs of the system must be less than the benefits received. In arriving at whether to have written methods, initial cost of the write-up must be considered along with the necessity for written versus individual judgments, the cost of maintaining the cards current, and the number of units to be manufactured.

The last item affecting cost to be discussed is that of effective utilization of manpower. Areas to be considered here are organization—which was previously discussed—job classification and wage scales, and the number of inspectors necessary. There must be a system of job classification and wage rates, if costs are to be controlled. Factories are now too specialized and organizations too large to rely on the judgments and memories of individuals to run an organization.

An example of a simple system is that of inspection work divided into classifications, such as parts inspector, subassembly inspector, and final assembly inspector. A wage rate range is assigned to each classification, depending on the necessary training, education, and skill necessary for the job. Three basic divisions of skills are used for each job, such as apprentice, second class, and first class. Thus, under each classification of the work we have three categories of skills. A job description may then be prepared for each division of work and each breakdown of skills. These descriptions give not only the details of the position to be filled but also the qualifications necessary, thus establishing a criterion for filling the billet as well as establishing a system for advancement. Within each category the men advance up the rate bracket on the basis of actual performance graded on the basis of quantity and quality of the work produced as well as the attitude and dependability demonstrated. Admittedly there is a top to each bracket and the man who arrives there does not get further increases unless he is given a supervisory position. The success of the program depends on the fairness of its administration. In addition, it is a waste of time and money to use a man of first class ability to do the work of an apprentice.

The means of determining the number of men to be used in the quality control department were mentioned previously. These include control of the numbers of inspectors by the local head of the operation, a definite ratio of the personnel engaged in manufacturing, and use of the ratio of production level to the number of inspectors needed.[7] The drawbacks of the first two include inflexibility, difficulty in reducing the numbers when production is cut back, and lack of a planned program for getting replacements. The best method for large organizations is associating the number of inspectors with the level of production. The production is usually planned months in advance by use of a Gantt chart. Information from this chart then is plotted to show the level of production for the year. With this information the number of inspectors is superimposed, thus showing the total numbers required, when to recruit more, when the slack periods are likely to occur, and, consequently, the cut-back level deemed advisable.

Time studies can be most helpful in the quality department. These would not be used to fix the wages or the performance of the inspector but rather to control or give information as to the numbers required. Additionally, motion studies result in saving of motions to accomplish the same coverage, thus cutting down the fatigue factor for the individual inspectors.

We now move from the field of the control of costs in the quality department to the field of paperwork. The frequency and numbers of reports considered essential present difficult economic decisions. As stated previously, in connection with the discussion of the manual and the methods cards, the costs of installing and maintaining records must always be balanced against the value realized. Frequently it is desirable to record

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[7] _Ibid._, p. 34.

results of operations for future guidance. For the quality department, as well as for others, it is frequently economical to centralize clerical functions.

Records and reports usually made and kept by the quality department consist of the rejection reports and tags, log books, inspection stamp control book, and a change control book.[8] Some companies have the individual departments keep their own personnel and equipment records; this is not normally done, nor is it economical.

The rejection type records include the tags and reports of material sent back for rework. These records are of importance for the following reasons:

1. They furnish a method for controlling rework and for checking rejections to insure that they are satisfactorily reworked or scrapped and do not get into the final product.

2. They give an indication of the relative efficiency of the plant departments.

3. They show the need for corrective action and give data to prevent recurrence of individual rejections or rework.

4. Raw materials for statistical methods may be obtained through these records.

There are many ways to tag or show rejected parts. Whatever method is used, all systems should include the following points:

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[8] Ibid., p. 40

1. Information should be forwarded for analysis and action as soon as possible after the rejection takes place. As in administration of all controls, effectiveness depends a great deal on prompt application to correct variance.

2. The system must indicate a check between the data and the actual rework or scrapping of parts. Paperwork for the sake of records only is of no value, and a system of periodic checkups must be used to determine justification for their continuance, or recommended modification.

3. Close cooperation with the manufacturing department should be maintained for best application of the results of the data obtained.[9] Frequently it is advisable for a representative of both inspection and manufacturing to observe the defective part to insure prompt corrective action.

The reject or rework tags themselves provide a useful function in earmarking defective parts. However, the records in this field should not stop here. Analysis sheets should be made out in order to watch for any discernable trends and as a means for measuring relative efficiency of the various sections in the manufacturing department. In this regard it is to be noted that the simple tabulation of the number of pieces rejected is not enough. These numbers must be correlated with the volume of production not only to give a true measure of the efficiency of the various departments but also to compare periods of time.

The remaining records are for the administration of the quality department itself. First we have the inspection log books. These logs

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[9]Feigenbaum, op. cit., p. 51.

list the method and sequence of checking and indicate the acceptance at various stages of manufacture. These books assure a systemized procedure. In addition, they show who is responsible for passing or rejecting the item, as well as affording a running record of the material through the whole operation.

Other records are those dealing with changes to the specifications and the inspection stamp control book. The problem in the administration of the changed specifications is to get the information to the inspector involved and to assure that the check has been made. This is accomplished in various ways. In the case of the former, a change attached to the referenced specification may be used. Another method is to change the drawing or specification itself insuring that all superseded drawings are collected. To assure that the work has actually been checked to conform to the new information, a recording of the change is made on the first applicable lot. Frequently, however, it is assumed, since the inspector received the change, that the change has been made. Positive control must be exercised to forestall this.

Introduction of new methods and frequent turnover of personnel compound the difficulties in administration of any training program, yet training programs are necessary. The program itself usually takes one of three forms, or a combination of all three, that is, apprenticeship, formalized training school, and in-service training courses. Industry has long used the apprentice system to train skilled craftsmen. Here the apprentice are assigned to the more experienced workers for a period of time, then are rotated

to other senior workers to gain the specialized know-how as well as a generally broad picture. For this method, a stabilized group must be available—something very difficult to get in these days of high wages paid to the semiskilled production line worker. Also, only a few trainees can be developed at any one time, since the services of experienced men are required.

Training schools operating at company expense became popular during World War II with the training of a large number of novices in a relatively short time. Here the subjects are apt to be more than just related to doing the job of inspection. They will encompass company and plant familiarization courses as well. The usual educational means are used, such as lecturing, demonstrating, performing and examining. This method's greatest advantage, as previously mentioned, is the large number of prospective workers it can produce. Other advantages are that the trainees do not disrupt the factory routine of production, the unfit are eliminated sooner, and the general company policies and organization are explained to the selectees. In-service training is really a short indoctrination type training school followed by actual on-the-job instruction and working. The trainee thus gets a good but fairly brief course on what he needs to know to do his job, followed by on-the-job training overseen by experienced supervisors.

Any training program must be justified on the basis of paying for itself. The decision to set up a formalized program depends on the situation at hand. The type used will depend on the caliber of trainees, the policies of the company in regard to "educating" its workers, and the scope of the job to be done.

Quality control personnel must work closely with other departments of the company. The aim of all departments is to produce a superior product economically. The usual complaint of the manufacturing department is that the quality control personnel hold up the process. They sometimes tend to think of the inspectors as necessary evils and, on occasion, even unnecessary. Although it is impossible to eliminate personalities entirely, much can be gained through the mutual understanding of each other's functions and problems. Many companies have established a program of shop inspection meetings to discuss the problems as they occur or to prevent their occurring. Although the problems are not so prevalent when dealing with departments other than manufacturing, problems do exist. In dealing with the other departments, the inspectors assist the engineers to arrive at realistic and economical standards. In the case of the sales department, inspectors receive information from the salesmen who tip them off on the little discrepancies they—the salesmen—have found in the field. The inspectors can thus do a better job in looking for defects in likely places. Here, again, cooperation makes for a better product at an economical cost.

## CHAPTER III

## SAMPLING INSPECTION

Three methods of inspection used to control the quality of manufactured products are: screening, lot-by-lot inspection, and process control. Screening is the 100% inspection of the entire product. As mentioned previously, screening sometimes is less reliable than a statistical control procedure and invariably the costs are higher. Lot-by-lot inspection involves examining a small segment of the total number of pieces and from the inspection judge the acceptability of the whole lot. This type of quality control will be the subject of this chapter, while the process procedure will be taken up in the following chapter.

The use of lot-by-lot inspection has certain limitations. There is always the possibility that the inspector will pick nonrepresentative samples. Thus, he may select a sample that contains more defectives than allowed; the lot is therefore rejected while, in fact, the population's distribution may be within the allowable limits. Conversely, the population may contain more defectives than allowed, but the sample shows the lot to be within the allowable limits. Errors of this type are known as sampling errors. This is where principles of statistical quality control come to the aid of the inspector giving him the proper plans for getting the maximum amount of protection for the minimum inspection costs. Without proper inspection plans there is either too much or too little inspection, with the resultant excessive costs or ineffective control.

