ORGANIZATION AS A PYRAMIDING, N-DIMENSIONAL NETWORK OF INTERCONNECTED AND OVERLAPPING CLOSED LOOP INFORMATION FEEDBACK SYSTEMS

by

John L. Vaughan II.

Thesis Submitted to the Graduate Faculty of the

VIRGINIA POLYTECHNIC INSTITUTE

in Candidacy for the Degree of

MASTER OF SCIENCE

in

INDUSTRIAL ENGINEERING

October 1963

Blacksburg, Virginia

TABLE OF CONTENTS

TABLE OF ILLUSTRATIONS

I

INTRODUCTION

The purpose of this thesis is to develop a theoretical framework for the design and operation of industrial organizations. Generally, the theory states,

"Effective industrial organizations should be conceptualized as pyramiding, n-dimensional networks of interconnected and overlapping closed-loop information feedback systems. To be effective, organization members must be made aware of the nature of these systems, since it is they who serve as the interpreters of a specific sensing device that functions to close the loops."

The theory is developed as follows:

A. Fundamentals of relatively simple closed-loop systems for physical process control are discussed and an example is presented and the basic criterion of stability is introduced.

B. Another, more complex type of closed-loop system is delineated, that of the statistical quality control cycle. The sensing device in this loop is described and the ultimate usefulness of the loop is discussed.

C. The complex system of many interlocking loops is presented and the applicability of an existing sensing device to their operation is suggested.

D. The design of the basic organizational closed-loop system is presented, together with the application of a sensing device that is uniquely suited for the operation of these systems.

E. The general plan for integrating these basic systems into a total organization is presented, along with several other design considerations intended to make the theory more readily operational.

II

CLOSED-LOOP SYSTEMS FOR PROCESS CONTROL

The discussion of closed-loop systems that follows proposes to devote consideration to their applications relative to electrical and mechanical machines and chemical processes. The basic concepts illustrated here will provide the conceptual framework necessary for developing a discussion of similar systems found in organizational processes.

Introduction to Closed-Loop Systems

It is obvious that electro-mechanical devices and chemical processes tend to produce results that are not perfectly constant at their desired level over a period of time. This is true because disturbances produce variation that makes some type of control over the machine or process necessary.

Generally, this control can be one of two types, open-sequence control or closed-loop control. Furthermore, the desired control can be achieved either through the operation of automatic electro-mechanical devices or through the action of human operators.

An open-loop or open-sequence control system is diagramed in Figure 1. The process is being exposed to disturbances, while being controlled by an element that operates based on expected or calibration conditions. This is a system that is not capable of making compensating changes as calibration conditions change.

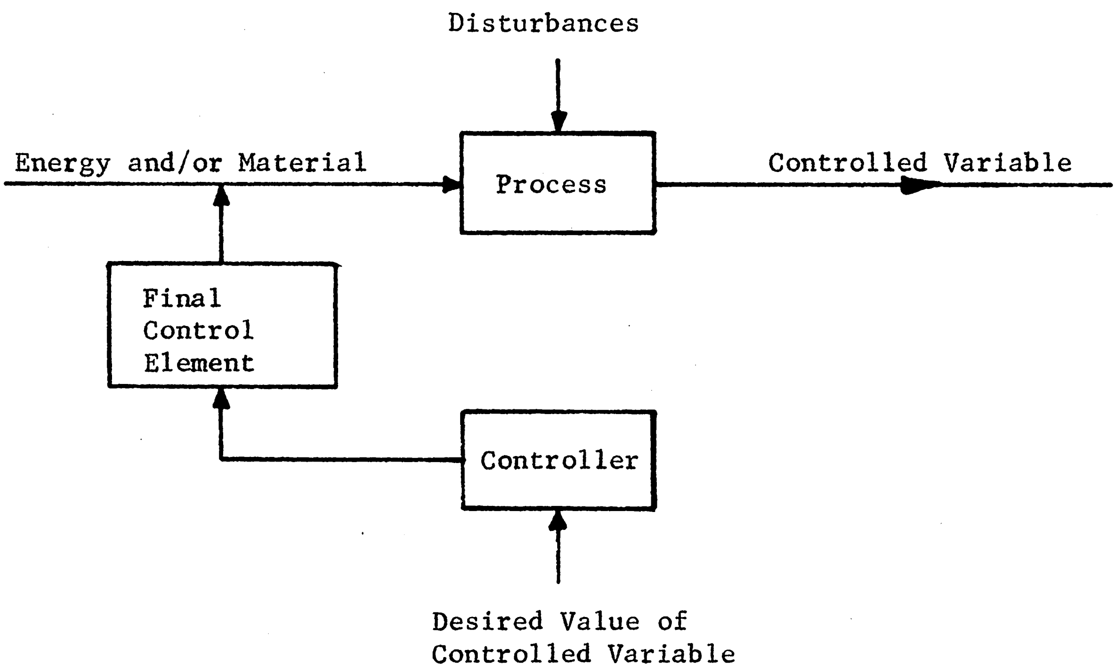

Figure 1. Functional Block Diagram of Open-Loop Control Systems[1]

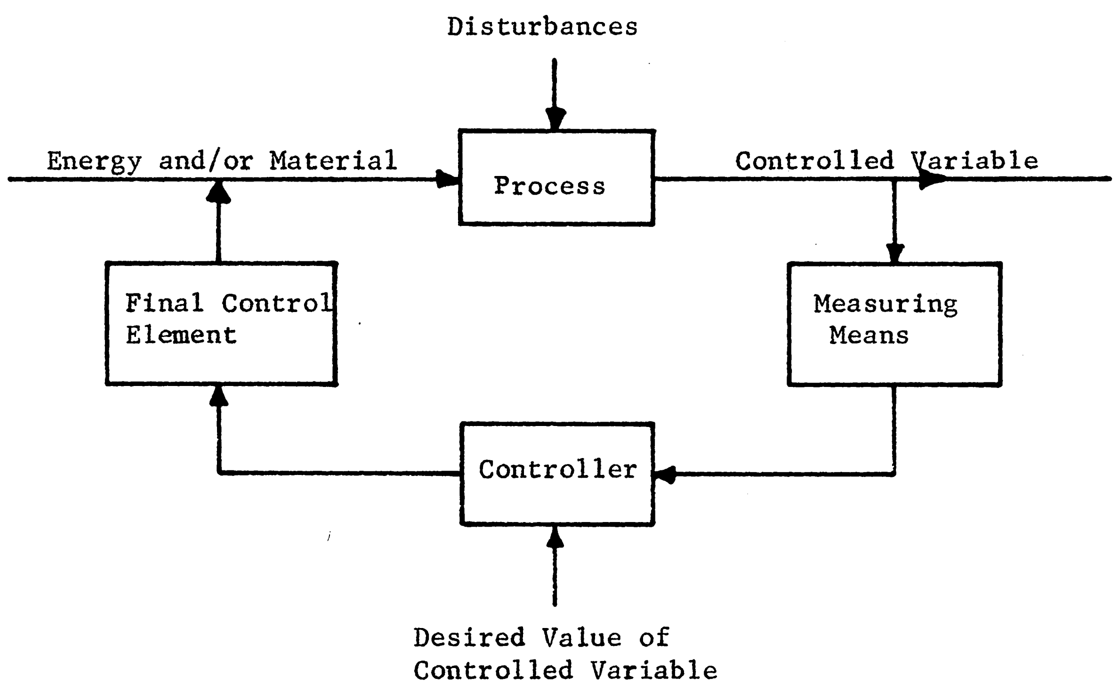

Figure 2. Functional Block Diagram of Closed-Loop (Feedback) Control Systems[2]

In contrast, a closed-loop system functions not only according to a predetermined calibration, but also as a function of what has happened as a result of this original control. Such a system provides a means of measuring the variable being controlled, compares the output being obtained with the output desired, and takes whatever corrective action is appropriate to cause the actual output to approach the desired output. Such a system is an information feedback system because information regarding results is fed back to the control components, where it provides a basis for calibration changes as results change, thus closing the loop. Forrester has defined such systems broadly as follows: "An information feedback system exists whenever the environment leads to a decision that results in action which affects the environment and thereby influences future decisions."[3] A functional diagram of such a closed-loop system is given in Figure 2.

It is possible to compare the general characteristics of open-loop and closed-loop systems by considering the example of a traffic light. The light operates according to a predetermined time cycle and this calibration is designed to achieve desired traffic flow for expected or "average" traffic conditions. Since the actual flow of traffic that the light controls does not have an effect on the action of the light, the system is of the open-loop variety.

However, as all those who operate an automobile know, this open-loop system is one that sometimes fails to effectively control the traffic and traffic jams often result during periods of abnormal traffic flow. When this happens, the only way to solve the problem is to change the system to one with closed-loop control. This can be accomplished by having a policeman operate the controls manually. He is able to observe varying traffic flow in all directions and operate the time cycle in a manner that enables all traffic to move with only a reasonable delay. The advantages of such a system are obvious.

In this system, a human operator - the policeman - performs the functions of measuring the traffic flow (the process) by observation and comparing this flow with his idea of what it should be for the prevailing conditions and taking the appropriate action by controlling the time cycle of the light. The equivalent closed-loop system controlling a machine or process in industry similarily achieves the desired result through the sequential observation and measurement of results, followed by adjustments to the machine or process - all these functions being performed by a human operator. The cycle repeats as often as necessary to achieve the degree of control desired.

However, the continuing trend that is demanding more and more consistent performance of machines and processes, seemingly approaching perfection, often quickly outstrips the manipulative skills of human operators. This means that automatic closed-loop controls are often essential to the effective performance of a machine or process. According to Porter[4], the basic weaknesses of human operators as the pivotal links in the control of physical processes can be attributed to four shortcomings:

(1) Human reaction time is such that manual control is inefficient in systems where high speeds of response are essential.

(2) Many machines and processes require continuous and accurate control over extended periods of time. Under these demands, physical fatigue and boredom may cause a significant deterioration of performance.

(3) It is impossible to standardize the reaction of human operators. Interpretation of error signals and the time required to take corrective action varies significantly from operator to operator.

(4) It will often prove uneconomical to use manual controls in applications where automatic controls can be developed that will result in labor savings.

These human frailties led to the evolution of automatic control that has contributed greatly to the productive uniformity so universally required today. It has also helped to reduce costs, improve quality, and reduce safety hazards.

Closed-Loop Control of a Chemical Process

The fundamental design considerations of such information feedback systems used in industry today can be illustrated by considering the closed-loop control of the process illustrated in Figure 3. It is desired to control the temperature of a liquid formed by mixing two constitutent liquids. A temperature sensitive device is placed in the path of the mixed liquid downstream from the mixing operation. We can assume that this location of the sensing device is necessary because the liquid must stabilize after mixing in order to obtain an accurate reading and because the temperature is critical downstream, rather than at the mixing point.

Recalling Figure 2, a functional block diagram of a closed-loop system, it is possible to define the functional components in this example. This is shown in Figure 4.

The temperature of the final liquid is measured by a thermocouple. This thermocouple causes a current, i_1, to flow. This current is proportional to the temperature of the liquid. This current is then compared with i_2, a current proportional to the desired temperature. The error current or difference, i_3, is caused to flow through an electromagnet. Its direction depends upon which is greater, i_2 or i_1, and if the current flow is great enough it causes the moveable magnet to open or close

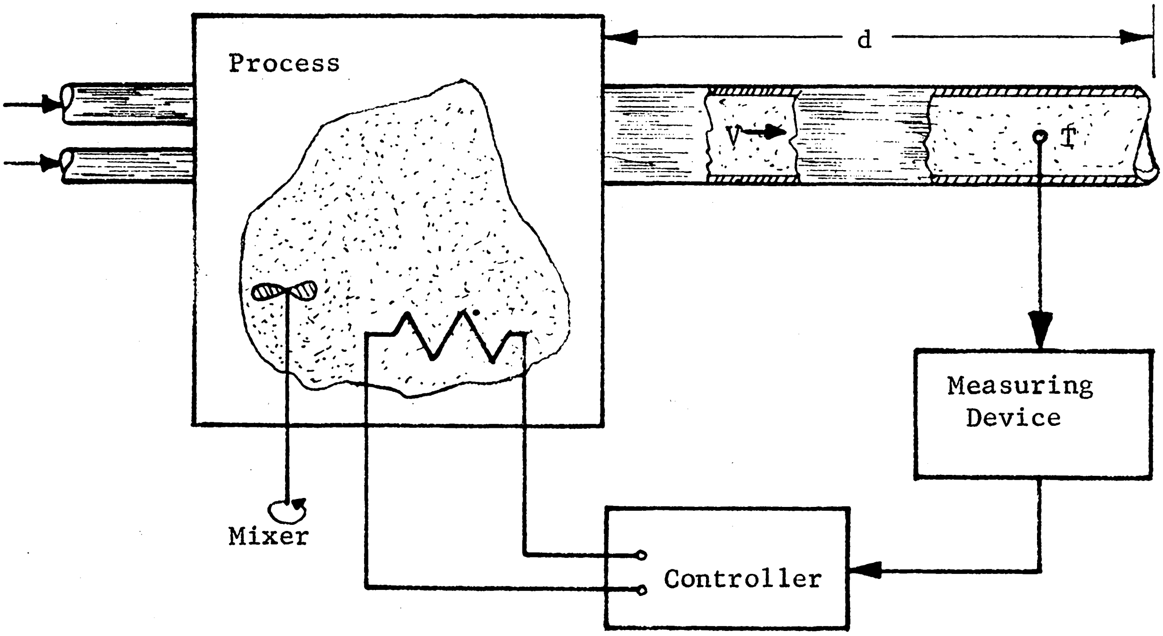

Figure 3. Closed-Loop Control of a Chemical Process[5]

