

Chapter III. Controls

1. Types of Controls

In our previous discussions we have given a great deal of attention to the subject of industrial organization. We have come to realize that the organization is a tool – an implement – used to put into effect the aims and ambitions, the policies and objectives of the owners and the managers of the enterprise. But, an organization, like a tool, cannot do work by itself. The tool must be directed, guided, governed, influenced and even restrained. In other words, the tool and the organization must be controlled.

In the administrative and management sense, the usual concept of the word ‘control’ is enlarged by adding to it the ideas of determining the objectives to be worked for, the programs and plans to be adopted, the leadership to be applied, and the unifying of all that is done to achieve the pre-planned results.

Inasmuch as control is a human activity made effective by the impact of the human will of those in authority and who have responsibility, it then follows that there are possible various types and kinds of controls.

Basically, we may say that there are two kinds of controls, man control and fact control.

Man, or personal control, is the autocratic, arbitrary, opinionated type of rule which is often found in dictatorships. Fact control or organization control is on the other hand, the democratic system of management which is becoming the universal system of management.

The famous industrial engineer, Henry L. Cantt, was very definite in his abhorrence of man control. He once said, “Actions based on opinions will lose in competition with actions based on facts”. And on another occasion he said, “We have no right morally to decide as a matter of opinion that which can be decided as a matter of fact”.

To place these two types of controls in contrast:

Man control is:

a. Personal

May be subject to
Bias
Prejudice
Whim

b. Limited

Based on one man's
Attitude
Experience
Knowledge

c. Arbitrary

Decisions may be
Autocratic
Dictatorial
Opinionated

Fact control is:

a. Impersonal

b. Common Agreement

Facts are concurred in all
concerned

c. Self-determining

"Facts speak for themselves"
"Facts are always triumphant over
opinions"

A fact is something that has happened, it is a statement of truth, it is something that is so. Technical engineering is based on such facts, the truths of science. The emphasis we put on fact control in industrial management is then in part, merely the application of sound engineering principles.

But that does not mean that a manager must be an engineer in order to be a good manager. Rather, what is required is what we call the engineer's type of mind, the scientific approach to thinking, clear, logical, factual thinking.

Ideally, the engineer and the scientist have this type of mind as a result of their specialized education and training. But also, the lawyer, the financier, and the businessmen develop this type of thinking not only because of their training, but also because of the nature of the problems with which they deal. The problems of finance, of personnel, of meeting the demands of the customer, and all the hundreds of situations which daily face the business manager are just as complex, as mysterious, and as vexing as are the experiments of the chemist, the investigations of the physicist, and the mathematical calculations of the engineer. But the methods that these scientifically trained persons use so successfully in attacking their problems can equally as well be used in attacking and solving the problems of management.

Their methods are first of all founded upon dealing with facts, upon separating personal opinions and wishes from facts, upon the complete analysis of problems in order to get all the facts, and finally, upon the making of decisions based only on facts.

But one of the biggest problems in industrial management is to get all the facts that affect a problem and then to determine what their inter-relation is. In this connection, let me tell you a story that is an example of bad fact control.

A young industrial engineer was once hired to work in a lumber mill. A few days after he started on his job he was watching the logs being brought to the mill on railroad cars. The logs would be dumped off the cars and they rolled down the embankment into a pond in front of the mill. Some of the logs floated on the water and some sank to the bottom of the pond. Being a bright young engineer, he set to work with his pencil and paper and calculated the ratio of logs that floated to those that sank. He then found out how many logs were sawed each month in the mill and then went to his boss with a startling recommendation that the company stop cutting down the trees in the forest for three months. His figures showed, he said, that there were enough logs which had sunk to the bottom of the pond to supply the saw mill for the next three months.

The engineer's calculations were probably correct but where he made his mistake was assuming that the logs which had sunk to the bottom of the pond were still there. Actually they were not, because as a standard operating procedure every month all the sunken logs were dragged out of the pond and brought to the mill.

This engineer dealt with facts and came to a decision based on those facts. But his decision was a ridiculous and wrong one because he did not deal with all of the facts of the problem.

Modern democratic business management leaves no doubt that the only effective control is fact control, and in that sense, we call modern business management *scientific* management. But, applied to the business enterprise, what forms and shapes does this fact control take in constituting what we have called the Organization for Control?

First of all, there is Administrative and Management control that we may also call Executive Control. This is the generalized control of the whole enterprise.

Then, there are the controls on operations which are made effective by the issuance of standard practise instructions.

In addition, there is:

- Production Control
- Material Control
 - Purchasing Control
 - Inventory Control
 - Stock Control
- Quality Control
- Cost Control
- Personnel Control.

Each of these controls is based, not on opinions or wishes and desires, but rather on actual, factual, provable data, information and facts.

a. Executive Control

Figure 112, which shows the relation of policies and organization indicates that the element of coordination is one of the major components of the Organization for Control. From our discussions of leadership and the application of the principles of organization, we have come to realize that coordination is to be practiced not only by the president and the general manager of a company, but by each and every supervisor in the entire organization.

Previously, we also talked about analyzing the company into its elemental functions and activities. Then, these elements, we said, are grouped together according to their similarity of nature or their direct relationship. But again, the grouping of functions alone will not guarantee that the operations of the company will be successful. What is required is *active* coordination by the executives of the company of every function of the enterprise. This, then, is what is meant by Executive Control.

In order to make the organization work smoothly all of the separate activities of the company must be timed in their operation so that each one is performed in its proper sequence according to an established schedule. The process of timing the activities and reuniting the subdivided work in an industrial organization is called coordination. Coordination means to combine separate and individual activity into a single consistent and harmonious action.

The highest form of coordination in an industrial enterprise is the conscious acceptance by the entire group of the objective and policies established by the management and a conscious agreement to the various forms of discipline (guidance) which are necessary to achieve the purposes of the enterprise. This type of coordination is possible only in a carefully selected, well-trained organization where employee morale is maintained at a high level.

This type of coordination is possible too, only in an organization which makes effective use of well-planned written procedural instructions which tell what is to be done, where, how, when, and why. To the same extent, coordination also depends for its success upon a steady flow returning to management of reports, data, and information which tell of the results which are accomplished by the people who carried out the orders of the company's leaders.

In other words, coordination is made effective by the *active* functioning of a management system.

On the administrative side, this management system is made up of (1) Administrative policies, (2) Organization charts, and (3) Organization procedures, which describe the methods to be followed in working toward the company objectives.

In addition to these things, there are certain reports upon which the Administrative system depends for its decisions and evaluations of the enterprise. There are general reports that are the Balance Sheet (Fig. 511), the Profit and Loss Statement (Fig. 312), and the Manufacturing Statement (Fig. 313).

And there are also operations reports that, for budget comparison purposes, included information of:

- Production
- Labor
- Expense
- Plant and Equipment

and for the evaluation of periodic (weekly or monthly) operations results:

- Plant Activity
- Production, labor, and overhead
- Idle time
- Production Cost
- Labor Cost
- Manufacturing Expense
- Estimated against Actual Costs

These latter reports usually come from the department chief level of the company where they have been summarized and combined before being passed on to the higher levels of management. In their original form they would be too detailed and take up too much time in their reading of the higher executive people.

The Balance Sheet is, of course, a concise presentation of the financial condition of the company. The Profit and Loss Statement is a summarization of the general income account of the company and conveys a general picture of operations in the periodic intervals during the times in between the issuance of Balance Sheets.

The Manufacturing Statement is a periodic presentation of the cost of the manufactured products sold.

Budget comparisons (Fig. 314) are needed frequently in industrial organizations in order to check budget allowances of money against actual operating performances, and in this way to control the work being done by its indication of where investigations of operations should be made.

On the management side of the business, there is a system of reports which is often used to clearly indicate the situation in the operations of the factory departments and shops. A typical list of these reports which are the bases for the summarized and combined reports mentioned earlier, would include the following:

Raw Materials	Worker's Efficiency
Supplies	Spoilage
Small Tools	Idle Machines (Fig. 316)
Direct Labor	Departmental Costs
Expense Labor	Inspection and Quality Reports
Controllable Expense	Stores and Materials

A very important and necessary part of establishing a system of reports is planning the routing of the reports to the various people who must handle them. Paper work, although necessary is burdensome and therefore it should be handled in a highly efficient manner. In its worst degree paper work is called red tape. But, a well-planned distribution system will enhance operations and prevent things from becoming tied up in red tape. Figure 317 is a chart that was designed by one company to establish the method of handling purchase orders. It shows operations, routings, and activities to be performed. Similar charts should be drawn up for the handling of every report form and paper used by your companies.

Reports, just like policies, are different for different companies. But there are certain essentials which are common to all reports. These are:

- (1) *A report must be prepared to meet the specific needs of a particular executive.*
For example, a production supervisor must have reported to him manufacturing information and data. Sales information included in a manufacturing report might not be useful to the production chief.
- (2) *A report should cover a period adapted to the needs of the executive.*
A president would find daily attendance reports too trivial for his needs, but the payroll clerk would require them for his purposes.
- (3) *A report should have a degree of permanency depending upon the executive's responsibility.*
The balance sheet for example must be in a permanent form because of the president's responsibility for the entire company.
- (4) *A report must present its information in simple easy-to-understand forms.*
- (5) *Reports must be prompt, accurate, and presented with sincerity.*
- (6) *Reports must be capable of being compared with previous reports.*
- (7) *Reports should clearly indicate variations in results.*
- (8) *Reports should be interpreted to show precisely any action that may be required.*
- (9) *A report should indicate the individual responsible for any indicated action.*

We have spent a considerable amount of time talking about report and report forms because they are an important part of the management system and are a means of conveying information from the operating centers of the company to the management levels of the company. By the use of reports, executive decisions and instructions are formulated, and executive control is exercised.