In setting up lot-by-lot inspection these four basic steps are generally followed: (1) set up the inspection lots; (2) arrange for rational lots; (3) establish an allowable percent defective; and (4) select a sampling plan.[10]

In setting up the lot to be used as the unit for inspection, that quantity of the product selected usually moves through the plant as a single unit. As will be shown later, lots should be in quantities of 300 or more. If the numbers are less, screening or process inspection should be used in preference to lot-by-lot. There is no theoretical upper limit, but the lots should be small enough to permit moving through the factory without requiring special handling. To show the variability of lots as far as numbers are concerned, some examples are: A barrel of plated washers numbering about 10,000; a skid box containing 5,000 tapered pins; or two tote boxes on a single hand truck containing a total of 450 blanks.

Frequently it is decided to sample the products from one machine after a certain time has elapsed. This, then, determines the lot size. One may wish to sample from a punch press producing 3000 stampings per hour. With an inspection every fifteen minutes, the lot size will average about 750. The fifteen-minute interval would be decided on the basis of the cost of inspection versus the risk in letting the process get out of control. With this small elapsed interval, detection of the malfunctioning of equipment or a poor lot of material is accomplished fairly soon. Thus, small lots give better control and prevent large material wastes. However, they must not be too small for economy and statistical reasons.

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[10] Norbert L. Enrick, Quality Control (New York: The Industrial Press, 1948), p. 5.

In order to obtain desired results of any procedure, the samples selected must be so picked as to be truly random. Each unit in the sample must be selected in such a way that each unit in the lot has an equal chance to be selected. All samples should not be taken from one locality of the population, but selections should be spread around. Hunting for defectives in any one location on the basis of a hunch, such as in the bottom corner, defeats the primary purpose of sampling. A true representation of the lot is not obtained in this manner, and, in the long run, would give misleading results.

To arrange to sample from rational lots is meant to take units which have been produced from the same source.[11] Where practical, lots should be so selected as to be from the same source of raw material; produced by the same machine, using the same mold or pattern; or the same shift. In actual practice it is not possible to separate and establish the lots following all the above principles. However, the closer the lots are and yet are separated, to conform to the principle of coming from one source, the easier will be the analysis, so that any difficulty that has crept into the production process may be subsequently corrected.

An example of using the rule of rational lots is the case of ball bearing tumblers. It is assumed that four tumblers are in operation. The bearings from these four tumblers are kept separated and are so tagged. As they move through the shop they are inspected. When the inspector finds one lot with bearings that are rough and chipped, he can examine the tag and put his finger on the exact tumbler that caused the difficulty. Had the bearings not been separated and tagged, the question of which machine was the offender would have to wait for results of further sampling with the consequent waste of valuable production and man hours, as well as material.

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[11]DOD, Supply and Logistics Handbook, op. cit., p. 17.

After the lots have been established for the control problem, the next step to be considered is that of establishing an allowable percent defective. Even with the most modern, perfected machinery, it is impossible to turn out 100% perfect parts using mass production methods. Thus it must be established what percent of the defectives will be allowed. Frequently it is more economical to allow a certain percent defectives to go through rather than resort to screening. This is illustrated in the case of stamping out washers where one percent of defectives has been found to be quite normal. After the sampling process, the washers are sent to the galvanizing process for finishing. At the end of this process, screening is used to eliminate the defectives. The galvanizing process is inexpensive; thus, it is considered economical to allow the one percent defective washers from the stamping process to go to the finishing stage. On the other hand, take, for example, a forging process where two percent are defectives. Here the material is subject to a large amount of machining after forging. Therefore, it is economical to screen out the two percent defectives after the forging.

The principle of establishing the allowable percent defectives is now apparent. In short, after it has been decided by experience what the normal percent defectives is for a given operation, the allowable percent defectives for future processing is fixed. If the percent defectives is not allowable, screening inspection must be installed. If, on the other hand, it is allowable, the proper sampling plan is set up to assure that in the long run the allowable percent defectives is permitted to go through to further processing and the operation is considered to be in control.

One and two percent defectives were the values used in the two most recent illustrations. To get this information, the process is

monitored for a period of time—usually about one week of normal operations. Sometimes the information is already available from past records of processes or machines.

For the sake of illustration, it is assumed that no past records are available. The machines in question are two punch presses. Following are the results of one day's observations in percent defectives:

| PUNCH PRESS No. 1 | PUNCH PRESS No. 2 |
|---|---|
| 1.1 | 0.8 |
| 2.3 | 1.2 |
| 1.6 | 1.2 |
| 0.8 | 2.1 |
| 4.8 | 1.8 |
| 1.7 | 2.3 |
| 2.0 | 1.2 |
| 1.5 | 1.9 |

Observations for another four days were taken with the results closely paralleling those shown above. The fifth observation under punch press No. 1 is clearly at variance with the remainder of the values. Investigation revealed this was due to a personal error; thus 4.8 may be eliminated from further consideration. The remaining values from inspection clearly fall roughly between the one and two percent values. Comparisons between operators and dies used were made, as well as the amount of scrap turned out. From all these data it is determined that the up to two percent defectives in any given lot is considered normal.

There is no set of tables to determine the normal percent defectives for the various machines and processes. It is more a matter of judgment than precise scientific measurement. To make up a standard table would be a monumental task, subject to many variables, such as: differences in raw materials; ages of the machines, as well as most recent overhaul; skill of

the operators; and many other reasons. Thus, each shop must determine its own value for each machine or process, striking an average for the individual operators. In some fields, this value comes under the general category of a figure of merit. Once the normal production of defectives is determined, the next step is to determine whether this is allowable or not—to be arrived at in consultation with the cost accountants, engineers, and the planners.

The allowable percent defectives for incoming materials is usually dependent upon the commercial standards for the product involved. Large procurement activities, both government and commercial, state in their purchase orders the percent defectives allowed. Whether arrived at by commercial standards or by specification, the inspection plan used for these incoming materials is based on the allowed percent. Groups of manufacturers frequently unite to establish the figure for the whole industry. An example is the manufacture of electron tubes for civilian as well as military use. Where possible, the military and government activities, in general, attempt to use the established commercial standards.

The manner of establishing lots and allowable percent defectives has been considered. The fourth and final step is that of selecting a sampling plan. The two major types of sampling plans are the average outgoing lot quality protection plan, and the lot quality protection plan. Either type may involve three methods: single, double, or multiple sampling.

Average outgoing lot quality means that in large numbers of lots the quality will be equal to or less than the specified average.[12] Some lots may be over this specified value; these will be compensated for by others that are under this value.

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[12] Rutherford, op. cit., p. 89.

Lot quality protection is a plan to assure that only a specified percentage of lots containing a limiting percentage of defectives will be accepted.[13] The average quality of the outgoing lots is better than the limiting percent defective. Rejected lots are screened 100%.

Both of these plans have advantages and one or the other may be the more desirable depending on the application. A customer who buys in large quantities may be satisfied if the average lot quality is assured. On the other hand, the user who buys only a single lot may find it desirable to be assured of that individual lot's quality. Another factor in determining which protection is desirable is whether the product is to be used for further assembly. Normally in such a case the protection afforded by the lot quality plan is the preferred procedure. The other plan is liable to pass a lot of poor quality and so entail costly production delays, much uneconomical hand-fitting, and failure of the assembly to perform properly in the field.[14] If the nature of the production is such that the product turned out is normally of a high quality, the average protection plan may serve the purpose, since any departure from normal operations would show up in this plan as well as in the lot quality plan.

The quality level obtained through each plan and the effect of the average incoming quality on their use are frequently misunderstood. For the lot quality plan, only a certain percentage of so-called defective lots would be accepted. This is considered in setting up the plan. The value for most industrial uses is 10%. As was previously pointed out, the average of the accepted lots would be superior to the limiting percentage of

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[13] _Ibid._, p. 87.

[14] Feigenbaum, _op. cit._, p. 144.

defectives allowed. Thus, the incoming lot must have an average appreciably higher than the selected lot percent defective; if this were not the case, there would be frequent rejections causing a high cost of processing. In average outgoing lot quality protection, the average quality of the outgoing lots is assured.

As stated above, each type of sampling plan may be used in either single, double, or multiple methods. Single sampling may be defined as that method of basing acceptance or rejection of a lot on the units of one sample drawn from that lot. Usually single sampling is used in conveyer type production operations, where it is possible to draw only one sample. Another application is where the lots contain a large variation in the percent defectives. In this case the use of single sampling is more economical than either double or multiple methods. In single sampling the procedure is to take the random sample from the lot, counting and noting the number of defectives. The lot is then rejected or accepted on the basis of this sample. The rejected lots are normally screened with the defectives being repaired or turned into scrap.