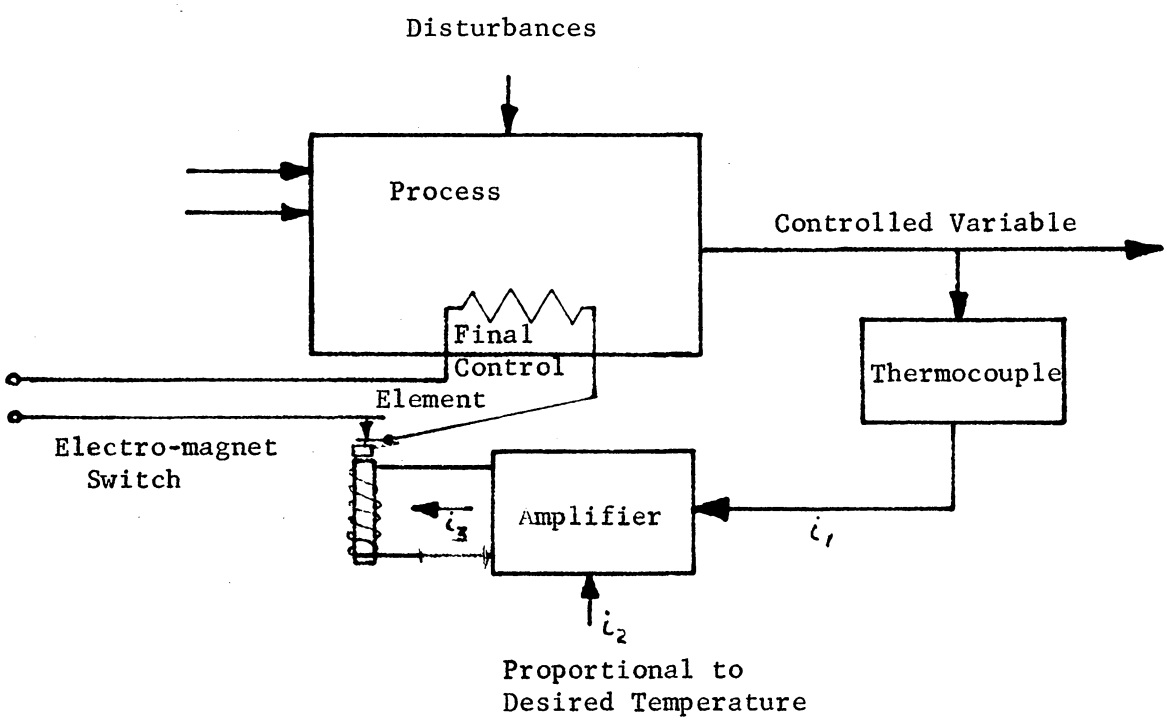

Figure 4. Functional Diagram of Closed-Loop Control of a Chemical Process

the circuit, causing the heater to turn on or off. If the current flow is not great enough to cause the magnet to move, the heater remains on or off, as the case may be.

Assume that the desired temperature of the liquid is T_0. When the actual temperature, T, is equal to T_0, i_1 is equal to i_2, and the error current, i_3, is equal to zero. However, if T is less than T_0, i_1 is less than i_2, and as a result, i_3 flows in a direction that tends to repel the moveable magnet. When i_3 is great enough, the magnet is forced away and the switch closes, causing the heater to turn on. Eventually, the temperature of the liquid will rise enough to cause i_1 to be greater than i_2, thus reversing the flow of current in the winding and reversing the polarity of the magnet. When i_3, flowing in this reverse direction, becomes large enough, the moveable magnet is attracted to the permanent magnet and the circuit is opened, causing the heater to turn off.

This is clearly a closed-loop system. A decision by the controller to turn the heater on leads to the action of the element heating, which causes the temperature of the liquid to rise, thus changing the environment, which eventually will lead to another decision to de-energize the heating element.

This type of system must be designed to meet the demands of both stability and accuracy. In other words, the system must cause the controlled variable to approach the desired value and it must cause the variable to exhibit only allowable variation about this desired value. To obtain the desired degree of accuracy and stability, it is necessary to consider the time lags in the system and the sensitivity, or the corrective effort per unit error.

When the variable being controlled varies away from the desired value there are four lags before its trend is checked. First, there is a measuring lag which is the delay between the time that the controlled variable changes and the time that this change is reported to the controller. In our example, the temperature rises in the process, but this is not detected until the mixed liquid flows downstream a distance d feet at a velocity of V feet per second. This means that the measuring lag would be approximately d/V seconds. This particular lag is sometimes called dead time or a distance-velocity lag.

The next lag is a controller lag, which is the delay in signaling the control element. This occurs because it is necessary to compare the actual temperature, in our case, with the desired temperature before an error signal can be sent to the final control element. In the system described for controlling the temperature of the liquid, this lag is relatively insignificant due to the speed of current flow. However, if a human being were performing this function it can be seen that the controller lag would be much more significant since the operator would have to calculate the error and decide on an appropriate error signal.

Furthermore, the magnitude of the lag would vary from cycle to cycle and from operator to operator. This would further complicate determination of the proper corrective action.

When the error signal is sent to the final control element another lag occurs. This is termed the final control element lag and it is the delay experienced by the control element in responding to the error signal. In this example, it is the time required by the heater to heat to temperature if the liquid is too cool. Or, if the liquid is above the desired temperature, it is the time required before the temperature of the element decreases to a stable lower temperature. The importance of this lag would be a major factor in determining what type of heater should be used.

Finally, the process lag must be considered. This is the time required for the process to react to the change being imposed upon it. After the heater rises to its specified temperature, the liquid must absorb the heat being produced before its temperature can be corrected.

The importance of these lags, along with the sensitivity of the system, must be considered when the capabilities of the control system - its accuracy and stability - are questioned. For example, if the total lag in the system is great enough, instability can be introduced. This would occur if the thermocouple records an excessively high temperature, and in the meantime, disturbances have acted to force the temperature down into the acceptable range. However, due to the long lag in the control system the final control element thinks that the temperature is still too high, so it acts to bring it down, which would likely serve to actually drive it below the lower limit, rather than simply reduce it to a position within the acceptable range. The severity of this "out of phase action" by the control element would depend upon the sensitivity of the system. If it is designed to call for a large corrective action in the presence of a relatively small error signal, it is essential to keep the total lag of the system small enough to prevent the occurrence of absolute instability.

Figure 5 shows how an unstable system reacts. The amplitude of the variable is increasing because the corrective action is out of phase. If this condition is allowed to continue, the system will destroy itself. In contrast, Figure 6 shows the behavior of a stable system. This is acting with a decreasing amplitude so that the controlled variable is approaching a stable condition which contains the desired value. The system exhibiting the better relative stability is the one that causes the controlled variable to approach the desired value in a shorter period of time.

The question of causing the controlled variable to approach a desired value rapidly raises the question of how a system should be damped. Generally, there are three alternatives, overdamping, underdamping, and critical damping. The basic difference between these systems is shown in Figure 7.

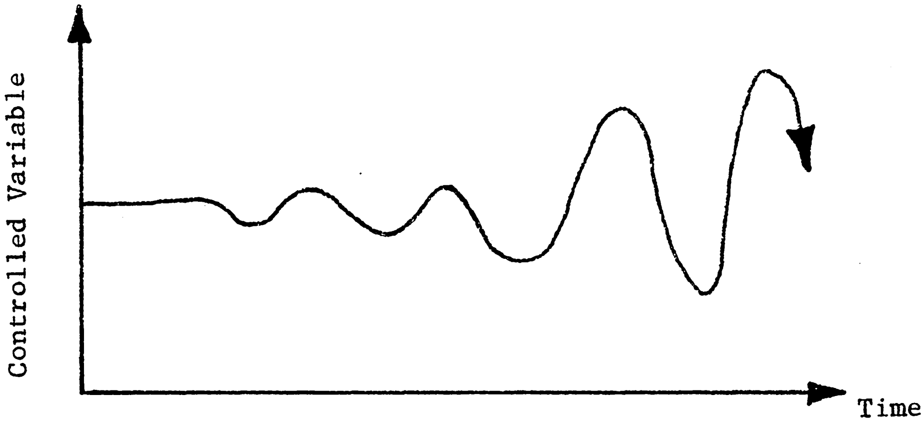

Figure 5. Behavior of Absolutely Unstable System

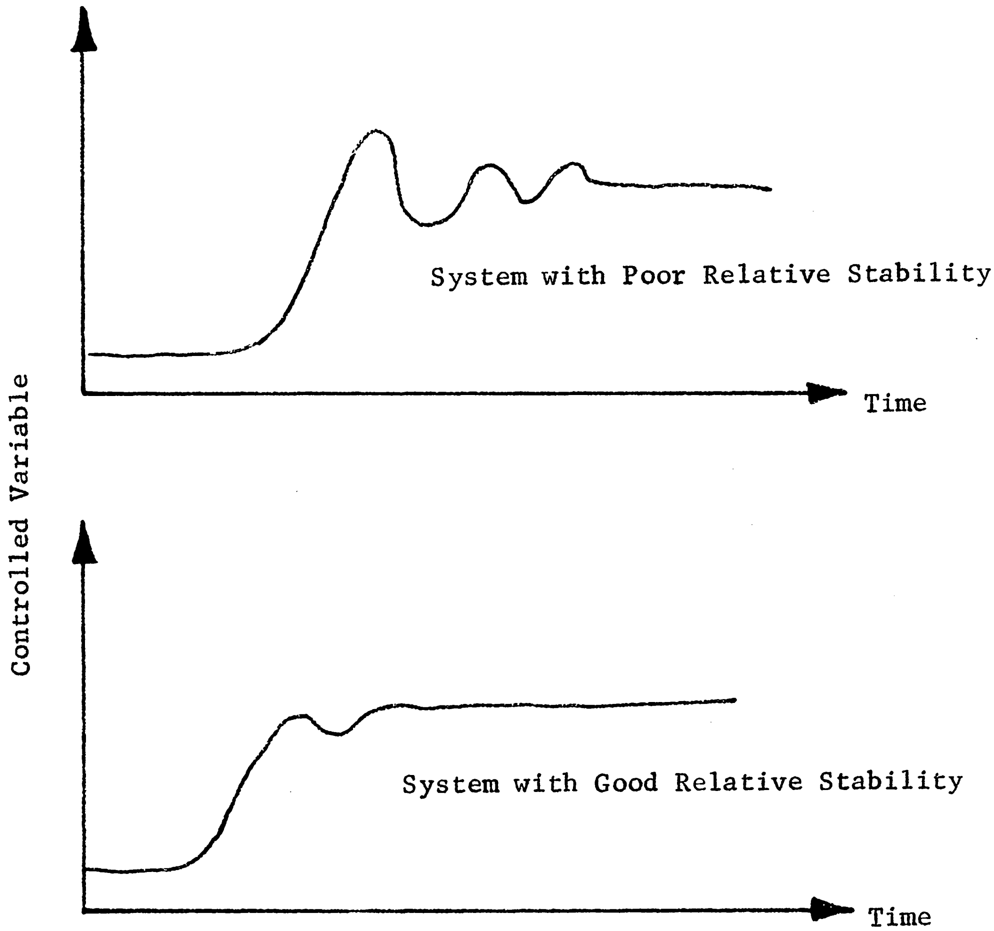

Figure 6. Meaning of Relative Stability[7]

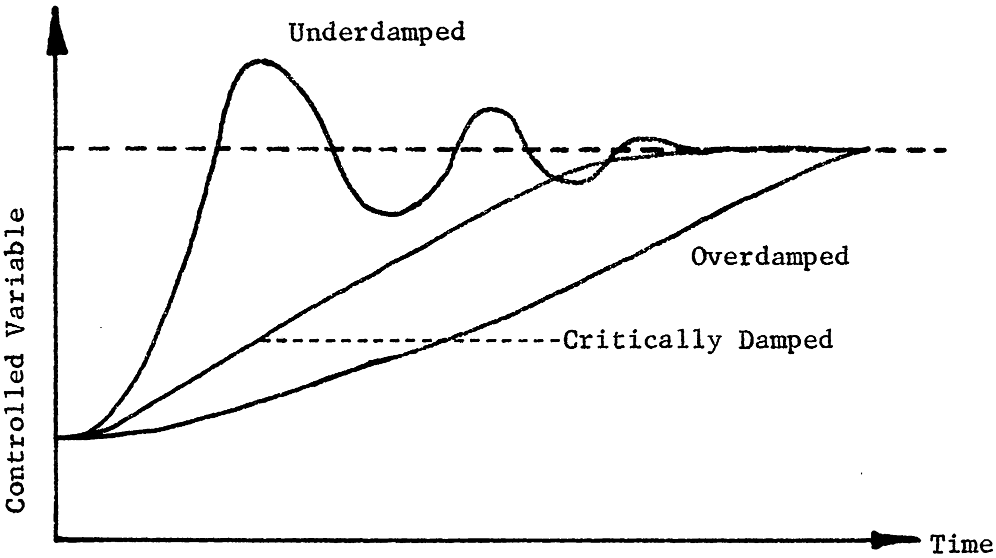

Figure 7. Damping of a System[8]

A system that is underdamped is one whose response time is relatively short, but it is one that causes the controlled variable to oscillate above and below the desired value as it approaches it. An overdamped system is one that does not overshoot the desired value, however, its time of response is relatively long. Between these two types is this critically damped system. This is the one that allows the controlled variable to approach the desired value in the shortest possible time without overshoot.