Previously we mentioned operations control and the standard practice instructions that are used to effectuate it. Figure 318 is one example of an instruction card. Other types of forms are also

used, some being charts, such as flow charts and the chart shown in Fig. 317, and still others are in a detailed written form.

Procedural instructions which affect the operations of the factory are generally written by the production engineering group or by some particular operating group for its own guidance. Standards for the operations of the office and clerical groups (i.e., Accounting, Purchasing, *etc.*) are usually written by the comptroller or the Accounting Department, although here again a particular group may design its own procedures for the control of its own operations. The form of the report to be used and who establishes it will generally be influenced by the nature of the particular problem and the assignment by management of this responsibility.

We have discussed two of the general controls used in the business enterprise; Executive control and operations control. In addition to these however, we have several specific controls which we will now discuss only briefly since a more complete treatment of them will be made in a later section of this course.

b. Production Control

Production Control comprises the planning, routing, scheduling, dispatching, and inspection functions in the productive process. These activities are organized in such a way that in spite of how the movements of materials, the performance of machines and the operations of labor may be subdivided, they are nevertheless directed and coordinated in regards to quantity, quality, time, and place.

Planning, that is, looking ahead to every step to be taken in the entire process of manufacturing, is the primary function of production control.

Although a great deal could and should be said of this subject, for the present we will leave it and return to it in a later part of this course.

c. Materials Control

Materials Control is another in the series of controls vital to the operation of the business. Here we find included Purchasing Control which is important to the welfare of the company for three main reasons:

First, purchasing is a primary function inasmuch as the cost of purchased materials will largely affect the final sales price of the finished product.

Secondly, efficient manufacturing requires the proper materials at the proper time. But, at the same time, a company cannot afford to invest a lot of its money in stock piles of materials. Thus purchasing must be wisely done making sure that not too much money is spent on materials and yet also making sure that enough materials are on hand so that the factory's work will not be impeded.

Thirdly, due to its outside contacts, the purchasing group can often advise on new materials which can be substituted for regularly used materials, changes in market trends, relations with other business firms, and possible new products which might be added to the company's line of sales products.

Inventory Control is another aspect of Material Control. In one sense, the accumulation of materials, parts, and stock in the company's warehouse may be thought of as money deposited in a bank. The company's money has been invested in materials that, when processed by manufacturing operations, will bring larger money returns.

In another sense, the materials in the warehouse can be thought of as service to the manufacturing processes, designed and organized to promote efficiency and minimize manufacturing costs.

In any event, Inventory Control must:

- (1) Maintain raw materials in sufficient quantities and qualities to meet the needs of the manufacturing activities.
- (2) Keep the investment in materials, supplies and finished product at a minimum.
- (3) Issue stores only upon proper authorization and at times, places and in the manner established by the company.
- (4) Maintain inventory records which will show at a glance the value and quantity of materials in storage, the deliveries of materials from the warehouse, and the point at which materials should be automatically requisitioned from the Purchasing Department.
- (5) Price all materials sent to the Manufacturing Department in order to help the Accounting Department begin an actual manufacturing cost record on the particular product being produced.

The Control of Warehousing (keeping stores) is another part of Materials control. This activity would include the receiving, putting away in proper storage, issuing, and generally having in physical possession, the materials used by the company.

d. Quality Control

Quality Control, including the function of inspection, is principally concerned with the attainment of standards of goodness by the company's products. It is planned to speak about Quality Control at greater length later on so we will pass over this subject now with no further comment.

e. Cost Control

Cost Control is often defined as the ability to provide for the consumption of materials, application of labor, and distribution of expenses, all on a sound basis. The purposes of this control are:

- (1) To determine actual costs
- (2) To control expenditures
- (3) To form a basis for pricing products
- (4) To provide a basis for operating policy formulation.

But more will be said about this subject too in a later section of this course.

f. Personnel Control

In Personnel Control we have a variety of functions all of which are aimed at providing for the company a body of employees possessing all the qualities necessary for the achievement of the company's goals. Therefore, within this control there are provisions for labor-management negotiations, employee welfare, benefit and training activities, job evaluations, wage setting, and other activities related to the attainment of high employee morale.

2. Prerequisite to the establishment of controls

The controls that a company uses, the effectiveness of the controls, and the degree to which work is speeded up and improved, are considerations of prime importance to the business managers. To a great degree, the success of a company depends directly upon the effectiveness of its controls.

However, controls must be developed and conditions made favorable in the company for the application and use of controls. None of the controls we have spoken of can be installed in the company in the way a telephone is installed or a desk moved into a room. You cannot one day be without controls and then suddenly have them the next day.

They are not of such a nature. While it is true that the results of controls are tangibles, the controls themselves are made up of both tangible and intangible qualities.

Therefore, I say, controls must be developed. And, in order to have one, it must have been preceded by another. And that, in turn, may have required that some other control must have been first established.

Thus, when we speak of production control, and quality control, and cost control and the others, you may ask what must I do in order to have these controls in my company. What are the prerequisites of these controls?

My answer to that must be: controls.

In other words, before any success can be expected from these major controls, there must be first of all established in the company such things as these:

- (1) A workable structural form of organization must be provided for the company.
- (2) The scope of the functions of every department of the company must be defined and must have been derived from the stated objectives of the enterprise.
- (3) Every person's job in the company must be clearly specified in writing.
- (4) The work of every person in the company must be capable of being supervised.

- (5) Working instructions must be standardized, written, and the employees trained in their use.
- (6) Every employee must be held accountable for carrying out his duties and responsibilities.
- (7) The work of every person must be in accordance with plans and schedules and must come in the proper sequence of operations.

In the final analysis then there must first of all be the stated objectives of the company — the goals that are desired to be attained.

From these, there must be established the organization so designed and so integrated as to make possible the actuality of attaining the stated goals.

Then, and only then, can the major controls be established in and upon the organization.

3. Application of Organization Controls

In all of our discussions we repeatedly stress coordination and previously we have reviewed the many and varied things that are necessary to insure proper and adequate control of the organization: such items as organization structure; job definition and delegation of responsibility and authority; defined policies and standardized practices, methods and procedures; reports, analyses, *etc.*

Now how can we best approach the problem of application of organization controls? We must make sure, among other things, that each management person carries his proportionate share of the burden. At the same time, we must avoid overlapping and duplication of functions, that will cause friction, confusion and working at cross purposes. Further, we must make certain that no essential function, operation or control is missing.

To insure these things that, grouped together, represent the function of organization control, we will discuss step by step the phases of this function. These are:

- a. Organization Planning
- b. Organization Charts
- c. Job Specifications
- d. Control Specifications
- e. Organization Manual
- f. Organization Changes – Initiation and Approval

Before proceeding with our analysis there is a question which logically arises. Who is going to do these things? Whose responsibilities are they? In some instances, of course, you have staff groups who handle some of these phases. In other cases you depend on one or more individuals in different branches of the company whose experience is helpful in shaping your course of action.

We believe that wherever possible this work should be consolidated under a responsible head in the general administrative zone of management. It should be made up of a small group of specialists who have had wide experience and familiarity with the different major functions of the company such as finance, engineering, manufacturing and marketing. This group should be given the advantage of education in this present industrial management course.

The importance and value of such a group cannot be over-emphasized. On the effectiveness of such a group depends the determination of needs; formulation of plans; obtaining necessary acceptance, cooperation and support; and the coordinated effectiveness of application to assure company operation with a minimum of organization (manpower).

Following is a detail analyses of each phase of this function:

a. *Organization Planning*

As we have stated previously, it is not usually practical to develop and put into effect at once an ultimate plan of organization that will be ideal for your company. There are too many problems of personnel availability, and other factors to make this possible. However, by applying the scientific approach to this problem, it is possible to set up such a plan as an *objective*. By doing this, your selection and training of personnel, and the step-by-step introduction of organization changes as these can be justified will be aimed at the ultimate reaching of a definite goal. Without such a goal, changes are meaningless. *Again we stress that "one man" plans are not good.* Get the opinions and viewpoints and ideas of as many management levels as possible. Do not overlook the value of opinions among your lower supervisory levels. *These are the people who can make your plans work or fail.*

Here are the essentials to comprehensive organization planning:

- (1) *Keep familiar* with the best thought and practice along industrial organization lines. This can be done only through constant study and review of literature on the subject and the exchange of ideas with other concerns.
- (2) Question and test the adequacy and soundness of every phase of the organization plan from a completely objective point of view. As pointed out in our study of organization structure this involves, first, the careful analysis of your present organization: the relationships, charts, functions, responsibilities and authority. And, second, it involves the consideration of ultimate objectives without being influenced by precedent or tradition, or present structure and personnel.
- (3) Block out in chart from the ultimate (ideal) plan that will meet the objective of an effective "management tool". Included are the classification of the zones or levels of management as to types of duties, responsibilities and authority as well as the agencies or primary divisions of the company that are to handle them. This means that these general functions are logical, distinct, and designed for most efficient and economical management application. This was discussed in some detail in the study of organization structure.