Double sampling is the selecting of one sample from the lot and, under certain conditions, selecting another sample before accepting or rejecting the lot in question. Double sampling starts out in a manner identical with the single method. However, in this method frequently the sample shows a defective number between the acceptance and rejection numbers. When this occurs, a second sample is drawn; the lot then is rejected or accepted depending on the combined number of defectives in the first and the second samples. Rejected lots are disposed of in the same manner as in single sampling. Double sampling sometimes is easier to sell

to management than is single, since it gives the idea of giving the lot a second chance before rejecting. This psychological advantage is not based on fact. However, double sampling does permit smaller first sample sizes than is specified for single plans. When the percent of defectives is low, it is possible to accept lots based on the results of this first sample. Also, should the percent defectives be high, rejection may also take place on the first test. In these instances, double sampling permits lower sampling costs. This method is the most popular.

Multiple sampling bases acceptance or rejection of a lot on the results of several samples drawn from the lot. Multiple sampling, then, is similar to double sampling but has more stages. Multiple sampling plans are more difficult to administer than double or single plans. The requirement for selecting successive samples in the proper sequence may call for greater administrative control and more highly skilled personnel. In much the same manner that double sampling may result in smaller sample sizes than single plans, multiple plans have the same advantage over double ones. In actual practice the greater cost of multiple plans, due to their complexity, frequently gives the advantage, cost wise, to the double plans. When the actual percent defectives is low—around 0.1%—the amount of inspection required for the single and double plans is about the same as the multiple plans.

In selecting a method, the type of product, the availability for inspection, and the specific type of tests to be applied are all matters that must be taken into consideration. The choice of a plan depends on the conditions under which the plan is to be used.[15] There is no such thing as

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[15]Grant, op. cit., p. 385.

the best plan. The so-called best plan is simply the best for the particular sampling conditions encountered.

Rather than design their own tables, many industrial quality control departments make use of various published material. The most popular and widely used of these are the Dodge-Romig tables, United States Army Ordnance tables, Wald's Sequential Plans, and the United States Navy Sampling Plans. The Dodge-Romig tables include double and single plans giving protection for both average outgoing quality and also lot quality. The Army tables are primarily for protection of lot quality with a mention of average outgoing quality. Both single and double plans are included. Wald's Sequential tables are used in multiple sampling and include plans up to seven samples. The United States Navy tables cover both lot quality protection and average outgoing lot quality with single, double and multiple plans. An example of the Dodge-Romig tables is shown as Appendix I.

The first example to be taken up concerns the use of sequential sampling and will use the tables from Appendix I. In this sample we shall assume that the allowable percent defectives is 2% and the lot size 1000. The information required is how many pieces to inspect, when to accept the lot, and when to reject it. All answers to the above questions are available from the tables. From the left-hand side of the tables, the lot size is given. In our example the 1000 assumed lot size is in the third grouping in the 800 to 1299 group. The next column contains the sample size beginning with twenty and progressing up in twenty number increments through 120, and then jumps to 160. The remaining columns are for the various assumed quality levels desired or allowable percent defective. In this example it is assumed a sample of forty items is drawn with two defectives. From inspection of the tables it may be seen that two falls between the acceptance

and rejection values of zero and four, respectively. These values are found in the horizontal line opposite forty in the proper lot size grouping and in the vertical column under the acceptance level of two. The procedure is then to go to the next sample size—which is sixty. Twenty additional samples are drawn with two more defectives included, making a total of four defectives out of a total sample size of sixty. This, again, is between the acceptance and rejection numbers and thus another sample of twenty must be drawn. This next increment gives two more defectives, making a total of five defectives out of a total sample size of eighty. This is included in the rejection number; hence, the lot would be rejected. This process might well have gone on until the highest sample size in this lot size was reached. This ultimate sample size of one hundred sixty is noted to contain acceptance and rejection numbers of seven and eight, respectively. For all the highest sample sizes in the table, the gap between acceptance and rejection disappears.

The subject of using single sampling plans will now be taken up. Appendices II and III are examples of Dodge-Romig type tables. These tables, with the explanatory information at the top, are rather straightforward, making their use simple and logical. It is to be noted, however, that for assumed process averages the size of the sample required increases as the assumed process average increases. For the table shown in Appendix II, it is further noted that the consumer's risk of accepting a lot containing more than the allowable percent defectives is ten percent. As stated previously, this is the normal risk for most industrial installations. However, others go down as low as 0.5%, while the other extreme is 25%.

Two examples of using single sampling procedures will be shown. In the first of these it is assumed that the consumer risk is ten percent, the

lot size is 2500, an assumed process average of one percent, and the lot tolerance percent defective of two percent. Reading from the table in Appendix II shows that the sample required is four hundred forty—the lot may be accepted if the number of defectives does not exceed five. The average outgoing lot quality is 0.56%.

For the second example of single sampling, the use of the table shown in Appendix III will be demonstrated. In this case a lot size of 3500 will be used and the following additional information: average outgoing quality limit is 0.1%, a process average of 0.1%, and a lot percent defective allowed of 0.6%. Reading directly from the table, the sample size required is 695; the lots will be rejected if the number of defectives exceeds one.

In some special cases there may be a requirement for sampling on the basis of major and minor defects. Each criterion would have its own sampling plan, and obviously the one applicable to minor defects would allow a larger value for the percent defectives. In examining steel blanks, for example, 1% might well be the allowable percent defectives for major defects, such as die marks variation in stock, and thick lines. On the other hand, slight scratches or burrs may be considered minor and might well be allowed up to 5% defectives. Separate sampling plans are then used and the material accepted or rejected on the basis of either the major or minor defects.

## CHAPTER IV

## PROCESS INSPECTION

Process inspection is that portion of quality control where an inspector checks on equipment, methods of operations, and occasional pieces of the product.[16] This check may be made either by a roving inspector or by several inspectors. The inspection of the product occurs at various steps from the introduction of the raw material to the finished product itself. The aim of process inspection is to discover defective products where and when they occur so that corrective action may be taken immediately. This method of quality control is concerned with all the causes of defective work, such as raw material, the operator, or the equipment.

In the interests of economy of operation it is apparent that inspectors cannot be established at every operation nor can roving inspectors be employed in sufficient numbers to check each process in the operation. As a result, considerable faulty material may slip through. This is especially true in such difficult operations as precision machining, intricate casting, and certain precise welding operations. In these cases the inspector finds the faulty product after the damage has already been done.

Because of the above shortcoming, it was found necessary to establish a method that would indicate quickly when something was wrong or about to go

[16] DOD, Supply and Logistics Handbook, op. cit., p. 1.

wrong. Statistical quality control has made this procedure possible through establishment of the control chart system. The primary purpose of control charts is to show trends toward the tolerances established for the acceptance or rejection of the product. These control charts show when the established limits have been exceeded; also, and far more important for control purposes, they provide means necessary to anticipate and correct the causes responsible for the defective product. Thus, their fundamental purpose is to prevent defective work rather than to detect and correct defects after they begin to appear.

Prior to discussing the construction and actual use of the control chart, a few general comments about establishment of the system will be given. First of all, there is the matter of randomness of the sample as mentioned in the previous chapter. In process inspection the concern is with controlling the process on a continuing basis rather than controlling the quality of separate lots. Therefore, the random sampling rule does not apply. Instead, a sample is selected directly from the machine, usually on a time schedule just prior to the arrival of the inspector. This furnishes the latest information to the inspector of what the machine is actually producing and thus gives timely information for detecting any impending trouble. The sample so selected should be truly representative of the latest production and every effort should be made to insure that the operator has not stacked the samples to make it appear that the machine is producing better than is actually the case.

There are many processes having many variable dimensions or qualities. It would not be economical to have control charts for each of these variables. It is essential to select one or two of the most important characteristics, usually one that will be the hardest to control, thus giv-

ing a good representation that the process is either in or out of control.[17] The other variables should be subject to spot checking so that nothing is left completely to chance. However, if the difficult dimensions are in control, the remainder are usually in line, especially in machining operations, such as on a turret lathe, where there is some interdependence of machining to dimensions.

Control chart installations differ in the many plants where they are used. The differences are due to the necessity to meet the individual plant conditions. Some of these differences are necessary because of the variations of the numbers in the sample, the methods of computing control limits, the measure of the central tendency used, and the chart form itself.

Sample sizes in industry range from around two to twenty. Normally sample sizes of two or three are not used due to their low accuracy. The most popular size for process inspection is five, with the adjacent numbers used to a slightly lesser extent. The low sample sizes are used where the sample is destroyed in the testing process, or the article has considerable economic value. The larger sample sizes of around twenty are used in such operations as multispindle operations. Here readings are taken and recorded from each spindle, resulting in a large sample. In determining the sample size to be used, a balance must be struck considering the following factors: number of units that may be economically included in each sample, and the statistical accuracy required to determine whether the process is in or out of control.