It is important to point out that there is only one critically damped system, while there are an infinite number of both overdamped and underdamped systems. The critically damped system is the one where the two roots to the second order differential equation describing the system are equal.

Therefore, the choice of damping for a system depends upon the speed of response desired and whether or not it is acceptable to allow the controlled variable to oscillate above and below the desired value. If speed of response is the primary consideration, an underdamped system can be used if stable oscillation is allowable. If rapid response is required but it is necessary to prevent overshoot, a critically damped system should be used. If stability is required even at the expense of speed of response, an overdamped system should be specified.

Summary

The preceding discussion of closed-loop systems as a type of process control has served to point out the factors that must be considered in the design of such systems. The three primary considerations are structure, delays, and sensitivity.

Figure 2 is a diagram of the functional structure of a closed-loop system. The structure involves specification of the various system components and how they are related to one another. The importance of the structure is to create an integrated design that is, in its entirety, more than simply the sum of its parts.

A consideration of delays in a system is a study of the importance of the element of time. Delays exist in all systems and in all stages of a system. The delays in the various functions of a system have been described in the example cited. It is clear that the importance of the various delays can range from entirely insignificant to very critical. In some systems, delays are essential and must be integrated into the total design of the system. Or, perhaps delays are highly undesirable, unexpected, and almost undetectable in the complexity of the system. Such situations create a demand for extensive systems analysis to locate delays, followed by extensive revisions in total system design to eliminate the unwanted sequence interruption.

Relative to total design, the importance of delays cannot be over-stressed. All delays in a system should be recognized.

To the greatest extent practical, the delays should be described verbally, and if possible, mathematically and statistically. This would include an explanation of what caused the delay and the net result of the delay. It is only through such detailed consideration of delays that an effective closed-loop information feedback system can ultimately be achieved.

Sensitivity is a consideration of the amplification of the system, or the amount of corrective action per unit of error. This must be specified in the light of delays in the system and with awareness of the fact that improper sensitivity can lead to either poor performance in terms of accuracy and relative stability, or even to absolute instability.

These myriad considerations serve to make the total design of feedback control systems similar to the one described in this section quite complex. However, complex as they are, it is possible to design such operational systems today by applying the concepts of various mathematical and engineering sciences.

III

THE CONCEPT OF STATISTICAL STABILITY

The Stability Model for the Production Process

This section will provide a brief introduction to the concept of statistical stability as it is applied to the control of quality characteristics of manufactured product. This concept is commonly referred to as statistical quality control and most of the early development is credited to W. A. Shewhart.

The underlying base of this model is the fact that all measured quality characteristics will inevitably exhibit some variation as a matter of chance. This is variation that is inherent to the process. It exists because the physical and chemical changes that are the essence of production processes cannot be exactly duplicated for all the product produced. Raw materials vary and the efficiency of energy conversion varies, which combine and interact to prevent perfect uniformity of product. Furthermore, it is obvious that our methods of measurement are far from perfect, meaning that even if perfection existed, we would be incapable of detecting it.

The concept of statistical quality control recognizes that it is impossible to eliminate this inherent variation in the production and measurement processes. It accepts the fact that no two products can be made exactly alike. Instead of demanding absolute uniformity, the goal of statistical quality control is to produce like products that are different only as a result of variation that is inherent to the particular productive and measuring process, as opposed to differences that are the result of some extraneous or assignable cause.

Eugene L. Grant has stated this concept of statistical quality control as follows: "Measured quality of manufactured product is always subject to a certain amount of variation as a result of chance. Some stable "system of chance causes" is inherent in any particular scheme of production and inspection. Variation within the stable pattern is inevitable. The reasons for variation outside this stable pattern may be discovered and corrected."[9] Therefore, this technique is a model, a tool that facilitates evaluation of the performance of a process. In other words, it is used to provide a basis for action.

In making use of this concept, it is first necessary to determine what the inherent variability of the process is and to determine the characteristic pattern of this inherent variability. The data for making this determination is derived by drawing samples from the production process. Samples are used, because as has already been recognized, we are always practically restricted to a sample. Variability is ever present and therefore any attempt to measure must result in only a sample of all measurements possible. However, it is essential to select samples that are what Shewhart called "rational subgroups". Grant indicates that the "subgroups should be selected in a way that makes each subgroup as homogeneous as possible and that gives the maximum opportunity for variation from one subgroup to another".[10] This rationality must be obtained if statistical quality control is to prove effective in distinguishing between variation that is inherent to the process and variation that is a result of assignable causes.

When we obtain these rational samples of the quality characteristic we are interested in two things, the average or central tendency of the measurements and the spread or dispersion of the measurements about the central value. Both of these statistical measures must be controlled in order to define the inherent pattern of variation of the process.

The statistic that is usually used as an indicator of the central tendency is the arithmetic mean, or the sum the measurements in the sample divided by the number of measurements. This statistic is denoted by the symbol $\bar{X}$. The variation that exists from $\bar{X}$ value to $\bar{X}$ value is a measure of the between sample variation. The statistic that is usually used to measure dispersion is the range. This is obtained by substracting the smallest value in the sample from the largest value and it is denoted by the symbol R. The variation that exists from R value to R value is the pattern of within sample variation.

In addition to the fact that we are always practically limited to a sample, the use of samples enables us to apply statistical theory to advantage, especially the central limit theorem. This theorem states that averages of samples drawn from any distribution will form a nearly normal distribution, regardless of the characteristics of the parent distribution. Applying this theory, procedures are followed for calculating limits for both $\bar{X}$ and R control charts and eventually limits are obtained that serve to define the pattern of stability for the process. The limits so determined are then extended into the future as a control chart. Future inherent variation of the statistic is expected to fall within these control limits. Also, since the $\bar{X}$ chart is a test to determine if the between sample variation is consistent with the within sample variation, a point that falls outside limits on the $\bar{X}$ chart is assumed to reflect the presence of a removable cause of variation that must be sought out and eliminated. Similarily, the R chart is a test to determine if stable variation exists within a sample. When the R control chart indicates that such variation is not present a removable cause of variation is assumed to exist. Thus, the control chart is a basis for action for control of the process.

The limits on the $\bar{X}$ control chart are set so that a known portion of the statistic from the underlying mathematical model of the $\bar{X}$ chart will fall outside of the limits. For this normally distributed abstract mathematical model, three-sigma limits are usually used, and in this case, 99.7% of the theoretical $\bar{X}$'s fall within limits. Furthermore, exactly 0.135% will fall above the upper limit and exactly 0.135% below the lower limit with an accuracy correct to three decimal places. Although the distribution of R values is not normal, it has been found that three-sigma limits will contain almost all values of R. For this reason, three-sigma limits are used for R as well as $\bar{\bar{X}}$ control charts.

Since almost any value can occur if enough measurements are taken and since the exact probabilities associated with mathematical models cannot be carried into the real world, it is possible to make two types of errors in interpreting a control chart. Type I error is looking for an assignable cause of variation when one is actually not present. In other words, a point has fallen outside of the control limits when it does in fact belong to the distribution. When we try to eliminate this "assignable cause" we are attempting to remove inherent variation. The result of such action is usually to introduce instability into the process where none existed.

Type II error is not looking for an assignable cause when one actually does exist. In this case, a sample mean (or R value) falls within limits when it should not. This means that the distribution has shifted and the probability that this shift will not be detected - the Type II error - is equal to the percentage of the shifted distribution that lies between the control limits being used.

The Statistical Quality Control Cycle

The above discussion has sketched a brief outline of the basic concepts of statistical stability, how they are applied to define a stable pattern of inherent variation, how the resulting control charts are utilized to maintain the desired stability over a period of time, and possible errors that can occur. This is the essence of statistical quality control as it is applied to the actual physical production of product. However, the total scope of the concept has a much broader value.

The determination of this stable pattern of inherent variation defines the capabilities of the production process. However, evidence of stability is not the criterion upon which the product is actually accepted. This decision is based on product specifications or what is wanted by those who purchase the product. Furthermore, the limits that define the inherent variability of the process are established for some sample statistic, whereas specification limits apply to individual units of production.

The first step in defining the desired relationship between specification limits and control limits is to introduce a third set of limits, natural tolerance limits. These limits apply to individual values rather than sample means. A point of significance is that the distribution of individual values always has a dispersion greater than the dispersion of sample means taken from this parent distribution. The first step in determining the location of these limits is to obtain an estimate of the distribution of individual values by taking measurements from an in-control system. The natural tolerance limits are determined by estimating the desired location of these limits at the extremes of both ends of the distribution. These distances are then converted to multiples of sigma prime. The simplest example would be the case where it is possible to assume that the parent distribution is normal. In this simple case, the natural tolerance limits would lie $\pm$ three-sigma prime from the mean of the parent distribution.

It is desirable for specification limits, therefore, to be outside of the natural tolerance limits on individual values. This would mean that temporary process shifts of a minor nature would produce very little unacceptable product, which would result in lower costs of production. Also, the further specification limits are outside of natural tolerance limits, the greater the process shifts that can be tolerated, and the less effort need be devoted to maintaining process centering.

The antithesis of this situation is the one where specification limits fall inside of natural tolerance limits, or even more regrettable, inside of control limits also. This means that some product produced within the stable pattern of variation inherent to the process will not conform to specifications. The result is a high rejection rate of manufactured product, resulting in high cost of production. Such specifications are said to be unrealistic when compared in the light of process capabilities.

This should make the ultimate usefulness of the concept of statistical quality control obvious. It means that realistically, specifications must be based not only on what is wanted, but also on the capabilities of the production process. This serves to form a specific closed-loop information feedback system that has generally become known as the statistical quality control cycle.

This cycle is an information feedback cycle, just as the method of controlling process temperature in Section II is an information feedback cycle. In that case, a vacuum tube controller was utilized to compare a current function of the actual temperature with a current function of the desired temperature. The result was an error signal and if the magnitude of that signal was great enough, it initiated action within the framework of the closed-loop. It is significant to note that certain variation is allowable and that no action is taken while only inherent variation is present. Thus, it is clear that the concept of stability is the essence of the process control system.

In this closed-loop cycle, one of the sensing devices is Shewhart's model for production and again, the central concept upon which action is based is the concept of stability. Inputs or what is wanted change, process capabilities change as equipment deteriorates, making the need for evaluating the reasonableness of specifications and the desirability of replacing equipment essentially continuous.