- (4) Design and write the specifications for each level of management and each general function (such as finance, engineering, *etc.*), also, each key job or group of similar jobs. Define and clarify objectives, functions, responsibilities, limits of authority, and relationships with other parts of the organization.
- (5) Compare the ultimate (ideal) plan with the present plan. Analyze and classify the changes needed to achieve the ultimate plan. Determine by careful analysis and study what steps can be taken at once, and initiate these changes. Determine what must be done in the way of personnel changes, selection and training, in order to take subsequent steps and establish a program for proper measurement of available people as to qualifications and ability. Follow this with a planned training program to educate present personnel and those selected in the future for key jobs.

b. Organization Charts

This has already been indicated as an essential of organization planning. In our previous study of organization structure we analyzed a typical Japanese company structure (present) as well as representative American company structures. The principles of analysis which were used are an excellent guide for practical application.

A good check of whether you have the *soundest* and *simplest* organization plan is whether it is easily and simply charted. If you have a plan that cannot be readily charted and which does not easily show organizational relationships it is apt to be illogical and confusing to those working under it. Organization charts should be available to, and understood by, all management personnel. They are the first step in organization control.

c. Job Specifications

We have discussed this phase of organization structure repeatedly in every step of our course. Job specifications, to be of value, must be workable. That is, they must not only cover what is expected in theory but they must also be capable of practical application. They must be clear and easily understood. *Here again, the experience, views, and opinions of the management people actually doing the job are invaluable.*

Preparation of Job Specifications is the second step in the application of organization controls. Only after clarification of the requirements of each management level, of the definition of the duties of each function, and of the responsibilities and authority of each management job, can each job holder know his proper place and part in the management function and concentrate on achieving his own objectives.

Similarly, the individual management job holder cannot be properly measured and his accomplishments evaluated by his superiors unless his job, its duties, responsibilities, and authority are clearly defined.

To define each job and write each job specification the following should be included:

- (1) Basic Functions, or duties

- (2) Scope – the general extent of responsibility
- (3) Limits of authority
- (4) Relationships with other organization units

Usually, as a control function, general objectives will be indicated which will serve as a measure of accomplishment in doing the job. An example of a job specification for one of the higher level management employees is shown on data sheet # III – 3.1 (discuss this Job Specification).

The first logical step in the preparation of management Job Specifications is to determine the present practice. Obtain from each supervisory level and type of management job the definition of what is *now understood to be their job by the people involved*.

This information will serve as the basis for analysis both of the adequacy of present understanding and also the weaknesses which must be corrected. In many cases you will have to request your people to write out their job functions because nothing is written as a guide. We also caution *against* having them refer to old job descriptions. Too frequently it will be found that these do not represent what is actually being done or should be done. Further, if you do have old job descriptions, this writing out of job functions by the management employees without reference to anything already written will provide a check as to how well *you have trained them to observe and follow established procedures*.

d. *Control Specifications*

As job descriptions are developed, wherein responsibilities and delegations of authority are required, it is evident that some means of control is necessary over activities with which each position is concerned. Such controls are essential on a company-wide basis and should indicate the respective functions, responsibilities and relationships of the different agencies having part in the control of any specific activity. These controls may be prepared in the form of “Control Specifications”, and will cover such items as:

- (1) Plan of Organization
- (2) Capital Expenditures
- (3) Operating
- (4) Manpower and Payroll
- (5) Wages and Salaries
- (6) Promotion and Transfer
- (7) Hiring and Dismissal
- (8) Line of Products

It will be noted that these items are applicable to problems of all departments or units of the company. Data sheet # III – 3.2 illustrates a control specification over capital expenditures.

Note: In the analysis of this control specification, point out that such a specification provides the basis for designation of control agencies and delegation of authority, responsibility and accountability. In this case the control plan (or specification) would be prepared by the Finance Organization with proper approval by Top Administration. In the

same manner, such items as (f) and (g) would be prepared by the Industrial Relations Organization with proper approval by Top Administration.

It should be noted, however, that regardless of who prepares these plans, the responsibility for application of the controls rests on appropriate management levels in every branch of the company.

e. *Organization Manual – Initiation and Approval*

In section 5 of the chapter on organization we showed two examples of Organization Manuals (figures 256 and 257). Beyond this previous discussion it is well to point out that the preparation of such manuals is not a routine clerical assignment. It is so very important that it requires men of high calibre. Therefore such work should be the responsibility of Top Management levels; having adequate assistance and guidance from experienced and capable experts in each field of activity. The control Specifications that we just reviewed would be logically included in an organization manual. Also included would be the organization charts, and ultimate organization plans as well as the job specifications for organization units and management levels such as:

- Board of Directors
- General Administration
- Departmental Administration
- Committees
- Supervisory Management
- Key Jobs

f. *Organization Changes – Initiation and Approval*

Since the proposal or initiation of changes in the plan of organization may result from suggestion from within the organization as well as from the group handling organization planning, it is advisable that all important changes be carefully reviewed by the organization planning group. Such changes must take into consideration their relationship with existing plans, conformance to the ultimate plan, and basic soundness.

Sound approval and authorization practices followed in many companies are as follows:

- (1) The general plan of organization for the Board of Directors is usually prescribed in the by-laws. Within these the board normally establishes:
 - (a) Internal Organization of the Board
 - (b) Functions delegated to General Administration
 - (c) Responsibilities delegated to General Administration
 - (d) Limits of Authority of General Administration
 - (e) Board approvals required by the company management on changes in general and departmental administrative organization structure.

- (2) Subject to the Board of Directors requirements as to approval, the general administrative official establishes:
 - (a) Organization plan for handling General Administrative functions
 - (b) Basic organization plan for Departmental Administrative functions
 - (c) Functions delegated to Departmental Administration
 - (d) Responsibilities delegated to Departmental Administration
 - (e) Limits of authority of Departmental Administration
 - (f) General management approvals required by the Departmental Administration on changes in Departmental and Supervisory Management structure.

- (3) Within the basic pattern of company organization and specific limitations of General Administration, Departmental Administration establishes:
 - (a) All adjustments and changes considered necessary in their organization plans.

Note: If proposed changes affect the interests of other departments such changes are referred to General Administration for approval.

General

While this subject of Organization Control is only one phase of the subject of controls it is extremely important. It is a direct and practical means of improving the efficiency and economical operation of the company. Fundamentally this may be considered a cost control because it has a vital bearing on the company overhead.

Indirectly, this control also applies to quality because product quality is dependent not only on product design and manufacturing processes but also on the effectiveness with which management does its job.

In conclusion we wish to emphasize again that changes should be made only when you have a planned objective and that such changes should be introduced only as they can be justified. However, there are many of the phases of this function that can and should be initiated immediately.

4. Quality Control

Andrew Carnegie was one of the greatest business managers the world has ever known. As a boy he had no special advantages and, in fact, he had little school education. Very early in life he had to go out into the world to earn his own livelihood.

But, from this poor beginning, he developed himself to the point where he became one of the richest men in the world owning one of the world's largest and wealthiest corporations – the United States Steel Company.

In his autobiography, he wrote down what he believed was the secret of his success. He said: "Instead of objecting to inspectors, they should be welcomed by all manufacturing

establishments. A high standard of excellence is easily maintained and men are educated in their effort to reach excellence. I have never known a concern to make a decided success that did not do good, honest work, and even in these days of the fiercest competition, when everything would seem to be a matter of price, there lies still at the root of great business success the very much more important factor of quality. The effect of attention to quality upon every man in the service, from the president of the concern down to the humblest laborer, cannot be overestimated. And bearing on the same question, clean, fine workshops and tools, well kept yards and surroundings, are of much greater importance than is usually supposed. But, the surest foundation of a business concern is quality. And after quality comes cost.”

This statement of Andrew Carnegie’s emphasizes what is nowadays generally accepted by all companies. A company that does not base its operations on quality is a company that has no pride in its product. And further, it is generally to be expected that a company that cannot control its quality cannot keep in control any of its other functions and activities. In other words, the state of the quality of a company’s products is a direct measure of the effectiveness of that company’s management and operations.

The term “quality” as applied to manufactured products refers to the characteristics which distinguish that product from a competitor’s, or one article from another, or one grade of product from another when both are turned out by the same manufacturing process.

There are two aspects to the concept of quality. One is the identification of a product, as in the case of comparison with a competitor’s articles. The other is a measure of the degree of perfection attained by the product.

In either case, quality is not an absolute quantity; it is only relative. The quality of any particular item can only be stated in terms of comparison with some ideal that is accepted as a standard. The quality of a product, then, can only be expressed as being higher or lower, better or worse than the standard.

Thus, quality not being absolute, must be a variable and when the permissible limits of variability have been specified in any one case, for that case, it may be said that the quality has been adequately defined.

The characteristics that enter into the determination of product quality include such things as size, material, form, shape, chemical composition, mechanical functioning, workmanship, and appearance. Such things as these elements can then be grouped under two headings: (a) quality of design, and (b) quality of conformance. The first is a description or specification and the latter is the manner and degree in which the product measures up to the specifications.

The quality of design involves a peculiar problem. The engineer, and the business manager too, are constantly faced with the necessity of balancing the value of a given result against the cost of a given result. For example, a cigarette lighter, if offered at a selling price of one yen, would find many buyers because the cost would be small compared to the utility value of the lighter. But, if the selling price were successively raised, to say one thousand yen, there would be less and less buyers. The cost would be too high compared to the lighter’s intrinsic value.