Various values are available to measure the central tendency. Some of these are the nominal value, the arithmetical average, and the median.

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[17] Grant, op. cit., p. 387.

The median is easier to work with than the average and, consequently, is used frequently even though it is subject to more variation. The median is used when competent people may not be available, or a high degree of statistical accuracy is not required.

The charts used differ widely in form from installation to installation. For some processes it is necessary to show both range and average variations. In some operations range is almost constant or is not important while there are considerable variations in the averages. In some cases the reverse is true. Tool wear, bearing play, and stock variation have different effects on different operations. For those cases where one characteristic is either nearly constant or is unimportant, only one characteristic need be shown.

The systems for computing the control limits are many and varied. Two of the more popular are: establish control limits in relation to process averages, and in relation to specifications. The method of computing the latter will be discussed and an example shown.

There are several advantages to using the specification limits rather than the process averages in establishing control limits.[18] The first of these is that this method usually saves time. When control limits are established using process averages, it is necessary to go through the lengthy process of recording data for each separate job. Control limits established by using specifications, on the other hand, eliminate much of this preliminary data taking. In those shops where a large number of machines are used and control procedures are necessary, or where a large

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[18] Feigenbaum, op. cit., p. 145.

variety of parts are made on these machines, the taking of preliminary data would be particularly expensive. In these shops, it is important to be able to establish control limits on a mass basis and to do so before production runs are made. This would be especially true where the production run is to be of short duration. The use of specifications makes it possible for relatively inexperienced office personnel to establish the control limits without use of individual sets of sample data. A parallel may be drawn between this method and the establishing of an incentive wage system when the number of jobs makes it impossible to make individual time studies.

Another advantage is that the ease in selling the plan to the men in the shop is facilitated when using specifications. Here is an item that is generally understood by all. There is a tendency to mistrust the taking of statistical information and its application is little understood.

In addition to saving time, another cost advantage is that more economical production runs may result. Control limits established, using process averages, cause the machine operator to set up his machine and to keep the average value at his average. On long production runs, where tool wear is an important factor, this procedure may prove uneconomical. Frequently in these cases up to one-half of the variation allowed by the specification will be discarded before the production run is begun.

In cases where the specification limits are wider than the control limits, advantage may be taken of setting up the job to take advantage of tool wear. This is done by setting up the job initially near the lower limit where direction of the tool wear is in the direction of the upper limit. This allows a longer run without retooling. This procedure may be inadvisable in machining of mating parts that are to be assembled. In this

case the designer assumed that the target would be the nominal value as specified on the drawing. The end result may be additional grinding or hand scraping at the time of fitting. However, the bulk of production is not of this variety; thus, establishing control limits as a result of specifications is usually both satisfactory and economical.

To demonstrate construction and use of a control chart, the following example is given:

(a) Specification limits rather than an average value will be used.

(b) Both range and average variation will be shown.

(c) The process in question is that of drop forging hammers to the nominal Rockwell hardness of 45.

(d) The tolerances allowed are plus or minus three.

(e) The readings and computation of values from sampling the production process are shown in the following table:

| Sample No. | First Hammer Tested | Second Hammer Tested | Third Hammer Tested | Fourth Hammer Tested | Sample Average | Sample Range |
|---|---|---|---|---|---|---|
| 1 | 46 | 45 | 45 | 44 | 45 | 2 |
| 2 | 46 | 47 | 46 | 46 | 46-1/4 | 1 |
| 3 | 45 | 45 | 46 | 46 | 45-1/2 | 1 |
| 4 | 46 | 45 | 45 | 45 | 45-3/4 | 1 |
| 5 | 46 | 47 | 45 | 47 | 46-1/4 | 2 |
| 6 | 46 | 46 | 47 | 47 | 46-1/2 | 1 |
| 7 | 46 | 48 | 47 | 45 | 46-1/2 | 3 |
| 8 | 45 | 46 | 44 | 45 | 45 | 2 |
| 9 | 45 | 46 | 46 | 45 | 45-1/2 | 1 |
| 10 | 46 | 47 | 46 | 45 | 46 | 2 |

The sum of the individual ranges gives a value of sixteen. The average range then is 1.6. This value is known as the process variability and is used in the construction of control limits.

Appendix IV contains a control chart for the above readings. In this case the sample averages are plotted rather than the individual readings. Some companies plot all these readings. The solid lines represent the specification limits. Thus, they are drawn at the values of 42 and 48, plus or minus three from the nominal value 45. The dotted lines are the upper and lower control limits and are 43.6 and 46.4, respectively. As stated previously, the values of the process variability are used to establish these. The process variability is added to the lower specification limit subtracted from the upper to get the control limits.

This direct method of computing the control limits is applicable when a sample size of four is used. For sample sizes greater or less than this value, an adjustment factor must be applied. The following are the factors to be applied for sample sizes other than four:

| Sample Size | Factor |
|---|---|
| 2 | 1.5 |
| 3 | 1.2 |
| 5,6,7 | 0.9 |
| 8,9,10 | 0.8 |

Appendix IV also contains the section of the control chart dealing with the range of variations. The purpose of this chart is to permit vigilance over the process in regard to range. The process may be centered perfectly as far as average is concerned, but may still be out of control. Excessive variability will result in an inferior product.

The range chart is used when the sample averages do not indicate that the process is in control.[19] This is arrived at only after a period of time. The range chart does not replace the sample average chart but merely supplements it with additional information about the production process. These range charts are used especially in industries where the equipment is worn or where the process is inherently one of variability. Examples of the latter are found in the plating processes, as well as in the micro- chemical biological productions of penicillin and yeast.

In preparing a range chart, it is essential to commence in the same manner as in the preparation of the sample averages control chart. Again the readings for the samples in the process are obtained. From these sample readings the process variability is determined as previously mentioned. This process variability is then multiplied by a factor to give the control limit. This factor is dependent on the sample size as in the sample averages chart as shown below:

| Sample Size | Control Limit Factor |
|---|---|
| 2 | 3.3 |
| 3 | 2.6 |
| 4 | 2.3 |
| 5 | 2.1 |
| 6 | 2.0 |
| 7 | 1.9 |
| 8 | 1,8 |
| 9,10 | 1.8 |
| 10,11,12,13,14,15 | 1.7 |

Thus, for the example shown previously, the process variability is 1.6 and the sample size is four. The factor is 2.3, giving a value of 3.68.

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[19] Enrick, *op. cit.*, p. 39.

Statistical computations have shown that by using these factors there is only a 0.5% or an erroneous indication of excessive variation occurring in the process when, in fact, none actually exists. This limit of variation is shown as a dotted line in Appendix IV.

The control chart is now constructed as shown in Appendix IV. This is but one example of a control chart, but the form is quite common where it is desirable to establish controls for both average and range. When the values are plotted, it is to be noted that from reading number five until reading number seven there was an indication that the process was trending towards the control limits, finally going over on readings six and seven. This could have been caused by such factors as the wrong heat treatment, excessive pressure on the forge, and many other variables. After sample seven, the process was stopped, the trouble analyzed and corrected, and finally the process was resumed with the indication that it is in control. The important thing here is to note that there was a definite trend established warning the operator that the process may be heading for difficulties.

# CHAPTER V

## APPLICATION OF QUALITY CONTROL

The general principles, the normal organizational methods, and the specific procedures of statistical quality control have been discussed. The problems and general applications in industry will now be considered.

In industrial applications the basic problem is whether the use of statistical quality control will be economic. For example, the precise measuring of rough forgings would be impractical. It then follows that it would be uneconomical to use exact statistical methods when merely rough checking of the process would suffice.

Frequently the quality program fails or is not received properly due to poor planning. Preliminary studies will usually provide a sound foundation upon which to build. There is nothing mysterious about the use of statistics. Industrial application of them depends on a thorough coverage of the technical and practical details. In addition, approved statistical techniques must also be followed for best results. Poor results will be experienced if such details as the provision for orderly reading and interpretation of results is omitted. Another common fault in planning and organizing a program is that of minimizing the importance of the human factor. Poorly trained people, in addition to their making mistakes, will be reluctant to accept the program. Results cannot be expected from the statistical gathering machines only. Gathering and grouping of these data

as well as the interpreting must be performed by the plant personnel. The complete cooperation of the entire work body is essential to get acceptance of the program and to take necessary corrective action when the statistics so indicate.

In the institution of any new program, it is far better to try a small segment of the operation for test purposes. This small portion of the whole should be selected in order to assure success from the outset. A complete and thorough job must be done here in order to lay the ground work for the complete installation. Here we take advantage of the psychological effect of commencing with a known and successful operation. It would be exceedingly disasterous to do a poor job on the initial attempt. This would have a tendency to build a barrier to the program that would require an even greater selling job than was originally planned or was necessary.