However, there is one very important difference between this closed-loop and the process control loop described in Section II. In the case of the process control loop, there was only one sensor to derive error signals and call for corrective action. However, in this loop sensors are distributed throughout. This thesis has described Shewhart's model for production as one

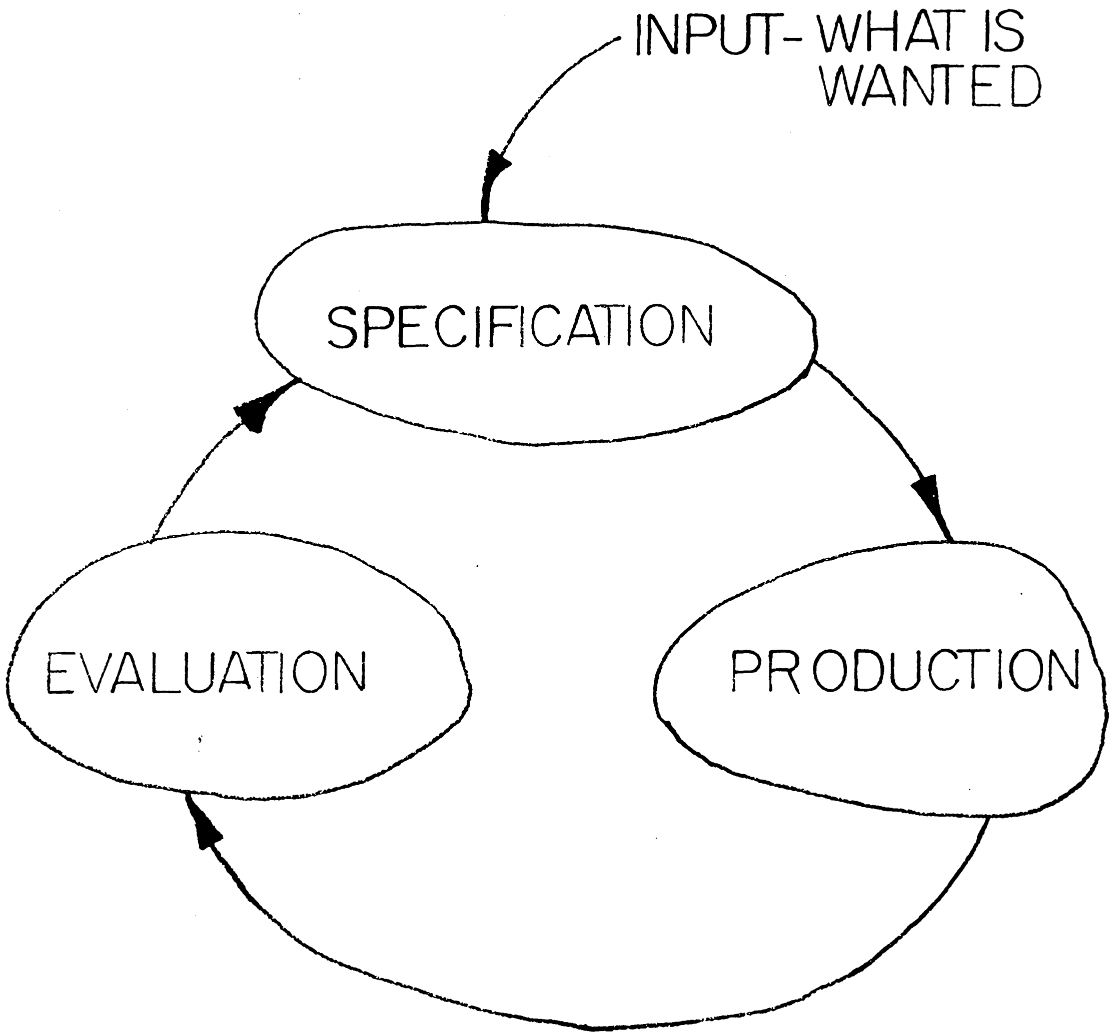

Figure 8. The Statistical Quality Control Cycle

of the sensing devices. However, it should be stressed that the people who interpret this tool are actually the real sensors. This sensor is actually located in the production component of the cycle.

However, there are also sensors in the specification and evaluation components and often there is more than one sensor in each component. This is a factor that makes the action of the loop much more complex than that of a relatively simple process control loop that employs only one electro-mechanical sensor.

Consider the evaluation or inspection component of the loop. The function of this component is to answer the question, "Did I in fact produce what I wanted to produce?" The sensing in this component is accomplished through prescribed procedures for inspecting the manufactured product. This inspection could be manual or automatic. It could be performed by one person or a very large group of people, or by specifically designed automated equipment. Thus, the sensing is complicated and it is probably performed by several sensors.

The ultimate result of this action is to send some sort of error signal to the specification component that serves to define that which the process is capable of producing. Here a sensor - probably a design engineer or a group of design engineers - decide what if any specification changes should be made after comparing that which is desired with process capabilities. Perhaps this error signal is passed on to other sensors in the specification component including the customer,[11] who must approve any change in design specifications.

Eventually, specifications are arrived at and passed on to the production component of the cycle. Here, sensors analyze the specifications and they are submitted to various closed-loops within the production component. Although the action of these loops will not be discussed in detail here, let it be said that various closed-loop systems operate within the production component to arrive at plans for the design of the process, the production rate, the production method, and various other considerations necessary for the actual production of the product. At length, actual production starts and the results are evaluated through use of the concept of statistical stability. This sensing device serves to point out the need for corrective action to eliminate assignable causes through the action of a closed-loop for process control. This contributes to the production of product consistent with process capabilities. The resulting product is submitted to the evaluation component, the point that we chose to enter the cycle.

This is just one example of a closed-loop information feedback system found in organizations today. It is similar to the basic process control loop discussed in Section II, yet it is infinitely more complicated because many human sensors operate within the loop. If this over simplified example is analyzed more closely, as it will be in the next section, it will be found that loops interconnect and overlap, thus greatly complicating the total organizational process.

In spite of the complexity involved, the logic of this relatively simple cycle seems clear and when it is presented it usually meets with few detractors. Nevertheless, it is appalling the number of times this process functions as an open-loop cycle, even today. Much has been written of instances where specifications have been made and kept with no consideration of process capabilities. With the always high cost of production that attend such fallacious decisions, the economic consequences that result are most severe and represent an unnecessary burden on a productive society. To avoid these severe consequences, it is necessary to make decisions within the framework of this closed-loop information feedback cycle that will cause specifications to be based not only on what is wanted, but also on the capabilities of the production process.

IV

THE COMPLEXITY OF INTERCONNECTED INFORMATION FEEDBACK SYSTEMS

As an introduction to the complex and varied characteristics of closely related closed-loop information feedback systems, it seems appropriate to consider an intricate system familar to those engaged in industrial activities and investigate its particular closed-loop properties. This means that the system must be operational today and, preferably, that the decisions made in the framework of the loop are rationally based on quantitative data and that sensing devices are available that provide some sort of an error signal to provide a basis for action.

Such a system is the physical production process. These processes are expected to produce a product that is acceptable to the customer. Implicit in this statement is the well known fact that products must conform to certain quality specifications. However, as this thesis pointed out in Section III, quality specifications to be realistic, must be based not only on what is wanted, but also on the capabilities of the process. This logic can only be achieved through the operation of a closed-loop information feedback system. This is the classic statistical quality control cycle of specification to production to inspection and back to specification. The primary sensing device in this loop is Shewhart's model of statistical stability and it is the consideration of this loop that forces quality specifications to be based not only on what is wanted but also on the capabilities of the process.

However, it is not enough just to realize the existence of this interdependence of quality specifications and process capabilities. Relative to the quality level - the environment in our basic closed-loop - there are also many other interlocking closed-loops that are of great significance in the total organizational process. Figure 9 illustrates some of these systems that are such an integral part of total operations.

For example, it is clear that the amount of labor utilized and the skill that it possesses affects and can be affected by the quality level of the physical product. There are many instances where not enough or too much labor adversely affects the quality level. It would be possible, and perhaps often desirable, to use Shewhart's model of statistical stability as the sensing device in this closed loop in order to evaluate labor requirements.

To illustrate, consider a process that involves the plating of a metallic substance on glass blanks, forming an electrical circuit. In order to achieve the desired electrical properties, it is necessary to wipe the glass surface to free it of contaminants. This operation is performed by hand, operators wiping the glass blanks as they pass by on a conveyor.

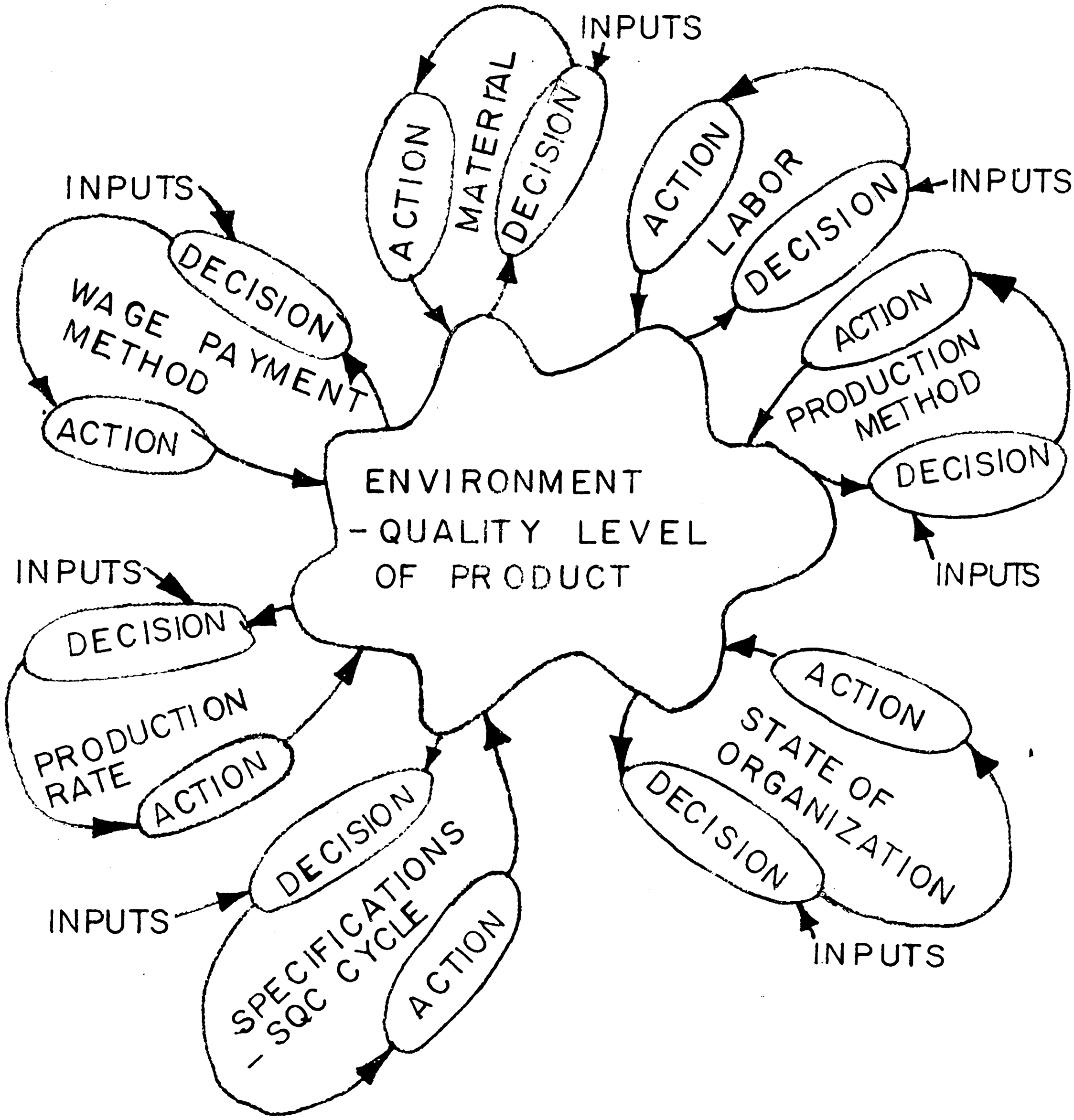

Figure 9. Interconnected Information Feedback Systems

Using Shewhart's model of statistical stability, it would be possible to vary the labor used on such an operation and determine the result on the quality level obtainable. However, if this is attempted, it is essential to recognize the existence of the various other loops that also operate on the quality level, and stabilize their effect so that significant variations that result are in fact contributed by varying the labor. Through such a procedure, labor costs could be "minimized".

In a similar manner, other factors that operate on the quality level could be analyzed in much the same way. Some are relatively obvious, such as the amount of labor discussed above. Other obvious examples would be the material used in the product, the method used, and the rate of production.

However, other loops are much more complicated and not nearly so obvious. Two such loops are the ones involving the method of wage payment and the state of organization. These two are similar in that they have a very real but more subtle affect on the level of quality obtainable and, as a result, there is a general tendency to overlook the operation of these loops - even if their existence is recognized - because it is considered difficult to analyze them quantitatively.

These are more accurately termed organizational process loops while the others have to do more with the actual physical production process. Yet as Figure 9 shows, the production and organizational loops all act on the same environment and they are, therefore, interconnected and to some degree overlapping. Furthermore, this thesis proposes that it is possible to use the same sensing device - Shewhart's stability model - to furnish the basis for decision making that will serve to close the organizational loops. It is possible that it will prove practical to use the model quantitatively for this purpose. However, it will probably be sufficient to use it conceptually in most instances.

Consider the wage payment question as the closed-loop cycle illustrated in Figure 9. There are many ways that this affects the quality level of the finished product and this information must be fed back to the decision point where wage issues are decided. Good wages are a factor in attracting capable workers and this is one of the many things that helps to create a quality conscious attitude. And it is not just the level of wages that is important, the method of wage payment must also be considered. What affect would the installation of incentives have upon the quality level? If incentives are being used, will a necessary downward revision in rates have an adverse affect on product quality?

This question of incentive rate revisions is always a difficult one for many reasons. One of the most important ones is the affect on quality. The answer is yes, rate revisions often have the result of causing a drop in the quality level and often the quantity of product. The possibility of this change in total process capabilities must be recognized and the value of measuring its effect through the use of Shewhart's model should not be overlooked.

Similarily, the state of organization affects the capabilities of the production process and as a result, has an effect on the quality level of the product. This state of organization can be generally defined as the result of the sum total of all relationships between individuals, between individuals and groups, and between individuals and machines.