In the same way, greater precision of dimensions, greater chemical purity, or the increasing enhancement of any quality characteristic may increase the value of the product, but it must also increase the cost of the item. Eventually, the point will be reached where the cost of the improvement is out of proportion to its value.

Thus, the designing engineer is continually faced with the problem of selecting the standard of quality which is adequate for the purpose intended for the product and yet he must keep the cost of quality within reasonable limits.

This problem affects the quality of conformance to the same degree. Suppose, for example, a manufacturing process, upon investigation, is shown to have a defective rate of 0.1%. That is, out of every one thousand of pieces of the product, one of these pieces is a reject. On the average then, one thousand pieces must be inspected in order to find the one bad one.

The cost of this inspection may be far greater than the loss caused the consumer if and when he receives the one bad part. In this case, the greater economy would be in not making a 100% inspection of the parts.

It would be an economy for the customer too since the cost of a 100% inspection would have to be included in the sales price of the product he buys.

So, inevitably, the cost of quality enters into the picture of both design and conformance. And inevitably too, the business manager, as well as the designing engineer, is called upon to decide the question of balancing the cost of the product's quality against the value of the quality of the product.

Many factors will weigh upon the problem. Some of these are the manufacturer's protection of his reputation among his customers, the ability of the skill of the workers and the precision of the production machines to match the required design quality, the control exercised over raw materials, and also the economical relation between cost and quality.

Figure 351 graphically represents this cost-quality relationship. In this example, a quality of #2 would be the most economical. A drop from #2 to #1 quality would reduce the cost of quality by amount A, but the value of quality, the intrinsic worthiness of the product would be reduced by the larger amount B. On the other hand, increasing quality to level #3 would raise the value of quality by the amount D, but this is less than the amount C, which is the concomitant raise in the cost of quality.

Thus, the first step to be taken in the establishment of quality control is the establishment of a reasonable quality standard. The next step is to set up a quality enforcing agency, which is the inspection group.

The inspectors perform what is largely a judicial function. They are called upon to judge the product against the quality standards that have been set up by the engineers.

The selection of personnel for inspectors' jobs is therefore an important one. The quality of the product and hence the reputation of the company rests very decidedly upon the skill, judgement and honesty of these people.

Also, to meet the requirements of quality control a large number of inspection standards are needed. These include standards for:

- Work in process
 - Condition
 - Form and dimension
 - Appearance and finish
- Working inspection
- Finished product
- Completed mechanism

These standards and specifications will generally be written by the designing engineer or some group in the engineering department. But in some cases they might be written by the production engineers. That would be a problem in the assignment of responsibility for management.

Quality must, of course, be worked into the product. Inspection cannot make a bad product good. You cannot inspect quality into a product. Responsibility for making products of up-to-standard quality must rest with those who make the product, the manufacturing groups. This division of responsibility is one of the prime reasons why most companies find it necessary to separate the inspection group from the manufacturing group in the factory organization plan.

Production is responsible for quality, inspection measures the achievement of quality. Thus, engineering design that sets the quality standard, production, and inspection, are separate but equally ranking independent functions in the manufacturing enterprise.

The failure to achieve the established quality standard may arise from (a) bad engineering or product design, (b) or failure or inability of the manufacturing activity to live up to the engineering design and specifications.

Putting the inspection activity in a position that is independent of both engineering and production gives to the group in charge of protecting the quality reputation of the company a certain degree of authority over both in its attempt to discover the cause of failing to meet quality standards.

Inspection could, in the case of continuous production of rejectable items, cause the manufacturing activity to stop operations until the cause for the reject is discovered and corrected.

By the same token, inspection could require engineering to make a design change if the original design was at fault.

The point to remember here is that the purpose of inspection is not to find production faults, but rather to prevent them.

There are various forms of inspections in use. Regarding inspection methods, there are Tool, First-piece, Patrolling, Operation, Sampling, and Final. And regarding inspection location in the factory, there are floor and centralized inspection.

Tool inspection is often used in punch press operations where many parts are made. The parts themselves are not inspected but the tool or dies are inspected from time to time for wear or damage.

First piece inspection is also used in repetitive processes and is concerned with getting the job started right. The assumption here is that if the first piece is made right, the subsequent production will be correct also.

Patrolling inspection, as the name implies, is that done by inspectors moving up and down the assembly line removing a few pieces here and there to check on the quality of work going through the line.

Operation inspection is one of the most commonly used systems. The inspector sits in the assembly line and all the items that come from one operation as process go to him before the items are passed on to the next operation.

Sampling inspection is less than 100% inspection. A definite number of products are taken out of a lot of products and the whole lot is judged by the results obtained from inspecting just the samples.

This type of inspection is based on the principle that any piece selected at random from a group of similar pieces probably is representative of all the pieces in the group. It is sound theory to assume that anything which happened under a set of certain circumstances will happen again if the conditions are again identical to those of before. But, manufacturing operations do not deal with conditions that are always the same. Workers' diligence changes as they get tired. Machines wear out. Materials used in production are not uniform. Therefore, the theory of sampling inspection must be closely scrutinized and applied with extreme care.

We will give much more attention to this subject a little later on. But now, let us continue with our brief description of inspection methods.

Final inspection is concerned with the inspection of the product when all work and operations on it have been finished and is performed just before the product is sent to the customer or to the stockroom.

Floor inspection is the name given to the type of inspection that is done at the place where the item is made. In other words, the inspector comes to the work.

Centralized inspection is just the opposite. Inspectors are situated away from the production processes and the work is brought to them. In centralized inspection it is possible to use less skilled labor because with all of them gathered in one place, intimate supervision over their work is possible. It is also possible to divide the inspecting work and put it on an assembly line basis.

The principles that govern the control of quality in a manufacturing concern are:

1. The quality of manufactured products is a variable and it has a tendency to improve under a competitive enterprise system.
2. The control of quality increases the amount of saleable goods, decreases the cost of manufacture and tends to make economic mass production possible.
3. For highest efficiency, the inspection function must be independent of engineering, manufacturing and sales, but must be coordinated with these activities.
4. The conformance of finished products to the design specification should be made, not by sorting the good from the bad after manufacturing is completed, but rather by avoiding the making of non-conforming goods.

As Andrew Carnegie stated, the importance of quality to the manager cannot be overestimated. But it is not sufficient that the executive know the number of good and bad products made in his factory. What is of more significance is a knowledge of the different classes of defects made. This will help him to understand where the responsibility lies for the making of non-conforming products and where corrective action must be concentrated to bring production into a state of control. There are generally four classes of defects used in inspection and quality control work.

1. Major. Would cause operating failure of the product as a whole.
2. Serious. Would probably cause failure of the product. But at least it would surely cause operating difficulties and service and maintenance costs would be high.
3. Important. Might cause operating failures. Likely to be below standard in the products operation. Maintenance costs would be excessive or the operating life of the product would be short.
4. Minor. Would not cause operating failure. Relatively small defects of appearance, finish or workmanship.

Relative weights are usually given to each of these classifications. That is, a Major defect is weighed at 100, Serious is worth 50, Important is set at 25, and Minor is 5 points. Then the number of defects in each class multiplied by the numerical weight of each type of defect gives the total demerits in that class.. For example, suppose for a five year period the total number of demerits was 56,000 and suppose also in that period a total number of 500,000 units of product were inspected. Then the average number of demerits per unit

would be $\frac{56000}{500000} = 0.112$

<i>Class of Defect</i>	<i>No. of Defect</i>	<i>Demerit Weight</i>	<i>Total Demerits</i>
1. Major	50	100	5,000
2. Serious	240	50	12,000
3. Important	800	25	20,000
4. Minor	<u>3,800</u>	5	<u>19,000</u>
Total	4,890		56,000

Each month such a table as this is constructed and with it an index figure can be derived. Say, for example that the current month's demerits total 1200 and 6000 pieces have been inspected. Then

the demerits per unit for this month would be $\frac{1200}{6000} = 0.200$. The index figure for the current month would then be $\frac{\text{current demerits per unit}}{\text{base period demerit per unit}}$. Then

$$I = \frac{0.200}{0.112} = 1.785$$

When $I = 1$, the two quality efficiencies are equal. When I is less than 1, the work is improving. Zero would be perfection. But a figure for I greater than 1 indicates that the work is becoming worse than the base period.

In past years, the control of quality was effected only through inspection. The good products were sorted out from the bad. Nowadays, however, a different interpretation is given to inspection. Inspection results now are being used to indicate the manufacturing situation in the factory and also to check on all factors in the company which bear upon or have influence on manufacturing.

In other words, in the past a company was content to select good pieces to send to its customers. In contrast, at present we are more interested in maintaining factory operations at a consistent level of efficiency. The quality of the product is used then to indicate the current state of production efficiency.

The purpose behind maintaining a consistent level of operations is the reduction of operating costs. Higher efficiency, economical use of materials, efficient use of labor, and the elimination of waste labor, waste time, and waste materials can all be realized when production flows along a steady course.

To achieve this purpose a new technique is being used in all kinds of factories. This technique is called statistical quality control.

Although used to some extent before the war, statistical quality control became popular and generally applied only within the past seven years. It was strongly advocated during the war first by the United States Navy and then later by all of the United States military agencies.

The problem was this. At the start of the war, the United States had almost no arms or munitions. And, the number of factories that made war material was small. There had to be sudden tremendous expansion of production capacity to meet military demands.