Statistical methods are more than charts, figures, and graphs. These groupings of material merely show data on the quality of the work, number of rejections and other related items. They, in fact, show the results of statistical work and are thus passive and one phase of the application of statistical methods. They, themselves, are not controls but rather aids to control. The use of charts does, however, point out some areas requiring attention in a clearer and more obvious manner than cold, bare figures. Statistical methods, on the other hand, serve as the basis for accepting or rejecting material, indicating the beginning of trouble in process control work, and providing the foundation for an alyzing and evaluating the data of all sampling techniques. Where statistical methods are neither necessary nor desirable, the use of charts and

graphs may give the information required in a manner suitable for easy use and understanding.

Whereas it sometimes is difficult to apply statistical methods to a manufacturing enterprise, adapting these techniques in the laboratory situation is usually easy. First of all these techniques have been used for a long period of time in the fields of testing and experimentation. The caliber of persons found in these fields frequently is superior to the average and, in addition, they are frequently familiar with the methods and the resulting advantages. The above does not hold true for the normal manufacturing establishments, no matter how progressive the management and how skilled the workers.

There are usually statistical applications for all types of manufacturing. The ideal situation is one in which there is high volume production of a repetitive nature. On the other hand, there are activities that manufacture but a single custom-built large unit. Here the adoption of statistical methods would probably serve no useful purpose and would not even be possible. Thus, the extent of the application depends to a large extent on the product and the process involved. Most processes are somewhere between the two extremes mentioned.

On occasion there are very simple manufacturing processes that do not require applied controls. The processes are those that have grown slowly over the years and are simple in themselves. Also, the products are such that the degree of quality is usually not important. For these operations little, if anything, of economic value would be gained by installation of a quality control setup. There are, however, only a very few of these industries producing modern products. If there is doubt whether to install

a new system or not, it is far better to study completely the present system of achieving quality than to rush into a new, untried, possibly uneconomical means of employing statistical analysis. Again, it is unwise to try to install the whole system at once; rather pick the most obvious application from the point of view of benefit as well as ease of installation.

The items to be considered for applications for statistical control in ones own operations are: (1) what types of product are being made; (2) what is the present quality record; and (3) what methods are used in the manufacturing process at the present time, or what is the proposed change that necessitates a change in the quality control method.[20]

Under the heading of what type of product is involved, we must ask: Just what are the standards of quality? To go further, are these standards the results of merely pleasing the customer or are they in the interests of safety? Would any lessening of standards be injurious to life and limb or to the company's reputation? The installation of new quality procedures, when standards are required because of safety, should be most carefully considered prior to installation. In applying the new procedures, it may be well to continue the old method until it has been proven beyond all doubt that the new method does produce the required quality.

In the area of the quality record of the product, it is well to determine if the quality can be improved by lowering the number of rejects and reworks. Fortunately, for most manufacturing, the answer is "yes".

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[20] Rutherford, op. cit., p. 178.

In only a few cases will the process itself approach 100 percent acceptable production. If quality control is to get the most economical production of a high quality competitive product, it must be installed when it is necessary to meet or beat the competition. This is also true when the customers demand a definite quality. Even when a company has complete coverage of the market, it cannot afford to disregard customer requests as to quality. Sooner or later a competitor will come along in the same field, or will supply an acceptable substitute.

The third area of operations to consider is that in the field of methods of manufacture. Here, the process approaches a production line operation; that is, the product is put through in large lots or, if run through a continuous process, the chances for improvements using statistical methods are very good. The records of the rejects and reworks for the various machines or lines--logical places to look for improvements--will be discussed later.

One of the first places to consider the application of statistical control methods is in receiving raw materials. This may be in the form of purchased finished goods to be used in assembly of the raw materials to be processed. If statistical methods are not used here (and they may not be necessary), the systems are usually of the following types: A complete inspection or screening of all items; a spot check conducted without any real statistical basis; and the use of standards arrived at as the result of experience alone. Usually improvements can be achieved if the present system is one of the first two. Here, again, it will depend on the actual material as previously mentioned in Chapter III. If material is being

accepted as a result of the latter method, no change to the statistical method should be made until further complete studies have been undertaken. Experience is a very sound factor in setting quality standards and any change should be approached cautiously. Frequently the trusted stock clerk does not know why he conducts his inspections as he does but, statistically, they may well be sound and the standards he uses well founded.

Another place where the application of statistical standards may be desirable is between manufacturing operations. The earlier in the process a defective part is detected, the more the actual savings. Savings may be realized in time, money, and future difficulties. This is especially true where the defective part is to be used in an internal assembly. However, the cost of doing the actual sampling must be balanced against the amount saved. Good cost accounting procedures and sound manufacturing techniques that in themselves are stable are essential.

The third of the more obvious applications of statistical control is in final inspection. It may be argued, on occasion, that screening of all finished products should be accomplished. This, because of the human error previously mentioned, does not give as good results as does a well-planned statistical method. The term "finished goods" here applies to those products that move from department to department and are thus finished goods as far as the first department is concerned. In this case it is frequently more economical to accept the possibility of a percent of defectives rather than inspect. In order to forestall arguments, the acceptance standards should be expressed in terms of the plan followed. Inspection carried out at the end of one department's work on a product may serve as a measure of that department's efficiency.

The theory of the application of statistical methods applied to process control was discussed in Chapter IV. These methods are of the preventive type and thus are most useful and effective controls. Control charts may apply to all phases of a specific manufacturing process, especially if the process is rather simple. On the other hand, if there are certain operations in the process that give most of the trouble, then it usually is more economical, as well as more effective, to apply the control to these particular points. As in any control tool, the savings and good will engendered must be balanced against the cost of the system.

The use of both process control and sampling for the same end product is common. These two methods of statistical quality control complement each other. The use of control charts on the process being fabricated or running through the line gives assurance as to the quality of the parts. Then the use of sampling gives the necessary verification of the results of the process control. Also, the use of control charts acts to warn of defective work and gives assurance of quality by using economical statistical controls. Sampling inspection then acts as an additional tool to check the results shown on the control chart showing that the process is in control and functioning satisfactorily.

Prior to applying these statistical methods, one must have a thorough understanding of the important factors involved. The installation should be a joint effort and the quality control personnel should acquaint the operators with the project from the beginning. The experienced men who are actually performing the work can lend invaluable assistance in devising practical methods. This utilization of experience saves valuable training time.

With each application of quality control, written instructions should be issued. These instructions should be as straightforward as possible leaving out nonessential technical and statistical terminology. When a procedure will be used for a considerable length of time, standard forms should be devised. These forms should be carefully designed to give complete information but to omit irrelevant data. Large quantities of forms should not be printed until the operation has been in existence for some time in order to obviate the necessity for making frequent changes in the forms.

The application of statistical control measures should always be under one group. When setting up the procedure, it is usually necessary for the trained group to do the actual selecting of the points of application, outline the process, and place the process in operation. Where the operational people on the floor are of high caliber and are interested in the project, much of the work in setting it up may be done by them. When this is the case, the statistical group then acts merely as the guide and overseer approving the methods and assisting in placing them in operation. In addition to the initial phase, it is necessary to monitor the procedure throughout its existence in order to assure that the system is in control.