It is logical to assume that the process that determines this state of organization should operate as an information feedback system. However, the quality level of product obtainable is not the only consideration that affects the decision that determines the state of organization, though it is certainly of great importance. Other considerations are represented by the inputs in this loop, which is an oversimplification. Actually, the state of organization is a factor present in many interlocking and overlapping systems, and because people are the essential element, these systems are considered n-dimensional. It is the intricies of these organizational feedback systems about which this thesis will be concerned.

V

THE BASIC CLOSED -LOOP SYSTEM IN ORGANIZATION

The Concept of Organizational Stability - The Sensing Device

This thesis has explored the use of various ramifications of the concept of stability in each of three sections. In Section II, the method of controlling a certain variable pertinent to the performance of a chemical process was studied. In this case, the general design of an electronic feedback control system was outlined that performed the function of effectively controlling the temperature of a liquid, Stability was a prime consideration in designing this control system because it recognized the fact that certain variation in the level of the controlled variable must be allowed to exist. When only this allowable variation was present, the control system did not call for corrective action. The necessity of designing the system through a consideration of its characteristic stability was supported by outlining how action predicated on factors that ignore this criterion can actually contribute to instability.

The second section dealt with the concept of statistical quality control and how this criterion is utilized as a sensing device in the closed-loop systems that control the process and that determine product specifications. This concept calls for the use of procedures and calculations that lead to an eventual determination of the stable pattern of variation that is inherent to the productive process. Stability is essential here because it recognizes that inherent variation cannot be eliminated. However, the concept signals the presence of assignable causes of variation that must be sought out and removed. Thus, the determination of the stable pattern of variation serves as a basis for action within the framework of closed-loops.

The fourth section investigated other, less obvious closed-loop systems that function in conjunction with the production process. The fact that these closed-loops interlock with those discussed in Section III was illustrated. Furthermore, it was suggested that the criterion of stability outlined in Section III could be employed, quantitatively or conceptually, as the sensing device within these loops upon which the action taken would be based. This has expanded the use of the concept of stability from a criterion for physical process control and a consideration in specification determination to one of the criteria for the determination of such diverse factors as materials, labor, production rate, production method, and state of organization.

However, it is obvious that it would be exceedingly difficult, if not impossible, to use Shewhart's model for production quantitatively as the sensing device in a closed-loop that determines the state of organization. There are many reasons why this cannot be done. Two of these reasons are the fact that the quality level is not sensitive enough to varying states of organization to provide a basis for decisions in this area and secondly, there are a multitude of considerations other than quality level upon which such decisions must also be based. These facts alone are sufficient complications to require some significant modification of Shewhart's model or some totally new criterion of stability to serve as a sensing device in the vastly complicated closed-loops found in organization.

Before considering such a model it is essential to reiterate the basic datum that the capability to achieve stability is in fact the most important consideration in the design and operation of information feedback systems, be they mechanical, electrical, biological, or the type that this thesis is concerned with, organizational. With such an obvious premise established, the usefulness of a model that will serve to define a pattern of stability inherent to organizational processes and that will provide a basis for action within the framework of organizational closed-loop information feedback systems is clear.

A concept that will perform this function has been developed by Roger L. Smith in the doctoral dissertation, "The Role of the Concept of Statistical Stability in Organization Theory".[12] The concepts that follow are a direct adaptation of Smith's model and consideration of these concepts is an essential prerequisite to evolving the theory of organization that follows.

The foundation of this concept is the fact that people as individuals operate within some stable pattern of variation, the characteristics of which are necessarily assumed to be n-dimensional owing to the incomprehensible complexity of humans. This idea of stability is a product of the recognition that all people develop certain traits that cause them to act and react consistently as themselves and not someone else. Although the fact that some stable pattern of variation in the characteristics of individuals is generally acknowledged, to date the life scientists have not provided us with quantatively measurable variables that describe these characteristics. Even if variables were available, mathematical science has not yet developed analytical methods that would enable us to construct the complex type of n-dimensional model necessary to predict the actions of men.

For these reasons, it is clear that such a model must of necessity be conceptual. The model chosen was the Shewhart model of statistical quality control for production processes. Although this model is only two dimensional, it does serve to represent the fact that variation in a physical process is either inherent to the process or the result of some assignable cause. Similarly, we can say that a person either operates within some stable pattern of variation that is inherent to him or he acts as a result of some assignable cause. In other words, some pressure that is not a part of the person's established pattern of stability has acted to force behavior that is not characteristic of the person.

However, in our society people function not only as individuals, but also as members of groups. Therefore, through direct deduction, it is possible to assert that groups of people also operate with some stable pattern of inherent variation if these groups are to continue in existence. Directly, the variables that describe the actions of the group are functions of the same variables that describe the actions of the group members as individuals.

Although we have no quantitatively measurable variables that precisely describe the actions of an individual, it is logical to assume that a person's actions stem from his wants and desires and this is the basic variable used in defining stable patterns of variation inherent to people and to groups. Smith supports this contention that human wants and desires are the basic variable in organization this way: "This was derived generally on the basis that people basically have wants and desires. Many of these wants and desires cannot be fulfilled until men join in association and pool their energy. The moment this happens, in order to fulfill some want or desire, an organization has been created. After creating this organization, the people concerned permit the organization to control their behavior in a specified manner. They permit this control not because organizations are superentities but because they wish to be controlled in order that they can fulfill their wants and desires. These organizations within which we are controlled are not static. They are dynamic ever changing processes because wants and desires of individuals are different and because the wants and desires of an individual change over time."[13]

Given this basic variable for organization and given the fact that the variation in this variable is a dynamic process, the applicability of Shewhart's concept of stability for a process is even more clear. Recalling the discussion of this model relative to the physical production process in Section III, it is possible to conceptually arrive at limits that serve to define the stable pattern of variation inherent to the wants and desires of the organizational members. Although the state of organization is actually a n-dimensional variable, for purposes of illustration this is reduced to two dimensions to fit the existing Shewhart model. Therefore, the state of organization in the two dimensional model becomes the degree of organization. It follows that these limits establish the state or degree of organization of the group. This would mean that a group of people with very similar wants and desires would have narrow limits on the wants and desires and the degree of organization would be great. In contrast, a group of people functioning as an organization who possess somewhat dissimilar wants and desires would cause the limits on the pattern of their wants and desires to be relatively wide and the degree of organization would be less. Conceptually, Shewhart's model as it would apply to an organizational process is shown in Figure 10.

The control limits on the organizational process are a function of the range of the wants and desires of rational sub-groups of organizational members. Furthermore, the integrated weighted mean of the wants and desires of all organizational members is the mean of the objectives of the organization. The fact that measures of wants and desires are weighted means recognizes the fact that the wants and desires of some people in the organization are more influential than others, as is indeed true. This is equivalent to saying that an organization can be only what the wants and desires of its members specify. In terms of the concepts presented in Section III, these limits are a measure of the capabilities of the organizational process.

The logic of this assertion can be supported by considering what happens when an organizational sub-objective is submitted to a sub-group of people who comprise an organizational process. The capabilities of this process are reflected by limits that serve to define the inherent variation in the wants and desires of those who make up the process. However, the sub-objective submitted to that group must be consistent with and contribute to overall organizational objectives. This means that it is possible to submit a sub-objective to a group of people that is not consistent with the wants and desires of those involved.

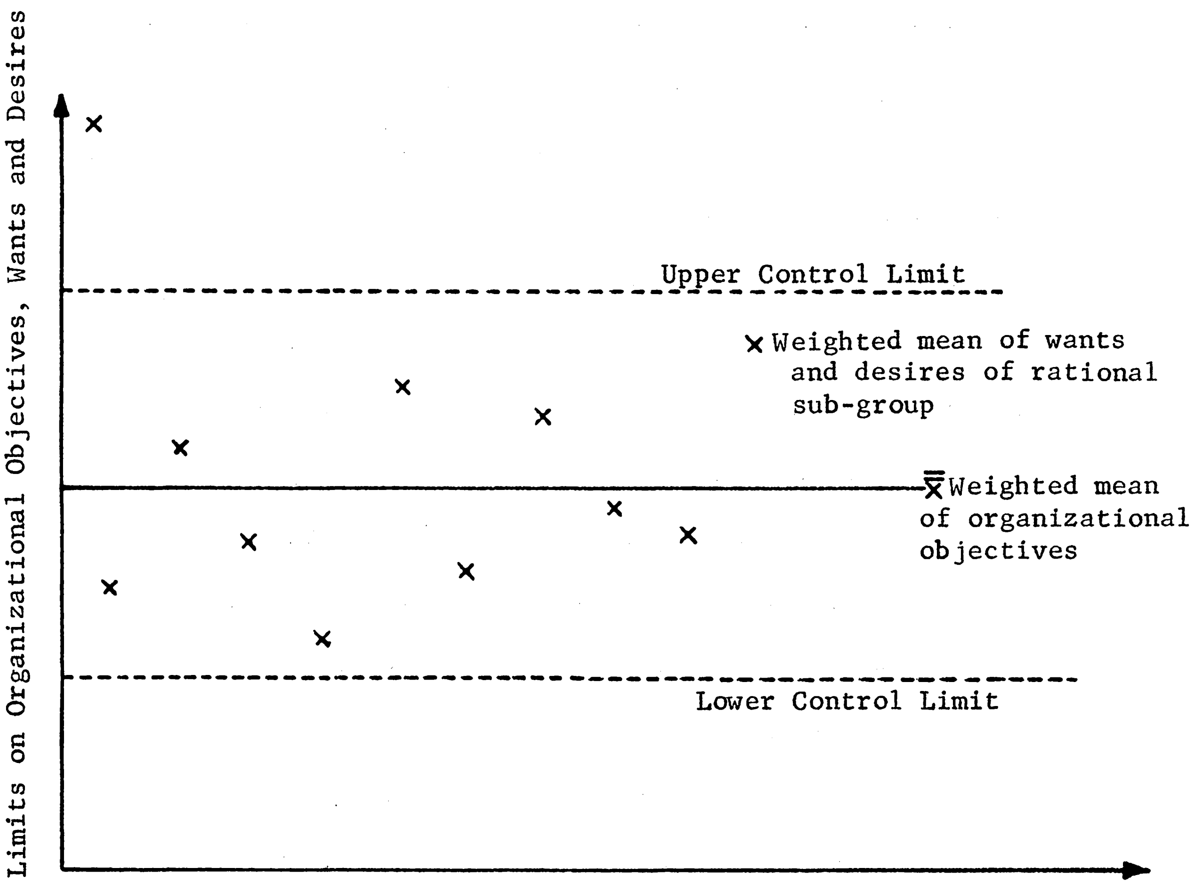

Figure 10. Organizational Stability

Within the concept of the stability model, this would be an objective that falls outside of the control limits on the organizational process. Such an organizational objective should be considered unrealistic when it is compared in the light of organizational process capabilities.

This is the general outline of how the concept of stability in the organizational processes must be considered. This stability criterion will be used as the sensing device in the closed-loop information feedback systems that are in fact the organizational processes with which this thesis is dealing.

<u>Characteristics of the Basic Closed-Loop in Organization</u>

The most basic concept that this thesis embraces is the concept of closed-loop systems. Such systems are characterized by the fact that the environment leads to a decision that results in action that affects the environment and this in turn affects future decisions. This thesis is asserting that these information feedback systems are the most fundamental components in the structure of an organization. Furthermore, each of these basic closed-loop systems should function to achieve some organizational sub-objective that is consistent with and contributes to over-all organizational objectives. Therefore, it is the characteristics of this most basic component in organization that must be described so that we may integrate many of these basic components to form an organization that is in every way effective.

Figure 11 is an illustration of the basic closed-loop system found in organization. In addition to the basic environment to decision to action and back to environment loop, there is a policy loop that interacts with the basic loop that serves to provide the required input to the decision-making function in basic organizational loop. The inputs to the basic loop should essentially consist of defining the sub-objective that the basic loop is to achieve and the policies that must be followed in the process of achieving the sub-objective. It is important to stress that while this is generally true, there is nevertheless, tremendous variation from loop to loop in the extent to which the sub-objective is spelled out and in the extent to which the process of achieving the sub-objective is specified by formal procedures and policies.

It is possible to specify the sub-objectives for basic organizational loops in many ways and the objective that a loop strives to attain is almost always some weighted overall sub-objective that is the result of a desire to achieve many things simultaneously. While it is true that a loop in production might exist primarily to produce a certain product in certain quantities at some specified quality level, the loop must also achieve - at the same time - other objectives relating to costs, employee relations, safety, and other considerations. All of these complications illustrate the complexity of objectives and sub-objectives and it helps us to realize that these objectives are indeed very difficult to define.