As a result of this need, companies which never in their business life had any production experience in this type of materials, (washing machine companies, typewriter factories, automobile manufacturers, *etc.*, for example) suddenly found themselves making parts of guns, or ammunition, or any of the things that an army or navy might have need of. Generally, those companies that converted themselves to war production were suppliers of parts to some main factory or company that did the assembly work.

Naturally, the problem of interchangeability of parts was a big one. Any of the parts from one company had to fit with any of the parts of another company when a third company made the assembly.

To make the problem more difficult, production rates were high, both as to speed and quantity. And the assembly factories had to have the assurance that the parts that were used would always have the expected quality.

The answer to the problem turned out to be statistical quality control. And, while there is still a lot of development work being done to improve this control, there is enough known about the subject nowadays to make it of inestimable value in its everyday use in peacetime factories.

Statistical quality control is based on the theory of probability. Briefly stated, the probability of an event is the ratio of the number of favorable cases to the total number of possible cases, all cases being equally likely to occur.

But before we go further into this discussion, let us define some of the terms that are commonly used in connection with quality control.

Unit refers to one item or thing taken out of a group of similar items or things.

A *Sample* is a group of units selected from a large number of units.

Lot is the name given to the group of units which are made under the same conditions in any periodic interval (day, hours, work shift, *etc.*), or by one machine during a certain period, and which are presented for inspection at the same time.

Universe is a number of lots. It is a great number of units made under similar conditions.

Random sampling is the selection of a sample wherein good and bad units, or units of any characteristic, have an equal chance to be included in the sample.

We mentioned before that the theory of probability was at the basis of quality control. In considering a universe, we are concerned with the probability that a certain set of circumstances will occur. We are also concerned with the desire to know how many times that set of circumstances will be repeated.

For example, suppose you have a pair of dice. Hold one of them so that the one spot is uppermost. As the other die is rotated, it will be noticed that the lowest possible combined number of spots on the two dice is two and the highest is seven.

Now, hold the one die so that the two spot is uppermost. As the other die is rotated to its various faces, it will be noted that the lowest combination of spots on both dies is three and the highest is eight.

If we were to continue this, putting the three spot uppermost on the fixed die then the four, five, and finally the six, while the other is rotated, we would have a distribution of sums as is shown in chart, figure 352.

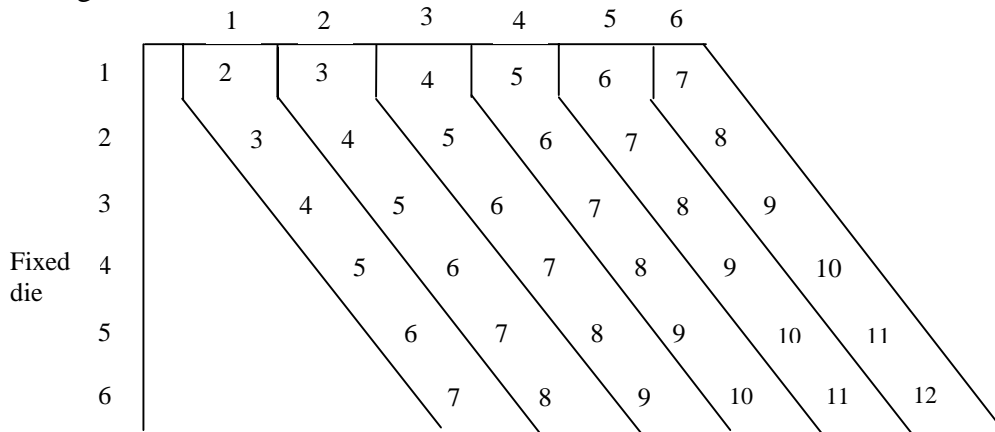


Figure 352

Now, by counting the number of times any of the sums occurs, we can say what the relative frequency of occurrence of any event is. (Each sum is called an event in quality control work.)

Event

1 2 3 4 5 6 7 8 9 10 11 12

Relative Frequency

0 1 2 3 4 5 6 5 4 3 2 1

% Frequency

0 2.78 5.56 8.33 11.11 13.89 16.67 13.89 11.11 8.33 5.56 2.78

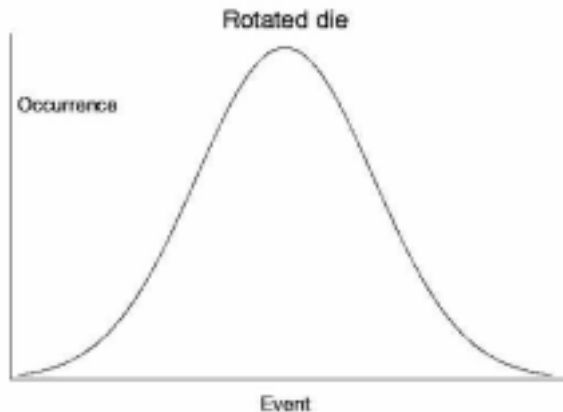
The total number of frequencies is 36 since that is the largest number saying it another way, the total number of all possible events with the dice is 36.

The possibility of throwing a seven then, according to our previous explanation would be the ratio of the number of favorable cases to the total number of cases, or $6/36 = 16.67\%$.

But this is only a possibility and not a probability, since throwing the dice a few times would be an isolated random sample out of a very great universe. The universe would consist of all the throws of the dice a man could make in his lifetime.

A single small sample, in this case, would not represent the true case of the universe as shown in figure 352 above. But, the larger the number of samples taken, the more nearly would the results approximate the theoretical expectations.

If we were to plot the relative frequency of occurrence from figure 352 on graph paper, the resulting curve would look like this:



Or again, suppose we have the example of an electrical heater where the wire that is used for the heater coil is specified to have a resistance no greater than 3.65 ohms, and no less than 3.25 ohms. The method used to make the heater coil is to cut one wire so as to measure exactly 3.45 ohms, and then to cut lengths of wire from a spool to the same linear dimension as the standard wire. Will this method give heater coil wires that will have the best resistance value, assuming that this value is 3.45 ohms?

To answer this, a heater coil is selected from among a group of such coils and upon being measured it is found to be 3.37 ohms. What does this mean? Does it mean that all the coils measure 3.37 ohms?

Of course not. Another coil is selected and it measures 3.29 ohms. These two measurements alone do not give us much information. But suppose we measure one hundred coils. The results are shown in Figure 354.

There are represented here one hundred facts. But the human mind cannot very easily interpret any useful information from one hundred of such facts. This then, is where statistical methods are brought in to interpret these facts.

The first step in the treatment of this data is to make what is called a frequency table. This is easily done as shown in Fig. 355.

This result is very useful. It is now possible to tell with a little study how these coils distribute themselves. It is easily possible to tell how many coils are outside of the prescribed limits, or how many lie within any given limits.

Notice that the measurements are grouped around the value 3.35 ohms, and that more coils measured 3.35 ohms than any other value. It is also obvious that about half the observations are above 3.35 ohms but none is 3.45 ohms or higher.

From the information contained in Fig 355 it would be possible to draw a frequency distribution curve. But again it would have the same general shape as in the case of the dice example. This curve which is described by the mathematical expression

$$\exp\{-1/2(x-\mu)^2 / \sigma^2\} / (2\pi \sigma^2)^{1/2}$$

is called Gaussian Curve, or, the curve of normal distribution.

Any large number of measurements made on any kind of item will generally match the form of this curve. But the shape of the curve, its flatness (kurtosis), the central location of the hump (skewness) or the width of the skirt of the curve (standard deviation) all contain and reveal important information about the things being measured.

One of the most important of all quality control measurements is the measurement of the spread of the curve of normal distribution. This is called the standard deviation and the Greek letter sigma (σ) is used to represent it.

In any set of data, such as that included in Figure 354, a central tendency will tend to be established. That is, some value of measurement will occur about which all of the observations will tend to group themselves. Central tendency is expressed in several ways; among them, are the arithmetical mean or average, (the sum of the observations divided by the number of observations) median, mode, geometric mean, *etc.*

The *average* is generally the most reliable and accurate measure of central tendency. The median (the center value in an ascending scale of values of observations) is a less precise measurement but it is easier to compute than the average. The mode, the value of observation most often repeated, is a rough indicator of central tendency but is the easiest to determine.

But, in any case, the central tendency will generally locate the mid-point of the distribution curve.

With this point known, the dispersion of observations, or how the data are scattered around this axis, must then be determined. It is necessary, in order to control production, to know if all the products tend to be very much alike, that is, their measured values tend to lie close to the central tendency; or if they are much unlike (lie far away from the midpoint) or have a scattered, unpredictable, and non-uniform characteristic.

Range is a rough estimate of the dispersion of observations. It is simply the difference between the maximum and minimum observations in a set of data.

This only gives knowledge of the extreme variation of the data without taking into account the intervening data. This may be useful when the number of data is small, but where more accurate information is desired, standard deviation is used.

As was said before, this is the most important and most useful measurement because it tells the extent of the dispersion of the data. It tends to locate the position of the majority of the data with reference to the axis of the central tendency. In that sense (σ) sigma is the axis of gyration of the observed values around the arithmetic mean of all the observations.

Referring to the curve of normal distribution, a value of σ on either side of the axis includes 68% of the area under the curve. A distance of 2σ on either side of the center includes 95.4% of the area. And $\pm 3\sigma$ includes 99.7% of the area under the curve.

That is to say, in any case where there is a Gaussian distribution of data above and below the mean value of the observations, only 0.3% of all possible observations will probably have some value that exceeds the value of the average plus, or minus, the amount 3 times the value of the standard deviation.