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APPENDICES

## APPENDIX I

### SAMPLING TABLE[a]

| Lot Size | Sample Size | ACCEPTABLE QUALITY LEVEL (Percent Defective) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.1 | | 0.25 | | 0.50 | | 0.75 | | 1 | | 1.5 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | | 12 | |
| | | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R | A | R |
| 499 | 40 | | | | | | | | | 0 | 3 | 0 | 3 | 1 | 4 | 1 | 4 | 1 | 6 | 2 | 6 | 2 | 7 | 3 | 7 | 3 | 8 | 4 | 9 | 4 | 9 | 5 | 10 |
| | 50 | | | | | | | | | 1 | 3 | 1 | 4 | 1 | 4 | 2 | 5 | 2 | 6 | 3 | 7 | 3 | 8 | 4 | 9 | 4 | 9 | 5 | 10 | 5 | 11 | 6 | 9 |
| or | 60 | | | | | | | | | 1 | 3 | 1 | 4 | 2 | 5 | 2 | 6 | 3 | 7 | 4 | 8 | 4 | 9 | 5 | 10 | 5 | 11 | 7 | 12 | 7 | 13 | 9 | 14 |
| less | 70 | | | | | | | | | 1 | 4 | 2 | 4 | 2 | 5 | 3 | 6 | 4 | 8 | 5 | 9 | 5 | 9 | 6 | 10 | 7 | 11 | 8 | 13 | 8 | 13 | 10 | 16 |
| | 80 | | | | | | | | | 3 | 4 | 3 | 4 | 4 | 5 | 5 | 6 | 7 | 8 | 8 | 9 | 8 | 9 | 9 | 10 | 10 | 11 | 12 | 13 | 12 | 13 | 15 | 16 |
| | 40 | | | | | | | 0 | 2 | 0 | 3 | 0 | 3 | 0 | 4 | 1 | 5 | 1 | 5 | 1 | 6 | 1 | 7 | 2 | 8 | 2 | 8 | 2 | 9 | 4 | 10 | 4 | 11 |
| 500 | 60 | | | | | | | 0 | 3 | 0 | 3 | 1 | 4 | 1 | 5 | 2 | 6 | 2 | 7 | 3 | 8 | 3 | 9 | 4 | 10 | 5 | 11 | 5 | 11 | 6 | 12 | 7 | 14 |
| to | 80 | | | | | | | 1 | 3 | 1 | 4 | 1 | 5 | 1 | 6 | 3 | 7 | 3 | 8 | 5 | 10 | 5 | 11 | 6 | 12 | 7 | 13 | 8 | 14 | 9 | 15 | 10 | 17 |
| 799 | 100 | | | | | | | 1 | 4 | 2 | 4 | 2 | 5 | 2 | 6 | 4 | 8 | 5 | 9 | 6 | 11 | 7 | 13 | 8 | 14 | 9 | 16 | 10 | 17 | 12 | 18 | 13 | 21 |
| | 120 | | | | | | | 3 | 4 | 3 | 4 | 4 | 5 | 5 | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 13 | 13 | 14 | 15 | 16 | 16 | 17 | 18 | 19 | 20 | 21 |
| | 40 | | | | | * | 2 | * | 2 | * | 3 | 0 | 3 | 0 | 4 | 0 | 5 | 0 | 6 | 1 | 6 | 1 | 7 | 1 | 8 | 2 | 8 | 2 | 9 | 2 | 10 | 3 | 11 |
| 800 | 60 | | | | | 0 | 2 | 0 | 3 | 0 | 3 | 0 | 4 | 1 | 5 | 1 | 6 | 2 | 7 | 2 | 8 | 3 | 9 | 3 | 10 | 4 | 11 | 4 | 12 | 5 | 12 | 6 | 14 |
| to | 80 | | | | | 0 | 3 | 1 | 3 | 1 | 4 | 1 | 5 | 2 | 6 | 2 | 7 | 3 | 8 | 4 | 10 | 5 | 11 | 5 | 12 | 6 | 13 | 8 | 15 | 8 | 15 | 9 | 17 |
| 1299 | 100 | | | | | 0 | 3 | 1 | 3 | 1 | 4 | 1 | 5 | 2 | 6 | 3 | 8 | 5 | 10 | 5 | 11 | 7 | 13 | 7 | 14 | 9 | 15 | 10 | 17 | 10 | 18 | 12 | 21 |
| | 120 | | | | | 1 | 3 | 2 | 4 | 2 | 5 | 2 | 6 | 3 | 7 | 5 | 9 | 6 | 11 | 7 | 13 | 8 | 14 | 9 | 16 | 11 | 18 | 12 | 19 | 13 | 21 | 15 | 24 |
| | 160 | | | | | 3 | 4 | 4 | 5 | 4 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | 10 | 11 | 13 | 14 | 15 | 16 | 16 | 17 | 18 | 19 | 19 | 20 | 22 | 23 | 25 | 26 |
| | 50 | | | * | 2 | * | 2 | * | 3 | * | 3 | 0 | 4 | 0 | 4 | 0 | 5 | 0 | 6 | 1 | 7 | 1 | 8 | 2 | 9 | 2 | 10 | 3 | 10 | 3 | 11 | 3 | 13 |
| 1300 | 75 | | | 0 | 2 | 0 | 3 | 0 | 3 | 0 | 4 | 0 | 5 | 1 | 5 | 2 | 7 | 2 | 8 | 3 | 9 | 4 | 10 | 4 | 12 | 5 | 12 | 6 | 14 | 6 | 15 | 7 | 17 |
| to | 100 | | | 0 | 2 | 0 | 3 | 1 | 4 | 1 | 4 | 1 | 5 | 2 | 6 | 3 | 8 | 4 | 9 | 5 | 11 | 6 | 12 | 6 | 14 | 8 | 15 | 9 | 17 | 10 | 18 | 11 | 21 |
| | 125 | | | 1 | 3 | 1 | 3 | 1 | 4 | 2 | 5 | 2 | 6 | 3 | 7 | 4 | 9 | 5 | 11 | 7 | 13 | 8 | 15 | 9 | 16 | 11 | 18 | 12 | 20 | 13 | 21 | 15 | 25 |
| 3199 | 150 | | | 1 | 3 | 2 | 4 | 2 | 5 | 2 | 5 | 3 | 7 | 4 | 7 | 6 | 10 | 7 | 13 | 9 | 15 | 10 | 17 | 11 | 19 | 14 | 21 | 15 | 23 | 16 | 25 | 19 | 28 |
| | 200 | | | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 6 | 7 | 10 | 11 | 13 | 14 | 17 | 18 | 17 | 18 | 20 | 21 | 22 | 23 | 25 | 26 | 27 | 28 | 31 | 32 |
| | 50 | * | 2 | * | 2 | * | 2 | * | 3 | * | 3 | * | 4 | * | 5 | 0 | 6 | 0 | 7 | 0 | 8 | 1 | 9 | 1 | 10 | 1 | 11 | 2 | 11 | 2 | 12 | 3 | 14 |
| 3200 | 100 | * | 2 | * | 2 | 0 | 3 | 0 | 4 | 1 | 4 | 1 | 5 | 1 | 7 | 2 | 8 | 3 | 10 | 4 | 12 | 5 | 13 | 5 | 15 | 6 | 16 | 8 | 17 | 9 | 19 | 10 | 21 |
| to | 150 | 0 | 2 | 0 | 3 | 1 | 4 | 1 | 5 | 2 | 5 | 2 | 7 | 2 | 8 | 5 | 11 | 5 | 13 | 8 | 15 | 9 | 17 | 10 | 19 | 11 | 21 | 13 | 23 | 15 | 25 | 17 | 29 |
| 7999 | 200 | 0 | 2 | 1 | 3 | 2 | 4 | 2 | 5 | 3 | 6 | 3 | 8 | 4 | 10 | 7 | 13 | 8 | 16 | 12 | 19 | 13 | 21 | 15 | 24 | 16 | 26 | 19 | 29 | 21 | 31 | 25 | 36 |
| | 250 | 1 | 3 | 1 | 4 | 2 | 5 | 2 | 6 | 4 | 8 | 5 | 9 | 6 | 11 | 9 | 15 | 11 | 18 | 15 | 22 | 17 | 25 | 19 | 28 | 22 | 32 | 25 | 35 | 28 | 38 | 32 | 44 |
| | 300 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 15 | 16 | 17 | 18 | 22 | 23 | 25 | 26 | 29 | 30 | 32 | 33 | 36 | 37 | 39 | 40 | 45 | 46 |

APPENDIX I (Continued)