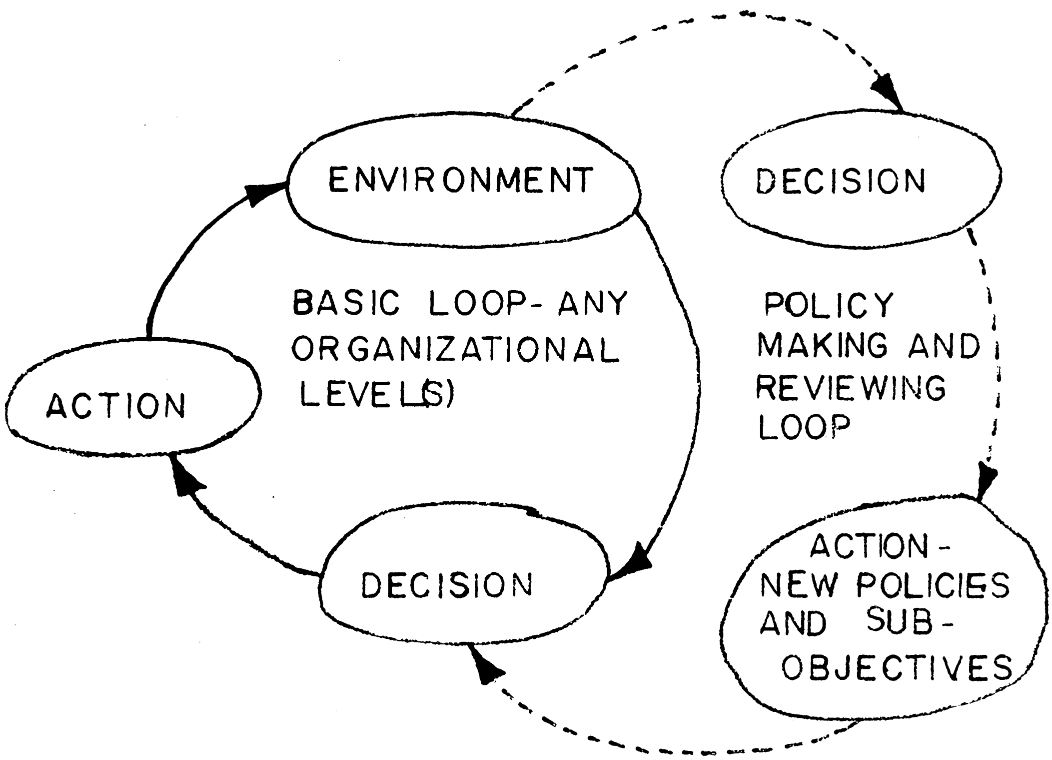

Figure 11. Basic Closed-Loop System in Organization

For this reason, this thesis uses the same basic variable in organization that Smith has proposed and that was discussed earlier in this section. This basic variable is human wants and desires. All organizational objectives, regardless of their nature, are in fact a result of human wants and desires. It is possible to note the logic of this assertion through a consideration of the various objectives imposed upon a basic loop in production discussed briefly just above. Such considerations as quality, quantities, cost, safety,and employee relations, varied though they are, are all functions of wants and desires of organizational members. As stated previously, this is a result of the fact that an organization can be only what the wants and desires of its members specify. Therefore, as we have already assumed, the overall objectives of an organization are the integrated weighted mean of the wants and desires of all organizational members.

However, in order to achieve these overall objectives, it is obviously necessary to reduce overall objectives to many sub-objectives, each obtainable through the operation of a basic organizational closed-loop system. It is therefore necessary that these sub-objectives be consistent with and contribute to overall objectives. And just as overall objectives are some function of wants and desires, the sub-objectives that are submitted to the basic organizational loops can and should be also conceptualized as functions of human wants and desires.

Since this organizational sub-objective is a function of the wants and desires of organizational members, it is most important that there be a way of determining how this sub-objective compares with the wants and desires of those who are expected to achieve it. These people are the ones who function within the basic organizational closed-loop that is expected to achieve this particular sub-objective. It can also be said that the people within this closed-loop function as an organizational process.

Applying Smith's model to the sub-group of people who operate an organizational process, we can say that the capabilities of that process are reflected by the limits on the inherent variation of the wants and desires of those who operate the organizational process. Therefore, the organizational sub-objective, in terms of wants and desires, must fall within these limits that define the organizational process capabilities if the sub-objective is to be effectively achieved.

It can be readily seen that this is a consideration of organizational process capabilities. It is similar to the concept outlined in Section III. In that case, it was concluded that specifications for physical product must, realistically, be based not only on what is wanted, but also on the capabilities of the production process. Here, and earlier in this section, this thesis is asserting that specifications which organizational processes are expected to meet, or organizational sub-objectives, must be based not only on what is wanted - overall organizational objectives - but also on the capabilities of the organizational process. These capabilities are determined by the conceptual control chart that places limits on the inherent variation in the dynamic pattern of the wants and desires of those human beings who comprise an organizational process.

This then, is the concept of stability that is the basic criterion in all closed-loop systems. This sensing device briefly described here and in more detail by Smith is the sensing device that is to be employed in organizational closed-loop systems. Those who operate these systems will interpret such a conceptual control chart and thus decide when corrective action should be taken within the framework of the closed-loop system.

In applying this concept, we are stating that those in higher levels of organization who must supply inputs or sub-objectives to the basic organizational loops must be careful in sensing the capabilities of an organizational process so that the sub-objective imposed is within the inherent variation of the wants and desires of those who comprise the process. This means that if the sub-objective is within these limits, we can realistically expect it to be effectively achieved. In this same context, when evaluation reveals that an organizational process is not achieving its sub-objective, there is reason to expect that the sub-objective is out of control on the conceptual control chart. The only solution to this situation lies in either revising the sub-objective to conform with existing organizational process capabilities or changing the process capabilities through attitude or personnel changes that yield control limits on wants and desires that contain the sub-objective.

It is the key people in organizational processes applying such conceptual control charts on the basic variable of wants and desires who take action that serves to close the loops. When such people can alter wants and desires through attitude or personnel changes that would enable the process capabilities to embrace an out of control sub-objective, then corrective action is taken within the framework of the basic organizational closed-loop system, as is indeed desirable.

When such an assignable cause occurs, however, this thesis asserts that while the basic loop is designed to take necessary corrective action, the policy loop serves the function of monitoring these assignable causes. Through this process of monitoring assignable causes, those who function as a part of the policy loop are in a position to determine if there has been a basic shift in the organizational process. If such out of control sub-objectives occur at a sufficiently high frequency, then decisions must be made at this higher organization level regarding whether or not such unrealistic sub-objectives should continue to be assigned to the organizational process. The policy loop would also decide whether or not revised policies would enable the process to better achieve the sub-objective. Or, perhaps the policy loop would decide that rather significant changes must be made in process capabilities that would bring about significant changes in the wants and desires of those who comprise the organizational process so that the desired objectives are obtained through the action of a revised process.

In any event, a shift in the capabilities of an organizational process should result in action by those who comprise the policy loop. Whatever decision is made at this higher organizational level is reflected by revised inputs to the basic operating loop. The revisions might be in the form of a revised sub-objective, revised policies to make the existing sub-objective more readily obtainable, revised process capabilities through personnel or attitude changes, or any conceivable combination of these types of changes.

This means that those in positions of responsibility are essentially involved with checking to determine if the basic organizational closed-loops are functioning as they should. This is what traditional organizational theory has recognized generally as the exception principle. Such a principle essentially calls for the "boss" to handle only those matters that are considered exceptional as opposed to those that are routine. However, the real problem has always been to differentiate between the routine and the exceptional. As all of those experienced in business know, a very high percentage of what happens today is in some way different from what happened yesterday and is, therefore, something of an exception. This means that those in positions of responsibility must somehow chose those matters that seem to be the most exceptional and, therefore, most deserving of their attention. Regretably, in the past the only way to make such decisions has been through intuitive judgment.

However, if this theory is followed, a criterion upon which such decisions can be made is provided. Although it is at this time only conceptual, it is nevertheless vastly superior to making such decisions through intuitive judgment. The criterion described here differentiates between assignable causes and inherent variation and limits on the pattern of inherent variation are conceptualized that makes the distinction possible. Through the continuing consideration of this theory, it is possible to keep objectives consistent with the capabilities of the organizational process that must achieve the objective.

This is not necessarily advocating sub-objectives that are always readily obtainable within the framework of existing process capabilities. It is often advantageous to submit a sub-objective to an organizational process that is slightly beyond present process capabilities. This is actually one method of changing process capabilities. When such action is taken, however, one must have some idea that the process is capable of modifying itself so that the objective can be attained. If the process is incapable of so modifying itself, the objective cannot be achieved. So even in cases where a goal is set beyond present process capabilities, the ability of the process to adjust to the goal must be considered when the decision is made regarding how far outside of the capability limits the goal should be set.

Again, this is a matter of varying the wants and desires of those who operate the basic organizational process. If a goal that is somewhat unrealistic is submitted to certain people, they prove capable of modifying their wants and desires in order to achieve the goal. Others, however, in a similar situation will give up when confronted with an unrealistic goal and actually become even more incapable of attaining the goal. This is just one dimension in the n-dimensional model of organizational process capabilities.

Operation of the Basic Closed-Loop in Organization

Since a closed-loop that exists within an organization exists to achieve a certain specified objective, there are as many closed-loop systems as there are objectives or sub-objectives. This means that as organizational objectives are broken down into various sub-objectives, an integral part of this planning is to simultaneously define the organizational process that is to achieve the specified sub-objective.

This is implying that the total organization itself functions as one gigantic n-dimensional closed-loop information feedback system and, this is indeed the case. The organization as a whole makes decisions, translates these decisions into action which causes a change in the environment and thus affects future decisions. As an example, a company periodically makes decisions to enter into a certain area of the market that they serve. Such action causes competitors to react and the total business environment that the firm operates within is changed. This, in turn affects future decisions.

Within this gigantic system, there exist other closed-loop systems that function to achieve specified sub-objectives. An example of this phenomenon would be the large corporation with several divisions, each functioning as a closed-loop system with certain specified sub-objectives within the total corporation that is itself a closed-loop system. In turn, these divisions themselves have sub-objectives and this breakdown could go on and on until the point is reached where it is no longer possible or advantageous to continue to define sub-objectives and the closed-loop organizational processes that are to achieve them. Depending upon the extent to which this analysis is carried out, the number of people who operate the basic organizational process can vary considerably, even down to only one person.

Generally, this is the concept of loops within loops. Through these interconnected processes, sub-objectives are obtained that contribute to the attainment of overall objectives. Furthermore, since organizational members usually contribute to the attainment of more than just one sub-objective and therefore operate as a part of several closed-loop systems, it is obvious that these systems must not only interconnect, but they also overlap.

Since application of this theory cannot be made without reference to today's organizations and contemporary principles of organizational design, it is completely impractical to divorce the thoughts contained here from existing concepts of organization. While today's theory recognizes that organizations do not and should not function as the existing model - the organization chart - indicates, there has not yet been developed a model that provides a more accurate respresentation of reality. However, this thesis is developing a conceptual model of organizations that is a greatly improved model of actual organizational structure.

Consider one department that functions as one segment in the total organization. Such departments are headed by one person who is responsible for the effective functioning of the entire group of people who make up the department to attain some specified objective. It is this department head, and only the department head, who, according to the formal contemporary model of organizations, has the only contact with the remainder of the organization. Is this an accurate representation of reality? Does this person and only this person in fact have the only contact with the remainder of the organization?

No, this is not an accurate representation of reality, nor does it represent ideal relationships.

Assuming that the objectives of this department are broad enough to require division into manageable sub-objectives and assuming that the department does not exist in a conceptual vacuum as a research department superficially might be considered, it will be necessary for the closed-loop systems that function to attain these objectives to include people from other departments. This means that organizational processes, streamlined and functionally designed to achieve some specified sub-objective, will cut across "formal" organizational relationships to carry information along the route that facilitates the most efficient achievement of the sub-objective.

Recalling the earlier theoretical assertion of this thesis that the function of the person responsible for the operation of a group of basic organizational loops is essentially to monitor assignable causes occuring on the conceptual control chart that serves as the sensing aid in the basic loops, the department head would thus be required to monitor assignable causes on organizational processes that include people not under his direct control in the formal sense. This situation must be considered because the degree to which loops overlap is so great that this monitoring of inter-departmental interactions will always be present.

It follows that the application of this theory requires some extensive reconsideration of the generally accepted principle of unilateral exercise of responsibility by a department head for the matters involving those in his department. This theory might possibly require the person responsible for the action of a closed-loop system to seek out an assignable cause when one occurs, especially if it seems to indicate a basic shift in the process, and take whatever corrective action might be necessary. It is certainly possible that such action might involve a person who is not the direct responsibility of the department head. It is the occurrence of this situation that would require some compromise in the usually accepted principle of unilateral responsibility by a department head.

Therefore, this theory calls for a re-evaluation of the principle of organizing on a department or functional basis alone. It is often clear that the division of an organization into various departments results in division of responsibility that proves somewhat artificial and an additional barrier to the effective attainment of objectives. In contrast, this theory is proposing organization that is primarily oriented toward the effective attainment of sub-objectives, each through the operation of a highly efficient closed-loop information feedback system that knows no formal organizational barriers.