For example, returning to our dice, it can be shown that if the dice are thrown two hundred times, on an average, a combination of seven will be likely to occur thirty-three times.

Throwing the dice two hundred times, you can expect 68% of the time to get from 28 to 38 sevens. We can expect to make from 23 to 432 sevens in 93% of the times we throw the dice. And 99% of our two hundred throws will result in a seven from 17 to 49 times.

However, if we were to throw fifty sevens during our two hundred throws, we had better not gamble with these dice. There would be something definitely suspicious about them because you could not expect to throw more than 49 sevens twice or three times out of a thousand throws.

Up to this point we have been talking about data being uniformly dispersed on both sides of the arithmetic mean, the average. But, in measuring quality attributes of products, there is often a directional tendency which will be taken by inspection data. This will give the distribution curve a lopsidedness or skewness for which the Greek letter kappa (κ) is used as a symbol. A negative value of skewness indicates that the observations below the average tend to deviate further from the average than the observations above the average. And the reverse situation is indicated when kappa has a positive value.

Kurtosis, Greek letter beta (β), refers to the density of occurrence of observations with respect to the central axis. A Kurtosis value of greater than three means that there are more observations very close to the average and also far from the average, with few in between, than in the case of the normal curve. Values of less than three indicate the reverse.

We have discussed some of the terms and procedures used in the interpretation of inspection data. But let us now look at the way a quality control system is operated.

Let us assume that a Quality Control Department has just been established in a company that has been operating for some time, although this company's production cannot be said to be in control. It already has an inspection system and a manufacturing organization. These we do not want to disturb because any interruption in routine operations will be bound to cause delays and increase costs just the opposite of the situation we hope to establish. We will then include the Quality Control functions in the engineering department not only for this reason, but also because of two others.

The quality control activity functions as an agent of the customer and guarantees to him an assured level of product quality. This activity also serves to keep management informed about quality matters in the company.

For these reasons, it has been generally felt necessary to remove the quality control function as far away as possible from such daily problems as factory costs and schedules, and thus remove it from operations activities. Also, the appraisals of quality require engineering judgement and engineering talent is required to develop and improve methods of appraising the quality of products. So it is quite right that we think of quality control as an engineering function.

Coming now to the matter of inspection, it is possible to realize the existence of two main types of inspection. One, the usual factory inspections, is essentially protective in nature and consists largely of sorting the good products from the bad, or determining the state of quality of a specific lot of product. The other is informative and is primarily concerned with the satisfactoriness of the manufacturing processes. Quality control inspections fit into the second category. Their primary interest is to verify that expected levels of quality are being maintained. In other words, the basic proposition of quality control is that if the manufacturing processes are in control and if there is assurance that they are maintained in control, the actual quality of each individual piece of product need be of no concern. It will automatically have an acceptable quality.

But, first of all there must be established specification limits. These are the maximum allowances given to any characteristic of the product that will still permit correct performance of each individual unit of product.

For example, a shaft which must fit inside of a bearing of 0.500 inches (inside diameter) might be specified as to diameter as 0.495 inches, plus or minus 0.004 inches. The specification limit in this case would be plus or minus 0.004 inches.

The designing engineer, who must take into account the material to be used for the product, the use intended for the product, the skill of the persons who make the unit, the machines used in production, the manufacturing processes by which the product will be fabricated, and all the other attendant factors, is the one responsible for the setting of the specification limits.

But, we have need of another set of limits. They are used, not for checking the quality of each unit of the product, but as a basis for judging the significance of the quality variations from sample to sample, or lot to lot, or from time to time. They supply a criterion for deciding whether a production process is being disturbed by causes of variation that are worthwhile identifying.

Control limits are expressed in terms of a unit of measure that refers to the collective quality of a group of units, a sample or a series of samples.

The most commonly used measurements of sample quality are the average or arithmetic means, the standard deviation, range, and the fraction defective. This last term is used in connection with the inspection of products simply on the basis of whether they do or do not confirm to a specified quality requirement.

The quality of a product as measured from one sample to another, or from one lot to another, shows variations that might be a result of any number of causes. These variations can be classified in one of two ways. It can be of slight significance so as to merit no investigation and, if such be the case, we say the variation is due to unassignable causes. But, it may be a

significant variation due to some serious or important cause, an assignable cause of trouble. This would be identified and corrected.

The control limits make it possible to identify the occurrence of assignable variations almost as they happen in production. When and where the assignable cause of trouble has occurred will be indicated. But the identification and the elimination of the cause of trouble is an engineering problem that is not the immediate concern of the quality control activity. An assignable cause of variation may be due to a lack of uniformity of materials or of workmanship, or irregular performance of manufacturing machines or equipment, or possibly the fault may be with the testing equipment.

But, by keeping a watch on the day by day performance of operations, the quality control group can help to decrease the variability of quality.

The system works this way. The Quality Control group, with the assistance of the designing engineers, select certain quality characteristics upon which to concentrate attention. These should be characteristics upon which the intended performance of the product depend. They could be characteristics measurable only in the finally completed product, or a group of data points including both in-process and final measurements. For example, in applying quality control to vacuum tube production, one of the measurements made by the quality control group might be the plate current of a certain type of power amplifiers after they have been given their final test. On the other hand, the group may measure not only this, but also the spacing between the cathode and grid during an intermediate production process.

Having selected the quality characteristic to be measured, the next step to be taken is an analysis of the production process. This is done in order to determine the kind and location of causes that are likely to give rise to troubles. First of all, the specifications and manufacturing instructions are studied to determine their bearing upon the quality characteristic which has been selected. Then next, the relation of each production step and this characteristic is studied and particular attention is paid to where and how quality might be affected by irregularities in raw materials, component parts, machine operations, human operations, *etc.*

The next investigation to be made concerns the method of the factory inspection being used to measure the selected characteristic. And particular attention must be paid here to any factors that may give rise to errors of observation. It frequently occurs that variations in quality are not due to faulty production but rather to faulty inspection. This may result from improper gauges, or improperly working test equipment, or bad work habits on the part of the inspector himself, or even incorrect instructions given to the inspector.

After this study has been completed, the decision must be made as to how the units of products will be handled. That is, the production lot size must be defined. Will it be one day's total production, or will a lot be all the products from one machine in one day, or one hour? Convenience of handling the product and the production rate will be the determining factor here. But, in any case, a lot must be rigidly defined.

The defining of lot size can be extremely important. This was emphasized by an experience some years ago. In a certain vacuum tube factory there were six automatic sealex machines all

making the same type of tube. The total output of all machines in one day was defined as one lot. The specification was that not more than ten percent of the lot should contain 2% or more defectives. But the lots were running 3% defective quite regularly.

This situation was turning out to be quite expensive. The rejects were high, the extra handling of the tubes was great, inspection costs were increasing, and altogether the situation was not good.

It was finally decided to re-define the lot size as the production of one machine in one day. And an immediate good result was obtained. Five of the machines were doing almost perfect work, but the sixth machine was turning out 18% defective. The entire day's production was being rejected before because of one machine that was at fault. But under the new lot definition, at least the five machines' production could be accepted and the sixth one could now be recognized as the one that was causing the troubles.

After the lot size has been decided and defined, the next step to be taken in installing the quality control system is to determine the earliest point in the production system at which inspection and testing can be made for the quality characteristic which has been selected.

This is required because of the nature of quality control. In protective inspection, the sorting of good and bad items, all of the manufacturing operations to be done on the product were completed by the time inspection was made. When bad products were found there was not much that could be done about the matter. The bad products were already made. They could be reworked, or repaired, or thrown away as scrap. But, in any case, there was a definite loss of money to the company.

The purpose of quality control, however, is to discover a tendency on the part of the manufacturing processes to make bad products and thus prevent rejects before they occur. For this reason, the quality control group must have the earliest possible chance in the productive process to measure any quality trend. It cannot afford to wait for its information until all of the processes have been completed.

But now the problem to be considered in setting up the control system is the planning of how inspection data is to be collected and grouped.

For the time being, we have decided that we are going to have the ordinary inspection normally done in the factory and in addition to that we will also have quality control inspections. The latter will be done by the control group which may have its own set of test and inspection equipment and its own separate working place.

Now, for the quality characteristic that has been selected to control, it must be decided what inspection data will be recorded and how it will be grouped.

First of all, it must be assured that the instructions for how the inspection is to be made are clearly written out and that the inspectors understand exactly how to follow instructions.

Now a decision must be made whether a measured value will be recorded for each item of product inspected, or whether, merely, it will be noted if the products being inspected do or do

not conform to specification requirements. This decision will govern what type of control chart is to be used: whether it will measure average (ξ), standard deviation (σ), fraction defective (p), range (R), *etc.*

On the basis of the study of the production processes previously made, the decision must now be made on how the inspection results are to be divided into groups and sub-groups so that the items which make up any of the groups are units which have been produced under the same essential conditions.

One of the essential features of the control chart method is the breaking up of inspection data into rational sub-groups, that is, to classify the observed data into sub-groups *within* which variation may for engineering reasons be considered due to non-assignable chance causes only, but *between* which there may be differences due to assignable causes.

Thus, in the sampling that the quality control group does, the sub-groups that make up the samples should have some important common factor. This may be for example, the units produced in the same short interval of time, or units coming from certain machines, or units being made from the same batch of materials.

The different sub-groups should represent suspected or possible differences in the production processes, such as different times of production, or materials, or machines.