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8000 | 100 | * | 2 | * | 3 | * | 3 | * | 4 | 0 | 5 | 0 | 6 | 0 | 7 | 1 | 9 | 1 | 11 | 3 | 12 | 3 | 14 | 4 | 16 | 5 | 17 | 7 | 18 |
| | 150 | * | 2 | * | 3 | 0 | 4 | 0 | 5 | 1 | 6 | 2 | 7 | 2 | 9 | 3 | 11 | 4 | 14 | 6 | 16 | 7 | 17 | 9 | 20 | 10 | 22 | 12 | 24 |
| to | 200 | 0 | 2 | 0 | 3 | 0 | 5 | 1 | 6 | 2 | 7 | 3 | 8 | 3 | 10 | 6 | 13 | 7 | 17 | 10 | 19 | 11 | 22 | 13 | 24 | 16 | 27 | 18 | 30 |
| | 250 | 0 | 2 | 0 | 4 | 1 | 5 | 2 | 6 | 2 | 8 | 4 | 9 | 5 | 12 | 8 | 16 | 10 | 19 | 13 | 22 | 15 | 25 | 18 | 29 | 19 | 32 | 24 | 35 |
| 21999 | 300 | 0 | 3 | 1 | 4 | 2 | 6 | 2 | 7 | 3 | 8 | 5 | 11 | 6 | 13 | 10 | 18 | 12 | 22 | 16 | 26 | 19 | 29 | 22 | 33 | 24 | 37 | 29 | 41 |
| | 400 | 1 | 3 | 1 | 4 | 3 | 7 | 4 | 8 | 5 | 10 | 8 | 14 | 10 | 16 | 14 | 22 | 18 | 27 | 23 | 33 | 27 | 37 | 31 | 42 | 34 | 47 | 40 | 52 |
| | 500 | 2 | 3 | 3 | 4 | 6 | 7 | 7 | 8 | 9 | 10 | 13 | 14 | 16 | 17 | 22 | 23 | 28 | 29 | 34 | 35 | 40 | 41 | 45 | 46 | 50 | 51 | 58 | 59 |
| | 100 | * | 2 | * | 3 | * | 4 | * | 5 | * | 6 | * | 8 | 0 | 8 | 0 | 11 | 1 | 13 | 2 | 16 | 3 | 16 | | | | | | |
| 22000 | 200 | * | 3 | * | 4 | 0 | 5 | 0 | 6 | 1 | 7 | 1 | 10 | 3 | 11 | 3 | 15 | 6 | 18 | 8 | 20 | 10 | 24 | | | | | | |
| to | 300 | 0 | 3 | 0 | 4 | 1 | 6 | 1 | 8 | 2 | 9 | 3 | 12 | 5 | 14 | 7 | 19 | 11 | 23 | 14 | 26 | 17 | 31 | | | | | | |
| | 400 | 0 | 3 | 1 | 5 | 2 | 7 | 3 | 9 | 4 | 11 | 5 | 14 | 8 | 17 | 11 | 23 | 16 | 28 | 21 | 33 | 25 | 39 | | | | | | |
| 99999 | 600 | 1 | 4 | 2 | 6 | 3 | 9 | 5 | 11 | 7 | 14 | 10 | 18 | 14 | 23 | 19 | 31 | 27 | 38 | 34 | 46 | 39 | 53 | | | | | | |
| | 800 | 1 | 4 | 3 | 7 | 5 | 11 | 8 | 14 | 11 | 17 | 14 | 23 | 20 | 28 | 27 | 38 | 37 | 49 | 46 | 58 | 54 | 68 | | | | | | |
| | 1000 | 3 | 4 | 6 | 7 | 10 | 11 | 13 | 14 | 17 | 18 | 22 | 23 | 30 | 31 | 40 | 41 | 53 | 54 | 65 | 66 | 76 | 77 | | | | | | |
| | 200 | * | 3 | * | 5 | * | 7 | * | 8 | 0 | 9 | 0 | 13 | 2 | 13 | 2 | 18 | 4 | 20 | | | | | | | | | | |
| 100,000 | 400 | * | 4 | 0 | 6 | 0 | 8 | 0 | 10 | 3 | 12 | 3 | 17 | 7 | 18 | 9 | 25 | 14 | 30 | | | | | | | | | | |
| | 600 | 0 | 4 | 1 | 7 | 2 | 10 | 2 | 12 | 5 | 15 | 7 | 20 | 12 | 22 | 17 | 33 | 24 | 40 | | | | | | | | | | |
| and | 800 | 1 | 5 | 2 | 8 | 4 | 11 | 5 | 14 | 8 | 18 | 11 | 24 | 18 | 29 | 24 | 40 | 34 | 50 | | | | | | | | | | |
| up | 1000 | 1 | 5 | 3 | 9 | 5 | 13 | 7 | 17 | 11 | 21 | 15 | 28 | 23 | 35 | 32 | 47 | 44 | 60 | | | | | | | | | | |
| | 1200 | 2 | 5 | 3 | 9 | 7 | 15 | 9 | 19 | 14 | 24 | 19 | 32 | 28 | 40 | 39 | 55 | 54 | 70 | | | | | | | | | | |
| | 1600 | 4 | 5 | 8 | 9 | 14 | 15 | 19 | 20 | 24 | 25 | 33 | 34 | 45 | 46 | 61 | 62 | 86 | 87 | | | | | | | | | | |

A - Acceptance number
R - Rejection number
* - Acceptance cannot be made at this sample size

Use first sampling table below arrows
(Form larger lots, if necessary)
Use first sampling table above arrows

[a]Source: A. V. Feigenbaum, Quality Control, Principles, Practice, and Administration (New York: McGraw-Hill Book Company, Inc., 1951), Fig. 7.10, pp. 200-201.

## APPENDIX II

SINGLE SAMPLING LOT INSPECTION TABLE - BASED ON STATED VALUES OF "LOT TOLERANCE PERCENT DEFECTIVE" AND CONSUMER'S RISK = 0.10 a

n = Size of sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable defect number for sample.
AOQL = Average outgoing quality limit.

Lot Tolerance Percent Defective = 2.0%

| Process average % | 0-.02 | | | .03-.20 | | | .21-.40 | | | .41-.60 | | | .61-.80 | | | .81-1.00 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lot Size | n | c | AOQL % | n | c | AOQL % | n | c | AOQL % | n | c | AOQL % | n | c | AOQL % | n | c | AOQL % |
| 1-75 | All | 0 | 0 | All | 0 | 0 | All | 0 | 0 | All | 0 | 0 | All | 0 | 0 | All | 0 | 0 |
| 76-100 | 70 | 0 | .16 | 70 | 0 | .16 | 70 | 0 | .16 | 70 | 0 | .16 | 70 | 0 | .16 | 70 | 0 | .16 |
| 101-200 | 85 | 0 | .25 | 85 | 0 | .25 | 85 | 0 | .25 | 85 | 0 | .25 | 85 | 0 | .25 | 85 | 0 | .25 |
| 201-300 | 95 | 0 | .26 | 95 | 0 | .26 | 95 | 0 | .26 | 95 | 0 | .26 | 95 | 0 | .26 | 95 | 0 | .26 |
| 301-400 | 100 | 0 | .28 | 100 | 0 | .28 | 100 | 0 | .28 | 160 | 1 | .32 | 160 | 1 | .32 | 160 | 1 | .32 |
| 401-500 | 105 | 0 | .28 | 105 | 0 | .28 | 105 | 0 | .28 | 165 | 1 | .34 | 165 | 1 | .34 | 165 | 1 | .34 |
| 501-600 | 105 | 0 | .29 | 105 | 0 | .29 | 175 | 1 | .34 | 175 | 1 | .34 | 175 | 1 | .34 | 235 | 2 | .36 |
| 601-800 | 110 | 0 | .29 | 110 | 0 | .29 | 180 | 1 | .36 | 240 | 2 | .40 | 240 | 2 | .40 | 300 | 3 | .41 |
| 801-1,000 | 115 | 0 | .28 | 115 | 0 | .28 | 185 | 1 | .37 | 245 | 2 | .42 | 305 | 3 | .44 | 305 | 3 | .44 |
| 1,001-2,000 | 115 | 0 | .30 | 190 | 1 | .40 | 255 | 2 | .47 | 325 | 3 | .50 | 380 | 4 | .54 | 440 | 5 | .56 |
| 2,001-3,000 | 115 | 0 | .31 | 190 | 1 | .41 | 260 | 2 | .48 | 385 | 4 | .58 | 450 | 5 | .60 | 565 | 7 | .64 |
| 3,001-4,000 | 115 | 0 | .31 | 195 | 1 | .41 | 330 | 3 | .54 | 450 | 5 | .63 | 510 | 6 | .65 | 690 | 9 | .70 |
| 4,001-5,000 | 195 | 1 | .41 | 260 | 2 | .50 | 335 | 3 | .54 | 455 | 5 | .63 | 575 | 7 | .69 | 750 | 10 | .74 |
| 5,001-7,000 | 195 | 1 | .42 | 265 | 2 | .50 | 335 | 3 | .55 | 515 | 6 | .69 | 640 | 8 | .73 | 870 | 12 | .80 |
| 7,001-10,000 | 195 | 1 | .42 | 265 | 2 | .50 | 395 | 4 | .62 | 520 | 6 | .69 | 760 | 10 | .79 | 1050 | 15 | .86 |
| 10,001-20,000 | 200 | 1 | .42 | 265 | 2 | .51 | 460 | 5 | .67 | 650 | 8 | .77 | 885 | 12 | .86 | 1230 | 18 | .94 |
| 20,001-50,000 | 200 | 1 | .42 | 335 | 3 | .58 | 520 | 6 | .73 | 710 | 9 | .81 | 1060 | 15 | .93 | 1520 | 23 | 1.0 |
| 50,001-100,000 | 200 | 1 | .42 | 335 | 3 | .58 | 585 | 7 | .76 | 770 | 10 | .84 | 1180 | 17 | .97 | 1690 | 26 | 1.1 |

[a] Source: John G. Rutherford, Quality Control in Industry - Methods and Systems (New York: Pitman Publishing Corporation, 1948), Table 9, pp. 190-191.

## APPENDIX III

### SINGLE SAMPLING LOT INSPECTION TABLE - BASED ON STATED VALUES OF "AVERAGE OUTGOING QUALITY LIMIT"[a]

n = Size of sample; entry of "All" indicates that each piece in lot is to be inspected.
c = Allowable defect number for sample.
$P_t$ = Lot tolerance percent defective corresponding to a consumer's risk ($P_c$) = 0.10.