This type of information flow can be contrasted to that specified by traditional organization theory where the department head or "boss" is the only contact with the remainder of the organization. This is equivalent to asserting that information that must necessarily involve other departments must flow through this one connection point. However, this is of course highly impractical and inefficient and organizations have never actually operated in this manner, with the possible exception of a pure line organization such as traditional military unit which is now largely extinct.

The existence of loops that cut across formal organizational lines has been generally recognized and referred to vaguely as "informal organization" or perhaps "horizontal coordination". But as a rule, the details of such organization have not been investigated to any significant extent. This is true largely because it is assumed to be different for all organizations and that no universally applicable principles seem to exist upon which such design considerations can be based. As a result, there is an unfortunate connotation that organizational relationships that do not follow specified channels are in some ways unhealthy for the organization. This feeling is usually some variation of the idea that the authority of a superior is being circumvented and the connotation that this is not exactly as it should be is shared by both the superior and those who participate in "informal" relationships.

If an organization is designed within the theoretical context of this thesis, the need to differentiate between formal and informal organizational relationships is greatly diminished if not completely eliminated. We are stating that a basic organizational process is designed in the form of a closed-loop information feedback system to achieve each specified sub-objective. This process is the most efficient one possible because it knows no traditional organizational barriers. It is entirely objective-oriented. When those who operate this process are made aware of its function, it becomes a directed, self-corrective cycle. The function of the person in a position of responsibility above this loop is to design the basic loop, to provide it with inputs in the form of the sub-objective and the policies to be followed, and to monitor the assignable causes that occur. If they occur at such a frequency that a basic shift in process capabilities is indicated, then the policy loop must take action that modifies the capabilities of the loop so that the sub-objective once again becomes obtainable or initiates action that results in a revised sub-objective that falls within the inherent pattern of the wants and desires of those who make up the organizational process.

Summary

This section has delineated the concept of the closed-loop information feedback system that this theory is proposing as the basic element in the design of organizations. As is true with all closed-loop systems, the criterion of stability is the central principle upon which the action taken within the framework of the loop is predicated. The actual application of the sensing device that incorporates this criterion as its basic principle was discussed in some detail. The remaining problem is to utilize this basic element to develop the concept of the total organization. This integration of principles follows in Section VI.

VI

THE TOTAL ORGANIZATION - A PYRAMIDING, N-DIMENSIONAL NETWORK OF INTERCONNECTED AND OVERLAPPING CLOSED-LOOP INFORMATION FEEDBACK SYSTEMS

In Section V of this thesis the general structure and operating characteristics of closed-loop information feedback systems were described as they apply to organizations. These systems are conceived as the basic processes in organizations, each functioning to attain some specific organizational sub-objective. The remaining problem is to utilize this basic component to achieve a design for the total organization.

Recall that the flow of information in the basic organizational loops is specified so that the sub-objective is attained in the most effective and efficient manner. This flow of information represents the structure of the organizational process. Furthermore, the capabilities of the process are reflected by the limits that contain the inherent variation of the dynamic pattern of wants and desires of those who function as a part of the process. The sensing device that provides the basis for action which keeps the process functioning requires that realistic sub-objectives must fall within these limits.

If this sensing device indicates the presence of an assignable cause - a sub-objective that is not consistent with the wants and desires of those who must achieve it - the basic loop functions to correct for the assignable cause and the policy loop simultaneously monitors its presence. If the frequency of such causes indicates a shift in process capabilities, the policy loop must take appropriate action to return the process to a state of control. Such action could be in the form of a revised sub-objective, revised policies to enable the process to better achieve the sub-objective, changes in process capabilities through personnel and/or attitude changes, or any conceivable combination of these changes. The decision that the policy loop makes on these matters is translated into action when the policy loop provides the basic loop with revised inputs.

The Concept of Organization - Nexus Centers and their Functions

This broad scope of the functions of the policy loop is an indication that the decision making nexus of this loop is located at what we shall consider a higher organizational level. This means that one decision making nexus determines the design of and inputs for many basic loops. This fundamental principle is the concept that functions to coordinate many complex closed-loop systems that interconnect and overlap. It is also an initial indication that the total organization will assume a generally pyramiding shape.

Each of these nexus points in the organization receives broad objectives from still higher organizational levels that are a function of total organizational objectives. It follows that one of the primary functions of this nexus is to break these objectives down still further into rational sub-objectives. It is fundamental to assert that the higher organizational levels are not concerned with the specific breakdown of the objectives by the nexus centers. The important factor is that the breakdown result in achievement of the objective.

Thus, the sub-objectives that result must be a function not only of what is wanted, but also of the capabilities of the organizational process that operates to achieve the sub-objective. Since the decision-making function in the nexus center has specified the design of these processes, and is monitoring their performance, it follows that this nexus has the necessary knowledge of process capabilities. For this reason, sub-objectives and the process to accomplish them are simultaneously specified at this level. In closed-loop terminology, the objective that specifies what is wanted occurs as an input from higher organizational levels and the knowledge of process capabilities is indicated by the conceptual control charts of wants and desires and is obtained through feedback of the basic loops.

The policies and procedures that the basic organizational loops are expected to follow in achieving the sub-objective are theoretically provided by the nexus center. However, in the case of policies, this usually involves simply passing on through the inputs to the basic loops overall organizational policies that originate at higher levels, plus whatever local policies the nexus deems necessary. These policies would be essentially identical for all the loops that operate in this area of the organization.

The procedures that outline the way in which the sub-objective is to be attained can vary greatly from loop to loop in the extent to which the process of achieving the sub-objective is spelled out. For some loops this involves little more than simply defining the sub-objective, while for other loops the process of attaining the sub-objective is spelled out in considerable detail by procedures. This wide variation in the scope of procedures is one of the most significant ways of illustrating the wide variation in the nature of inputs that can occur from loop to loop.

This type of relationship that exists between a nexus center and a group of basic organizational loops is the most important type of connection that occurs to integrate the action of many closed-loop systems. To make a general comparison with the contemporary organizational theory and model, such a nexus center would be somewhat equivalent to the head of a department. However, the equivalence is not exact because the nexus center is monitoring assignable causes of loops that cut across traditional organizational lines. This occurs because the organizational processes are objective oriented and this very often calls for information flow and interactions that involve many functional areas of the organization.

This orientation toward objectives is the primary reason for rather extensive overlapping of closed-loops, especially in certain key areas of the organization. Simply stated, an overlap occurs when a person is involved in more than one organizational process, where the processes are not specifically connected. The distinction between a connection and an overlap is largely one of degree, since any two closed-loops in organization cannot be considered completely independent because both are necessary for the attainment of overall organizational objectives. Therefore, the loops must be in some way or ways connected in the n-dimensional array that is the total organization. However, the distinction here is that when a person is involved in more than one process and this person does not perform the function of connecting the processes, an overlap occurs.

The occurrence of these overlaps strongly suggests the importance of the problem of possible conflict situations. This was discussed briefly in the previous section. It was suggested there that this theory calls for some extensive reconsideration of the principle of organizing on a functional basis alone.

Since basic organizational closed-loops cut across formal lines of responsibility, it was pointed out that assignable causes could possibly be traced to areas in the organization that are not the formal responsibility of the nexus center who must take action if these causes indicate a basic shift in process capabilities. Furthermore, owing to widespread overlap throughout the organization, such conflict situations must be expected and some general outline for dealing with these situations should be specified.

An appreciation for the complexity of such conflicts can be developed through a brief consideration of the variable that most accurately describes the nature of the organizational processes, human wants and desires. If one chooses to take corrective action by operating on the wants and desires of the person who seems to be imposing restrictions on process capabilities, it is clear that the capabilities of not just one, but several loops will be affected if such a person represents a point in the organization where significant overlap occurs. This is true because the wants and desires of a person are constant at any one instant and do not vary depending upon the process to which they are being related. Thus, a change in such a person's wants and desires would affect the capabilities of several organizational processes.

The determination of the course of action that should be taken when such a conflict arises is considered the objective of specific closed-loop system. This system can be conceptualized as connecting all the nexus points that monitor the processes that such a key person functions as a part of. This is essential because the capabilities of all of these processes would be affected to some degree if this person's wants and desires change or if this person is replaced in the organization. This type of n-dimensional coordination is thus involved with evaluating the relative importance of organizational sub-objectives distributed throughout the total network. This evaluation is of course subject to inputs from higher levels and, if necessary, coordination problems are relayed to higher levels. This would occur if n-dimensional coordination by nexus centers results in the general consensus that the various objectives submitted to these nexus centers are in irresolvable conflict or are the completely inconsistent with existing process capabilities.

Within the theoretical framework of this theory, such problems would become evident to even higher organizational levels since they in fact represent assignable causes. Just as basic organizational loops have policy making and reviewing loops, these n-dimensional loops that provide organizational coordination by connecting pertinent nexus points also have policy making and reviewing loops. The decision making function in these loops, in turn rests at some level of organization that is still higher in our network of closed-loops systems that is now obviously pyramiding.

Furthermore, these second level nexus centers monitor assignable causes for many of these coordinating loops. This means that the concepts of organization at this level are essentially the same as discussed for the first level nexus centers coordinating the basic organizational closed-loops. The basic variable is also the same and the sensing device is interpreted in the same general way. The basic difference is that the objectives submitted to the nexus center and the sub-objectives specified by the nexus center become broader as the apex of the pyramiding system is approached.

The two general catergories of responsibility of nexus centers are, therefore, to direct a group of basic loops and to participate in organizational processes that function to coordinate the efforts of many clusters of loops within the total network. It can be seen that the responsibility of the nexus centers increases as the scope of the problems involved becomes broader, or as the apex of the pyramiding system is approached.

Leadership Characteristics for Nexus Centers

This responsibility that becomes increasingly critical in higher organizational levels clearly calls for people with leadership abilities to function as nexus centers throughout the organization. It follows that, in order to place effective people in these pivotal positions, some measure of desirable leadership characteristics should be developed within the framework of this theory. Such a determination should prove useful by those seeking to make this model operational.

Although much has been written on the characteristics of a leader, the basic problem of defining variables and making measurements in the area of the life sciences has rendered such efforts to be largely descriptive in nature. And these efforts have the common short-coming of a lack of any real scientific basis. This type of work seems to arrive at the general consensus that we really don't know what a leader is except that he is different. Yet, it is always essential to add that a leader must also have much in common with those who choose to follow him.

In developing the concept of a leader within the framework of this theory, it is necessary to assume that the primary positions of responsibility and leadership within an organization are the nexus centers discussed in this section. Furthermore, as we move up the pyramiding array, the nexus centers at higher levels require a greater degree of leadership. This is true because objectives and organizational processes are more complex at these higher levels. Also, the interconnected and overlapping loops that exist at these levels should be conceptualized as involving more dimensions than those at lower levels. It follows that the degree of leadership necessary to integrate and coordinate these loops is indeed more significant.

It is necessary to return to a consideration of our basic organizational variable, human wants and desires. Recall that the wants and desires of all people exist at some generally identifiable level and that the pattern of these wants and desires over time results in limits that define the stable inherent variation present. This concept of stability applies to groups as well as individuals, and the integrated weighted mean of the wants and desires of all organizational members is in fact the mean of overall organizational objectives.

This thesis is proposing a ramification of this concept to define the most basic characteristic of a leader. It is proposing that the wants and desires of those capable of operating in areas of significant leadership must not only reflect stability, but they must also have a broad pattern of inherent variation.

This basic characteristic must be present in leaders for many reasons, three of which will be briefly mentioned here. First, at the higher levels where a leader functions, the many objectives that must be achieved by the processes that the leader functions within or monitors are extremely varied in nature. However, all of these diverse objectives must fall within the limits that conceptualize the inherent pattern of variation in his wants and desires if he is to contribute to their achievement. Thus, the essential requirement that this pattern of variation be broad. Secondly, a broad pattern of variation in this basic variable means that many people whose wants and desires exist at various levels with relatively narrow patterns of variation can identify with the leader and choose to follow him. This is an essential condition for the productive interactions between a superior and a subordinate that must occur as a part of organizational processes. It enables the feedback from the subordinate to the superior to affect decisions at higher organizational levels and it contributes to the effective implementation of sub-objectives. Thirdly, this broad pattern of wants and desires enables the superior or nexus center to rationally deal with situations involving the element of conflict. When such a situation occurs, a leader with a broad pattern of variation can resolve the problem, whereas a person with a narrow pattern of variation would likely find himself definitely aligned with one of the combatants because of similar wants and desires. Conceptually, this means that the position of one party would be outside of the control limits of the leader as well as the opposite party. The solution reached in this latter situation would be completely unsatisfactory to one of the parties and it would surely have a disruptive effect on the total organization.

An example of the need for a broad pattern of inherent variation in wants and desires at the executive level is the person who is responsible for research and development activities. Such a person must be exceedingly tolerant of conflicting opinions. People in a research organization should be specifically selected so that an abundance of new and varied ideas will be created. Of course, this will result in tremendous competition in an area where only a small percentage of the ideas can be fully developed. The tremendously important decisions that distinguish between projects and ideas to be developed and those not to be developed must be made only after careful consideration of every possibility.