The application of quality control is made less complicated and easier to use when samples, all containing the same number of units, are selected on a planned basis. This could be once an hour, or once a day, or a sample from every lot, or on any other basis which would be convenient and also be representative of the production.

But in order to have the samples represent the universe from which they come they must be random samples. There are two precautions that must be considered at this point.

1. A periodic selection of samples must not be allowed to coincide with any periodic factor in the production process which may have some influence on quality.
2. The selection of samples should not be made on a fixed time schedule. For example, if samples were selected every hour on the hour, the workers knowing this may have their work so influenced that the quality of the product would be affected.

In deciding upon the size of samples and the number of samples to be taken, it should be taken into consideration that several samples of a small number of units each is more informative than a few samples that contain a large number of units.

Obviously, the method of recording inspection data is of great importance. Specific data should be kept so as to be able to relate it to specific times or occurrences in the production processes. This would make it easier to locate observed data irregularities associated with causes of trouble in the factory.

A chart form for recording quality control inspection data has been developed and it is widely used by companies engaged in this type of work. Figure 356 is an illustration of this form.

In our previous discussion we have mentioned the words “control chart” several times. Let us now see what sort of thing this is. Referring to Fig. 356, the control chart is very much like a highway. In the case of the highway there is a pavement, and beyond that on either side are the shoulders of the road. And usually beyond the edge of the shoulders there is a ditch.

The width of the pavement is largely determined by the type of traffic that the road is expected to carry. If only bicycles use the highway it can be very narrow. But, high speed automobiles require a wider road.

The control chart is very much the same as this. The width of the central safety zone is, to a large extent, determined by the production process used in the factory. The control limits, of which we spoke before, are like the edges of the pavement and they determine the boundary of the safety zone.

If a wheel of an automobile goes over the edge of the pavement into the shoulder, the driver had better make some corrective action with his steering wheel or his brake or he will soon be in danger. It is the same way with the control chart. As points are plotted on the chart from the control inspection data, any tendency to approach one or the other of the control limits, or a tendency to go over into the caution zone must be corrected before real trouble occurs.

If the automobile goes into the ditch, the driver is in real trouble. And so too in the factory, if the products pass the specification limits and go into the danger zone (the control chart's "ditch") the factory will be in real trouble. If this occurs, production must be stopped until the cause of out-of-limits production is cleared up or some other drastic action may have to be taken to bring production back into control.

When the assignable causes of variation have been eliminated from the production process to the extent that practically all of the points plotted on the control chart remain within the control limits, the production can then be said to be in a state of control with respect to the quality characteristic being measured. But, when a state of control has been reached, no higher degree of uniformity of quality can be attained with the production processes then in use. Greater quality uniformity can only be attained through a basic change in the process itself.

Now it sometimes occurs that a state of control is achieved but the level of quality is not completely satisfactory. This would be true when all the plotted points lie within the control limits but are all close to one of them. In this case two corrective measures could be taken:

1. the control level could be shifted by making some basic changes in the production processes used in manufacturing; or
2. the specification limits could be shifted to center the existing level of control.

In order that a quality control system which is to be set up might be entirely successful in its application, the management of a company must be convinced of the good which can be expected

to be derived from it. A state of quality control has some definite practical advantages for the manufacturer and also for his customers. The benefits which can be realized are:

1. with control, the variations between individual units of products will be at a minimum.
2. with control, data from samples of the manufactured products have the greatest possible reliability as a basis for judging the quality of manufacture. This means that with control established, the amount of inspection performed and hence the cost of inspection, and indirectly too, the cost of manufacture can be reduced to a minimum. It often follows too, that a sampling inspection is frequently satisfactory evidence to the customer of the manufacturer's maintenance of an established quality level.
3. with control, the percentage of products whose quality lies within any given limits may be predicted with the highest degree of accuracy.
4. with control, there is a reliable basis for determining whether there would be any practical advantage in changing the existing specification limits.

This question may come up in connection with deciding whether to set wide specification limits and make assemblies by selecting particular components that match mechanically, or setting narrow specification limits so that complete interchangeability is achieved, or in other words, any component can be matched with any other in assembly.

5. And finally, as an advantageous selling point, with control the manufacturer's product may be accepted by the customer solely on the evidence of quality control.

The purchaser of the manufacturer's product may be encouraged to accept the idea of his not having to make an inspection, other than perhaps a check inspection, on the incoming products as long as there is evidence of manufacturing quality control. To this extent, the purchaser also saves money on inspection costs.

For any single product there may be one or more quality characteristics selected for control. Or, for any product there may be one or more stages in the production process selected for control. For example, certain important raw materials of which the product is made, and some intermediate production process, and some final quality characteristic may all be placed under a control system.

Then for each of the items to be controlled there would be a control chart made and control limits would be established for each case. In addition to the separate charts there would generally be a summarized one that would combine all of the separate information and tell at a glance the general situation of the state of control of the product.

In setting up the control limits for the charts either of two methods could be used. One way would be to compute them on the basis of past and present production experiences. The manufacturing records of the product under consideration would be gathered together and the data concerning the quality characteristic selected for control would be processed by statistical methods. Without going too deeply into what these methods are just now, we can, nevertheless, briefly outline the process. Groups and sub-groups of the data would be established according to the time of production or other conditions and the average value of each of these divisions would then be determined. The mean value of *all* of the data (or a sufficient amount of it to permit

arriving at conclusions that will be sure to be representative of the whole mass of data) is then computed.

A frequency distribution curve, such as is shown in connection with Figure 352, can then be drawn from the data. The abscissa of the curve will be the scale of values of the data and the ordinate will be the number of times each particular value occurs in the data. (Refer to Figure 355.) If there is a regular distribution of data points, the resulting curve will be symmetrical on either side of the average value. But in any case, an inspection of the curve will reveal at once the characteristic nature and tendencies of the data. Kurtosis, skewness, and standard deviation of the curve will be noted and can be interpreted according to our previous discussion.

From the curve, it will be possible to discover the value of the average squared deviation of the data points from the arithmetical mean and thus arrive at a value for sigma (σ). An approximate value for σ can be estimated by selecting a point on the vertical line that denotes the mean value, that is two thirds of the distance down from the apex of the curve to the base line. An extension from this point parallel to the base of the curve is then made to a point where the curve is intersected. The horizontal distance from this point to the average value is a rough measure of the standard deviation σ .

From our previous discussion it will be recalled that the algebraic sum of the mean and three times the standard deviation ($\xi \pm 3\sigma$) can be estimated to include 99.7% of all the data points. This sum can then be the value selected for the control limits. It can be predicted that, if the manufacturing process from which the past production data has resulted is the one still in use in the factory, then the control limits that are established on the basis of the past data will include 99.7% of all future production.

But, there is yet one consideration that must be made. The control limits, we will say, have been set at $\xi \pm 3\sigma$. (Say just by way of example that the average of the data (ξ) is 7, and sigma (σ) is 0.50. Then, $\xi \pm 3\sigma$ would be $7 \pm 3 \times 0.50$ or 7 ± 1.50 . That means that the upper limit would be 8.50 and the lower limit would be 5.50.) This must now be compared with the engineering design for the particular characteristic under consideration. Will (the specification limits) permit any value from $\xi \pm 3\sigma$ to $\xi - 3\sigma$ (for example, 8.5 to 5.5) be used? Will the product work just as well *with any of these values*? Or, must the limits be set at a more narrow pair of values? This must be answered by an engineering investigation. The question here is one of product quality and product usefulness to determine if the product will suffer any disadvantage because of the *permitted* variation.

If the limits must be more narrow, then they might have to have some value such as $\xi \pm 2\sigma$, or $\xi \pm 1\sigma$. But, if this is the case, we immediately know that using the present production process, only 95%, or 68% of the production will fall inside of these control limits. The rejections will therefore be likely to be high. We also know that if the limits need be set at a more narrow value, that only some basic change in the production process will be able to prevent the probable expected rejection rate. In other words, σ must have a new value.

The second method by which control limits can be established is by computations using formulas that have been mathematically derived from the statistical approach to quality control problems.

There has been a great deal of practical use made of these formulas in actual practice and there is much evidence of the accuracy of the theoretical approach that has been used.

The use of the formulas to determine the control limits does not take into account much of the past performance of the manufacturing processes. In a sense, it applies an artificial boundary since there is no direct relation made to actual plant operations as does the first method of computation. Nevertheless, experience shows that there is usually close agreement between the results of the two methods, and the second has the advantage of being somewhat less laborious since there is no need to process an accumulation of data as is required by the other method of control limits computation.

The control chart has two principal uses of interest to us here. One is its assistance in determining whether or not a state of control does exist in the manufacturing processes in use (See Fig. 358). The other is the use of the chart in actually attaining a state of control. (See Fig. 359)

However, the ultimate and most important purpose of the control chart is to provide a definite operational procedure for controlling quality in the manufacturing plant. But, before setting up a system of control of future operations, it is usually desirable if not necessary to establish a clear picture of the past history of the quality of the product. In view of the past accomplishments of the factory, at least some knowledge of what tentative control limits could have been used in the past can be gained, and it will also show, in an approximate fashion, what sort of control has existed in the past. Therefore, in putting the control chart method to work, one of its first uses is often the analysis of previous quality records.

In achieving the use of control charts in order to determine whether a state of control exists, an accumulation of data is divided into small groups, called rational sub-groups, wherein the unit differences are small and therefore the variations in the data can be said to be due to unassignable causes. Averages, standard deviations, and other measurements are determined for each sub-group and control limits are computed from the data itself.