Average Outgoing Quality Limit = 0.1%

| Process average % | 0-.002 | | | .003-.020 | | | .021-.040 | | | .041-.060 | | | .061-.080 | | | .081-.100 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lot size | n | c | $P_t$% | n | c | $P_t$% | n | c | $P_t$% | n | c | $P_t$% | n | c | $P_t$% | n | c | $P_t$% |
| 1-75 | All | 0 | - | All | 0 | - | All | 0 | - | All | 0 | - | All | 0 | - | All | 0 | - |
| 76-95 | 75 | 0 | 1.5 | 75 | 0 | 1.5 | 75 | 0 | 1.5 | 75 | 0 | 1.5 | 75 | 0 | 1.5 | 75 | 0 | 1.5 |
| 96-130 | 95 | 0 | 1.4 | 95 | 0 | 1.4 | 95 | 0 | 1.4 | 95 | 0 | 1.4 | 95 | 0 | 1.4 | 95 | 0 | 1.4 |
| 131-200 | 130 | 0 | 1.2 | 130 | 0 | 1.2 | 130 | 0 | 1.2 | 130 | 0 | 1.2 | 130 | 0 | 1.2 | 130 | 0 | 1.2 |
| 201-300 | 165 | 0 | 1.1 | 165 | 0 | 1.1 | 165 | 0 | 1.1 | 165 | 0 | 1.1 | 165 | 0 | 1.1 | 165 | 0 | 1.1 |
| 301-400 | 190 | 0 | .96 | 190 | 0 | .96 | 190 | 0 | .96 | 190 | 0 | .96 | 190 | 0 | .96 | 190 | 0 | .96 |
| 401-500 | 210 | 0 | .91 | 210 | 0 | .91 | 210 | 0 | .91 | 210 | 0 | .91 | 210 | 0 | .91 | 210 | 0 | .91 |
| 501-600 | 230 | 0 | .86 | 230 | 0 | .86 | 230 | 0 | .86 | 230 | 0 | .86 | 230 | 0 | .86 | 230 | 0 | .86 |
| 601-800 | 250 | 0 | .81 | 250 | 0 | .81 | 250 | 0 | .81 | 250 | 0 | .81 | 250 | 0 | .81 | 250 | 0 | .81 |
| 801-1,000 | 270 | 0 | .76 | 270 | 0 | .76 | 270 | 0 | .76 | 270 | 0 | .76 | 270 | 0 | .76 | 270 | 0 | .76 |
| 1,001-2,000 | 310 | 0 | .71 | 310 | 0 | .71 | 310 | 0 | .71 | 310 | 0 | .71 | 310 | 0 | .71 | 310 | 0 | .71 |
| 2,001-3,000 | 330 | 0 | .67 | 330 | 0 | .67 | 330 | 0 | .67 | 330 | 0 | .67 | 330 | 0 | .67 | 655 | 1 | .64 |
| 3,001-4,000 | 340 | 0 | .64 | 340 | 0 | .64 | 340 | 0 | .64 | 695 | 1 | .59 | 695 | 1 | .59 | 695 | 1 | .59 |
| 4,001-5,000 | 345 | 0 | .62 | 345 | 0 | .62 | 345 | 0 | .62 | 720 | 1 | .54 | 720 | 1 | .54 | 720 | 1 | .54 |
| 5,001-7,000 | 350 | 0 | .61 | 350 | 0 | .61 | 750 | 1 | .51 | 750 | 1 | .51 | 750 | 1 | .51 | 750 | 1 | .51 |
| 7,001-10,000 | 355 | 0 | .60 | 355 | 0 | .60 | 775 | 1 | .49 | 775 | 1 | .49 | 775 | 1 | .49 | 1210 | 2 | .44 |
| 10,001-20,000 | 360 | 0 | .59 | 810 | 1 | .48 | 810 | 1 | .48 | 1280 | 2 | .42 | 1280 | 2 | .42 | 1770 | 3 | .38 |
| 20,001-50,000 | 365 | 0 | .58 | 830 | 1 | .47 | 1330 | 2 | .41 | 1870 | 3 | .37 | 2420 | 4 | .34 | 2980 | 5 | .33 |
| 50,001-100,000 | 365 | 0 | .58 | 835 | 1 | .46 | 1350 | 2 | .40 | 2480 | 4 | .33 | 3070 | 5 | .32 | 4270 | 7 | .30 |

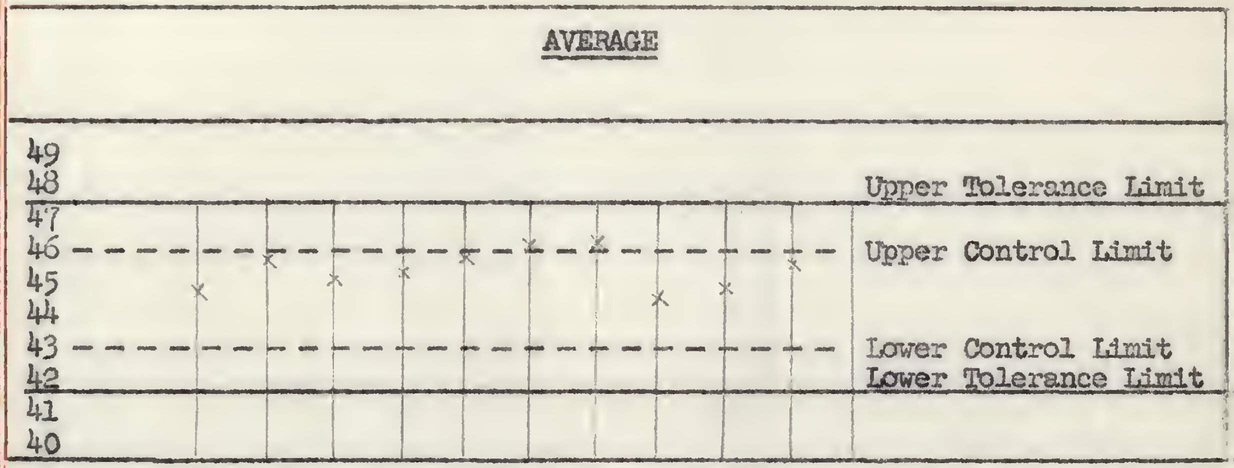
[a]Source: John G. Rutherford, Quality Control in Industry - Methods and Systems (New York: Pitman Publishing Corporation, 1948), Table 10, p. 192.

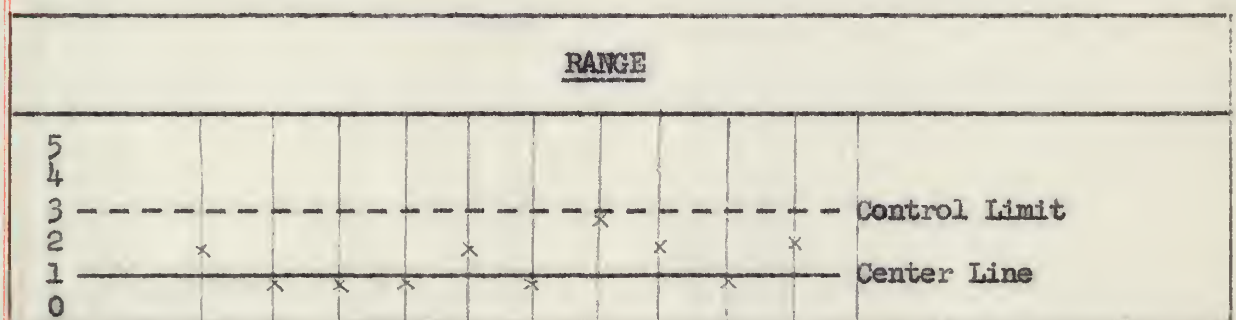
## APPENDIX IV

QUALITY CONTROL CHART NUMBER

PRODUCT Drop Forged Hammers PERIOD ________

INSPECTION OR TEST Hardness SPECIFICATIONS 45 ± 3 SAMPLE SIZE 4




| SAMPLE | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measurement | 1 | 46 | 46 | 45 | 46 | 46 | 46 | 46 | 45 | 45 | 46 | | | | |
| | 2 | 45 | 47 | 45 | 45 | 47 | 46 | 48 | 46 | 46 | 47 | | | | |
| | 3 | 45 | 46 | 46 | 45 | 45 | 47 | 47 | 44 | 46 | 46 | | | | |
| | 4 | 44 | 46 | 46 | 45 | 47 | 45 | 45 | 45 | 45 | 45 | | | | |
| $\overline{X}$[1] | | 45 | 46.2 | 45.5 | 45.8 | 46.2 | 46.5 | 46.5 | 45 | 45.5 | 46 | | | | |
| R | | 2 | 1 | 1 | 1 | 2 | 1 | 3 | 2 | 1 | 2 | | | | |

[1]Note: The term $\overline{X}$ refers to the Sample Average