It is this extensive analysis that demands a person possessing a very broad pattern of inherent variation in his wants and desires if his analysis is to be complete and his final decision rational.

The importance of selecting executives who function as nexus centers through a consideration of this criterion cannot be overemphasized. This is indeed necessary for the effective functioning of an organization, which means that evaluations should be made to determine whether or not those who now have broad responsibilities do in fact have this characteristic. Also, this is of great importance as a design consideration, since one of the most essential facets of the organizational design process is to select people to function as nexus centers.

Nexus Span of Control

Another important design consideration is the question of how many closed-loop systems a nexus center can effectively monitor and how many additional processes or loops he can actually function as a part of. Relative to traditional theories or organization, this is somewhat similar to the consideration of span of control, which is usually defined as the number of subordinates that can be effectively supervised by one man. The actual number is generally set between three and six.[14] However, the difference between the functions of a nexus center as outlined by this theory and an executive in the traditional sense are so different that they should be emphasized here.

The contemporary functions of an executive, stated very generally, are to direct and supervise. The actual extent to which the executive exercises this broad responsibility is of course greatly tempered by the degree to which "delegation of authority" is practiced. Nevertheless, such an executive is essentially free to delegate or to become involved in the responsibilities that primarily belong to a subordinate as he sees fit. Contemporary theories and models offer little or no assistance in defining the degree of involvement, except to acknowledge that it exists and it does in fact vary from superior to superior and from subordinate to subordinate and from function to function. In addition, there is little theoretical assistance to indicate the need for involvement by the superior. Therefore, the three to six range mentioned above as the usual span of control is the range that is representative of current management practice.

The contrast between this span of control and the concept of control that this theory is advocating is certainly significant. Recall that the functions of a nexus center or an executive, as specified by this theory, consist of designing a closed-loop system to achieve a specified sub-objective. This sub-objective, along with policies and procedures, occurs as an input to that loop. The nexus center also monitors the operation of this process by monitoring the occurance of assignable causes as indicated by the conceptual control chart. Thus, once the process is operating as it should to achieve the sub-objective, the nexus center knows not to become involved because the process is functioning with only inherent variation present.

If assignable causes occur at such a frequency that a basic shift in process capabilities seems to be indicated, even though objectives remain essentially constant, or if the process is not capable of adjusting to new sub-objectives, then it is clearly the responsibility of the nexus center to take action that serves to return sub-objectives and process capabilities to a state of compatability. It follows that the number of loops that nexus centers can coordinate varies greatly as a result of several factors. The most important consideration is the frequency of input revisions and personnel or attitude changes, since these developments can result in assignable causes. This is essentially a consideration of the characteristics stability of the process, or the probability of assignable causes. Another consideration is the leadership characteristics of the person functioning as the nexus center. The broader the pattern of his wants and desires, the more diverse types of loops he can handle, which would likely result in an increase in the number of loops he would coordinate.

Therefore, the span of control, or the number of loops that one nexus can effectively monitor, depends upon the characteristic stability of the specific loops involved and the inherent variation in the wants and desires of the person who functions as the nexus center. Also, the number of other processes that the nexus center must function as an integral part of has an effect on the number of basic loops he can coordinate. Certainly, it is completely irrational to specify a number or range of loops as an ideal "span of control".

Errors by Nexus Centers

This idea of span of control within the framework of this theory should foster the realization that the nexus center will not be immediately aware of every assignable cause in every loop that the center is monitoring. In the practical sense, this is impossible. It is more realistic to assume that the immediate awareness of assignable causes will vary with time. Furthermore, awareness will vary from nexus center to nexus center. Such a limitation can only be considered reasonable because the nexus center reviews and integrates the activities of many loops, in addition to the loops that the nexus functions within. The essence of this characteristic is that the nexus is unable to immediately note assignable causes in a particular loop if he is occupied with correcting for more significant variations in other loops. However, the essential design consideration here is to be certain that the monitoring is sensitive enough to detect universe shifts that call for the corrective actions described herein.

Since it is unrealistic to assume that the monitoring process is perfectly efficient, the user of this theory should recognize the possibility that two types of errors can occur.

These were discussed in Section III relative to the physical production process. It will be recalled that Type I error was looking for an assignable cause of variation when one was not present and Type II error was not looking for an assignable cause when one does in fact exist.

When considering these errors relative to organizational processes, we shall assume that the assignable causes reflect process shifts and they should, therefore, be detected by the nexus center. This means that Type I error occurs when the nexus center takes action to correct for an organizational sub-objective that is thought to be outside of existing process capabilities, when actually it is not. For ease of discussion, assume such action takes the form of modifying the sub-objective in hopes of fitting it to the process or making personnel or attitude changes to enable process to embrace the "out of control" sub-objective. It is obvious that either of these changes would likely lead to very undesirable results.

In the first instance, the revised sub-objective would not represent a maximum contribution to overall objectives. This sort of compromise could be expected to result in higher costs and generally reduced organizational effectiveness because the revised sub-objective would also necessitate other adjustments in other parts of the organization. The second action would also be undesirable. Changing the capabilities of the process would be disruptive and after the error is discovered, it is possible that the process will have to be changed again to restore it to its original capabilities.

Thus, the conceptual control chart on wants and desires that is so important to the effective operation of organizational processes is also subject to errors in interpretation. One must recognize the possibility of these errors occuring and develop some feel for the probability of their occurrence. Also, a general idea of the proper action to take upon the discovery of such errors will be helpful in taking the proper action with only a minimum time lag.

The Apex of the Network

Consideration of such ideas as nexus centers, leadership characteristics, span of control, and possible errors is fundamental to the optimum design and operation of the type of organization that this thesis is proposing. These considerations must be made in all areas of the n-dimensional network or array that is the total organization. However, it has been shown that this array has a generally pyramiding shape. Therefore, the ultimate nexus center in this array occurs at the apex of the total system. Because the apex is unique in the array, its special characteristics should be described.

The nexus at the apex of our organization is generally comparable to the top spot on the traditional organization chart, usually the board of directors. Recall the earlier assertion of this thesis, that the total organization described herein itself functions as one gigantic closed-loop system with n-dimensional characteristics. It follows that such a system must have an input applied to its controller or decision making function. This input for the total organization is assumed to occur through the apex of the array, and its ultimate value should be conceptualized as total society.

Because of the nature of this total society input, the apex nexus center must interpret what the wants and desires of society seem to be. This is then translated into organizational action that affects the business and social environment of the organization. Resulting profits and other performance indicators are then fed back to the apex nexus and new organizational decisions and action result and the cycle repeats on a continual basis. Therefore, with an awareness of this nature of the total organizational process, the system becomes a directed self corrective cycle and organizational effectiveness is maximized.

This assertion must be true because the organization exists in what we call our total society and if society is to allow its continued existence, its objectives must be compatible with the wants and desires of society. This is not saying, however, that society exerts its only influence on the organization through its apex. Quite to the contrary, the impact of society is much broader. As has already been asserted, the organization is a function of the wants and desires of all its members. Total society has a great affect on these wants and desires because so few wants and desires are inherent to human beings. This means that society has a great deal to do with organizational process capabilities because society does much to control the wants and desires of organizational members, which, in turn, controls the process capabilities. However, the important point is that at the apex of the total organization, the only input must be conceptualized as total society.

This ultimate nexus center must relate the input of total society to the capabilities of the total organizational process. The result is overall organizational objectives. It is necessary for the attainment of these objectives to in someway contribute to what total society deems wantable or desirable if the organization is to continue in existence.

VII

CONCLUSION

The theoretical contention of this thesis is that organizations are in fact pyramiding, n-dimensional networks of interconnected and overlapping closed-loop information feedback systems. Although detailed design considerations are beyond the scope of this thesis, attention has been given to cogitations that the author deems most compelling.

The operating characteristics of physical closed-loop systems were reviewed and the fundamental concepts were applied to the development of a basic closed-loop system for organizational processes. Each of these processes operates to achieve a specified sub-objective and decisions within these processes are based upon the concept of organizational stability.

The n-dimensional network that is the total organization is made up of many of these basic systems. Distinction was made between systems that are connected and those that overlap. The important connecting and coordinating functions of nexus centers has been discussed at some length. Also, the fundamental characteristic of leaders who function as these nexus centers has been described, as well as this theory's equivalent to traditional theory's span of control concept. The possibility of error has been recognized and error types have been discussed. Finally, the ultimate input to the total closed-loop system has been described.

It seems obvious that these considerations, numerous and complex as they are, are only basic to a myriad of considerations. As such, however, they represent the framework of a theory that is a conceptual representation of operational reality. Organizations to be effective, must operate in the general manner proposed.

Therefore, the value of this theory increases as more people become aware of it. This awareness will result in a greater appreciation of actual organizational operation and increased organizational effectiveness. It should also mean that when people become aware of the fact that organizational process capabilities and organizational objectives are a function of their wants and desires, we will witness greater freedom in our industrial society than ever before.

VIII

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. Roger L. Smith and Prof. H. L. Manning for their careful review of this thesis and the many helpful suggestions that they offered. A special debt of gratitude is offered to Dr. Smith for providing the theoretical base for the thesis through his earlier work in the area of organization theory.

Finally, appreciation is extended to for her typing of the draft and final copy and to for her assistance in making the enclosed drawings.

IX

BIBLIOGRAPHY

1. Clough, Donald J., Concepts in Management Science. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1963.

2. Doebelin, Ernest O., Dynamic Analysis and Feedback Control. New York: McGraw-Hill Book Company, Inc., 1962.

3. Forrester, Jay W., Industrial Dynamics. New York: The M.I.T. Press, Massachusetts Institute of Technology, and John Wiley and Sons, Inc., 1961.

4. Grant, Eugene L., Statistical Quality Control. New York: McGraw-Hill Book Company, Inc., 1952.

5. Ireson, William Grant and Grant, Eugene L., Editors, Handbook of Industrial Engineering and Management. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1955.

6. Laitala, Everett, Engineering and Organization. Homewood, Illinois: Richard D. Irwin, Inc., 1959.

7. LaJoy, Millard H., Industrial Automatic Controls. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1954.

8. Porter, A., An Introduction to Servo-Mechanisms. London: Methuen and Co. Ltd. and New York: John Wiley and Sons, Inc., 1950.

9. Smith, R. L., "The Role of the Concept of Statistical Stability in Organization Theory." New York: Columbia University (Doctoral Dissertation), 1959.

X

REFERENCES CITED

1. Doebelin, Ernest O., Dynamic Analysis and Feedback Control (New York: McGraw-Hill Book Company, Inc., 1962), p. 3.

2. Ibid., p. 5.

3. Forrester, Jay W., Industrial Dynamics (New York: The M.I.T. Press, Massachusetts Institute of Technology, and John Wiley and Sons, Inc., 1961), p. 14.

4. Porter, A., An Introduction to Servo-Mechanisms (London: Methuen and Co. Ltd. and New York: John Wiley and Sons, Inc., 1950), p. 1, 2.

5. Doebelin, Ernest O., Dynamic Analysis and Feedback Control (New York: McGraw-Hill Book Company, Inc., 1962), p. 127.

6. Ibid., p. 20.

7. Ibid., p. 20.

8. Ibid., p. 97.

9. Grant, Eugene L., Statistical Quality Control (New York: McGraw-Hill Book Company, Inc., 1952) p. 3.

10. Ibid., p. 133.

11. Laitala, Everett, Engineering and Organization (Homewood, Ill.: Richard D. Irwin, Inc., 1959), p. 35.

12. Smith, R. L., "The Role of the Concept of Statistical Stability in Organization Theory" (New York: Columbia University (Doctoral Dissertation), 1959).

13. Ibid., p. 123.

14. Ireson, William Grant and Grant, Eugene L., Editors, Handbook of Industrial Engineering and Management (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1955) p. 12, 13.

The vita has been removed from the scanned document

ABSTRACT OF THESIS ON

ORGANIZATION AS A PYRAMIDING, N-DIMENSIONAL NETWORK OF INTERCONNECTED AND OVERLAPPING CLOSED LOOP INFORMATION FEEDBACK SYSTEMS

The theory of organization that this thesis proposes possesses a characteristic plasticity that should enable it to span the gap that has traditionally existed between the two broad types of current organizational theories. Generally, one type of theory proposes to describe how organizations should function and the other type proposes to describe how organizations actually do function.

The first type of theory often seems to result in proposals derived from formal, mechanistic concepts that are necessary, but largely superficial and not profoundly significant in an operational sense. The second type of theory essentially seems to suggest that an "informal organization" actually functions to achieve the organizational objectives and such an organization is a function of existing personalities and, as a result, no universally applicable principles appear to exist upon which design considerations can be based. Such conclusions are usually drawn from some form of case studies that inherently produce knowledge that proves incomplete and ephemeral as events move on and organizations evolve.

Therefore, this theory seeks to reconcile and integrate the basic principles of these two types of theories by conceptualizing the basic principles of engineering design and statistical stability as they apply to organizational processes.