The sub-grouping may be based on time; for example, the products made in some ten-minute period of each hour, or during some hour of a work shift, *etc.* Or, it may be based on some other factor that affects manufacture, such as the machine operator, or the production machine itself, or a particular lot of raw material.

Information of this type regarding the state of control would be required, for example, by a manufacturer who wants to install a quality control system. He would have to know what the present state of affairs is in order to know what could be expected if the control system is established.

Also knowledge of the state of control would be required by a purchaser of materials who would need to know about the uniformity of the goods that were being sold to him. The uniformity of the quality of his own products would depend to a great extent upon the evenness of the quality of the materials from which his product is made.

Usually it cannot safely be estimated that a state of controlled quality exists unless at least twenty-five successive subgroups have their plotted points fall within the established control limits.

On the other hand, a lack of control may be concluded from only one or, of course, more points out of a much smaller number of sub-groups, falling outside of the limit lines.

The other use of the control chart, that is for the attaining of a state of control, is a continuing record of the quality of the product while production is going on. The purpose here is to discover assignable causes of quality variations as soon as they occur.

This is the way this system is usually put to work. A tentative standard level of control for use in future operations is set up usually on the basis of past experience, or it could also be done by computation, making use of the quality control mathematical formulas which were mentioned before. Control limits are placed above and below the standard level at distances determined with the method previously discussed. The number of observations to be taken each time the product is sampled is then decided. A consideration that also enters here is the percentage of the products which can be *expected* to fall within these limits. The number of products which will probably be rejected can be estimated at this time.

The values obtained from inspecting the samples, recorded on such data sheets as shown in Figure 356, are then plotted on the chart *as soon as they are obtained*. A plotted point falling outside of the control limits is taken as an indication of the presence of a disturbing factor in the production process, an assignable cause of quality variation.

This cause must be identified, and if practical, it must be eliminated. The quality control group, upon discovering the out-of-limit point, will issue a warning statement to the manufacturing department chief and also to the immediate supervisor concerned with the process under consideration of which the quality characteristic is being measured. A copy of the warning statement also goes to the production engineering group and possibly to the design engineering group, too, since the item in question may be within their area of responsibility also.

The warning from the quality control group places an immediate responsibility upon the manufacturing group to clear up the matter which has been called to their attention. To make the control system effective, the obligation inherent in the warning to take corrective action at once must be of primary importance to the production people.

But this does not mean that hysterical or unplanned action is to be taken. Rather, the problem pointed out by the warning must be clearly identified, the present and current facts of the situation must be determined, these must be analysed and the most proper and adequate solution of the problem must then be planned. After this, that plan must be carefully put into practice and the results of it checked carefully to make sure that the problem has been really solved and is not likely to occur again.

A report of the action taken by the immediate supervisor of the process in question must be made to his immediate supervisor so that there can be a general assurance that the problem has been finally settled.

The quality control group will know if it has been settled by the plotting of subsequent data. If the next series of points are within limits, there is no further special attention required. But, if the condition worsens, some action more drastic than a mere warning will be required, with the complete stopping of production activity until the problem is cleared up as an ultimate possibility.

The control limits, which are used to initiate the procedure which has just been described, thus serve as a criterion for *action* and for this reason they are also called *action limits*.

By repeating the method we have been discussing, the identification of the causes of variations and their subsequent elimination again and again, and by seeking the assurance that once a cause of troubles has been removed it will remain removed from the production processes, manufacturing is brought closer and ever closer to an ideal state of quality control. Perfection would be reached when all of the plotted points consistently fall on a line that is half-way between the two limit lines of the control chart. But the practical purposes of control will be satisfied when all of the plotted points consistently fall *within* the area between the control limits.

The most effective use of the quality control activity is made when the chart method we have been discussing is applied to that part of the manufacturing system which is considered to be the most likely to cause troubles. The control limits will then indicate the need for action with a minimum of delay and the overall efficiency of operations will be continually enhanced. As production goes ahead day after day and month after month, more data and other manufacturing information will be collected and it will be possible to recalculate the control limits setting them at new and different value, thus setting each time a new and improved quality control level, if that is found to be both desirable and economically feasible.

So, the control chart method of controlling quality is one that is perpetually seeking to find an improvement in the state of production affairs. And, every step taken toward the achievement of statistical control, that is, the removal of causes of troubles in manufacturing, brings the whole productive system closer to the highest level of economy.

Our discussion up to this point has been somewhat confined to control charts and the elements that enter into their construction. But the function of the quality group is not limited only to the making and maintaining of these charts and doing sampling inspections. There is another major activity that also comes within the scope of responsibility of this control group. This is the Quality Survey.

Quality Surveys are a complete examination of the basic engineering and manufacturing information for a given product, a check of tool and machine accuracy and a review of the current processes and operations and also of the past production history of the product under consideration. Usually the product selected for survey is one that is being produced on a large quantity basis and that is a regular item of the company's production. Depending upon the current state of control and the availability of sufficient time for the proper persons to make an adequate survey, the number of surveys which are made varies from time to time. The minimum should be one per year, although in most cases it is desirable to have more than this.

Each survey is conducted by a committee made up of a member from the Quality Control Department, Inspection Department, Engineering Department, and the Manufacturing Department. (This may also include the Production Engineering Group.) The committee is only a temporary one existing only during the period of the survey. Its members are appointed by the general manager, or some other proper executive, on the recommendation of the department heads concerned, and the committee membership may differ from one time to the next.

The Quality Control Department usually is responsible for recommending to the general manager of the company the subject of each survey and the dates scheduled for its start and finish. This executive generally passes on the recommendation before the work actually starts.

The survey is planned so that there will be sufficient time allowed before the scheduled starting date to permit each member of the committee to circulate to the other members a preliminary report based on his pre-analysis of the product to be surveyed. For example, the engineering member will sift through the standards and specifications, drawings and bills of materials to determine if they contain clear, concise, and precise information. He will make notations of any matter in this regard that comes to his attention that he feels should be discussed and clarified.

The Quality Control member will check the manufacturing information used in the factory to make sure that operations are prescribed in adequate detail. He will also make sure that the factory information matches the latest engineering instructions. He will look for any changes in instructions which might have been put into effect by the factory groups without the knowledge or approval of the engineers concerned. The quality control member will also make analyses of complaints related to the product under consideration regardless of whatever source they might have come. In addition, he will check on sampling procedures being used and also factory inspection results.

The factory member will report on his findings relating to the machinery and other production equipment in use, materials, handling of stocks and stores, factory personnel, difficulties experienced during production and other factors relating to and possibly having some bearing on product quality.

The inspection member will study and advise on the condition of inspection and test equipment, the accuracy and frequency of recalibration of the equipment, and any difficulties being experienced in connection with the inspection work.

On the date set, the committee members meet and discuss the various preliminary reports and try to settle any questions that might have arisen during the pre-survey study. Other persons, not members of the committee who might be able to give expert information on any of the problems being discussed, may be called in as needed to supply data that might not otherwise have been available. The committee does not limit itself to the conference table but also goes into the factory to watch and study each phase of the operations under survey even including the inspection activities — factory and quality control both.

At the conclusion of its review, the committee writes a report of its findings and all members sign it to indicate their agreement to its contents and their sharing equally in the responsibility for the work accomplished.

The survey report usually is of three parts. The first, which goes to the top management level, indicates briefly the committee's opinion as to the satisfactoriness of the engineering and manufacturing information and the degree to which the product is conforming to the intent of the design.

The committee may have uncovered some problems during its studies that may require corrective action. If so, a listing is made, and what is wrong and a suggested correction or a suggested approach to the solution of each problem is indicated along with a notation as to which group in the company should be charged with the responsibility for solving the problem.

The second part of the report is sent to the engineering group. This is a much more detailed analysis of each item regarded by the committee as being of sufficient importance to be worthy of action by the Engineering Department. The problems mentioned in the first report are gone into more thoroughly here and specific requests for greater clarity, enlargement of information, or more adequate instructions, as required, are made.

The third part of the survey report goes to the manufacturing group and deals in detail with problems that fall within the factory's scope. Required corrective action is outlined here in the same manner as was done in the part of the report that was sent to the Engineering Department.

The committee is a fact-finding body and as such has no authority to require action on the part of any department on any of the items brought out in the survey report. However, a conscientious management will keep the report handy and will demand from time to time information from the various departments concerned on what has been accomplished by them in successfully meeting the challenge of the survey group. Top management may even require that periodic reports be made which will tell what steps have been taken to solve the reported problems, the results obtained, and the problems yet remaining unsolved. And too, management may at times feel called upon to reconvene the survey committee to review these reports and to determine the adequacy of the indicated accomplishments.

A third important division of the quality control function is the investigation of products or items upon which quality complaints have been received. This is almost equal in importance to the first two phases of the control we have been discussing — statistical quality control and quality surveys. No matter if the complainant is a customer or another part of the company organization which uses the item in its work, an item which has proved to be unsatisfactory in use might become a useful source of information in supplying knowledge of possibly avoidable production faults or errors. From this point of view, it is quite worthwhile to have the product in question analyzed and the cause of the complaint identified. Perhaps the matter can be traced back to the factory or to the design or to some other factor and thus effect a significant quality improvement. In some cases a study of customer complaints can turn out to be a shortcut to controlled quality.

However, complaint investigations are not and can never be a substitute for the control procedures that are principally designed to promote the attainment of a state of control. The value of the investigations lies in serving as added checks on the entire productive system.