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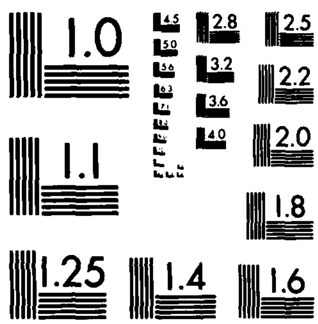

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QUALITY CONTROL IN CONSTRUCTION

BY

EDWARD ENG

A REPORT PRESENTED TO THE GRADUATE COMMITTEE
OF THE DEPARTMENT OF CIVIL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

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To my fiancée, Donna

ACKNOWLEDGEMENTS

I would like to acknowledge The Crom Corporation of Gainesville, Florida for their special assistance and cooperation in the preparation of this report. Special thanks are owed to Mr. R. Bruce Simpson, the President, Chief Executive and Chief Operating Officer of Crom, who allowed me to seek and discover some of the reasons for Crom's success in consistently delivering high quality products. Thanks also belong to Mr. Samuel O. Sawyer, Mr. Robert R. Hendrix, and Mr. James N. Roland for their insightful discussions on quality control.

I would like to especially acknowledge Professor Willard G. Shafer for his guidance and direction in leading me to a more thorough understanding of the subject of quality. Without his personal involvement, this report would not have been possible.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The concept of quality control has been in existence as long as man has had the ability to build and make products. Evidence of this age long concern for quality in construction endures today with the Egyptian pyramids, Greek monuments and Roman structures.

During medieval times, this concern emerged into trade guilds which established standards of workmanship and craftsmanship training to insure quality work. For the most part, this approach to quality control was based on the individual worker's pride. The craftsman had to design, build, inspect, and test his work until he was satisfied with it. Only when his personal standards were met, would he allow his name to be put on it.[1] This approach, although crude and primitive, was effective for its time and to some extent is still found today.

As time passed and the population of societies increased, the needs of the people grew so rapidly that they necessitated a trend toward mass production. This trend brought with it both advantages and disadvantages.

Basically, the advantages were that vast numbers of people could avail themselves of goods and services produced in mass quantities and the individual skill required to produce them were also significantly less. The main disadvantage was that standardization and interchangeability of parts required a more systematic and formalized approach to insure product quality. This effort of precision in standardizing parts added another element to the cost of production. That is the cost of quality assurance.

The science of controlling quality began in the late 1700s and early 1800s with Eli Whitney and his concept of interchangeability. The requirements of this revolutionary concept were that parts had to be made with precision and within limited variances. As the Industrial Revolution took hold, production machinery and processes largely superseded the tools and skills of the individual craftsman.[2] This development alienated the worker from identification with the product and as a result, product integrity suffered.

In order to regain command of product quality, an inspector was used to supplant the once proud craftsman in the assurance phase of the process. As the automation age matured, machine speed (output) was replacing the skill of the craftsman (quality).[3] It was only natural then that the quality control function would become specialized as well. One group would specify quality by establishing standards, another group would perform inspection and tests, another would interpret the inspection and test results, and so on. Even though the players were all specialized, no visible improvement in the final product could be seen. It was not until the early 1920s when Dr. Walter A. Shewhart of Bell Telephone Laboratories began to apply statistical methods to help control quality that the science of quality control become more effective. Dr. Shewhart opened the door for a scientific method approach to the problem of quality. Although slow in being accepted at first, it soon received widespread acceptance with the outbreak of World War II and the country's massive mobilization and procurement effort.

The realm of quality control soon began to conceive distinct areas of specialization such as reliability, maintainability, safety and constructability. These various control disciplines depict the necessity for input from various organizational branches. For example, reliability, maintainability, safety and constructability are all a function of design as well as a function of production. It will be presented later in this report that an integrated quality control system is required rather than various separate disconnected activities.

1.2 Definitions

What does the term "quality control" mean? Many writers on the subject suggest that the best way to understand its meaning is to examine the words "quality" and "control" separately.[4] Quality has a variety of definitions which include:

1. The degree to which a specific product satisfies the wants of a specific consumer. This is the historic definition which prevailed (and still prevails) in those situations where commerce was transacted directly between the one-man producer (tailor, shoemaker, etc.) and the ultimate consumer. This might be termed "market-place quality."
2. The degree to which a class of product possesses potential satisfactions for people generally. This degree is sometimes identified by a "grade" to distinguish it from other degrees of potential satisfaction. The term "quality of design" is also used to describe this degree of potential satisfaction. The term "brand" is often used to describe a producer's designation for a particular grade.
3. The degree to which a specific product conforms to a design or specification. This is known as "quality of conformance."
4. The degree to which a specific product is preferred over competing products of equivalent grade, based on comparative tests by consumers. This is sometimes called "consumer preference."
5. A distinguishing feature of a grade or product, i.e., appearance, performance, length of life, dependability, reliability, durability, maintainability, taste, odor, etc. This is usually referred to as a "quality characteristic."[5]

The word control also has a variety of definitions although it is not nearly as meandering in its meaning as is the word quality. Included in the meaning given to the word control are:

1. The act of direction, influence, restraint, or command over something.
2. The act of verification or correction of something.
3. A device which directs, influences restrains or commands something.
4. A cause or determinant of a resulting phenomenon.
5. A standard of comparison against which to check the results of an experiment.[6]

Combined, the words quality and control have a wide spectrum of interpretation. To some people, it refers only to the testing and inspection function. But that is a severely restrictive and limited interpretation at best. In organizations with a fully developed commitment to quality, quality control encompasses all the activities necessary to ensure the desired level of quality in a product.[7]

A further discussion must be made between the terms quality control and quality assurance. These two terms are often used interchangeably which is incorrect. The differentiation lies in the fact that quality assurance (QA) is defined as "all those planned and systematic actions necessary to provide adequate confidence that a structure, system or component will perform satisfactorily when in service.[8] By comparison, quality control (QC) are those quality assurance actions which provide a means to control and measure the characteristics of a material, structure, component or system to established requirements.[9] The distinction between these terms was clarified in a July 23, 1983 Engineering News Record article addressing quality problems in construction. In the article, the term quality management (QM) was introduced. Quality management stood for the overall program of quality assurance plus quality control. As an equation, it reads QM=QA+QC.

1.3 Purpose

The purpose of this report is to investigate the science of quality control with particular applications in the construction industry. In order to fully understand this topic, an exploration into the evolutionary stages of its growth must first be undertaken. Briefly, quality control was at first, completely vested in the individual craftsman or operator. With expansion and growth it then came under the foreman's responsibility. As prosperity continued to increase, so did the need for a more formalized approach to quality control. Full-time inspectors appeared on the scene, and formally established inspection organizations were created. These organizations were completely separate from production organizations. When the enormous procurement and production requirements of World War II came about, Dr. Walter A. Shewhart's use of statistical control charts significantly improved the inspection process and made it more efficient. Instead of one hundred percent inspection, a sampling inspection technique was employed.

The present evolutionary stage of quality control is termed "total quality control" or a "quality system." This approach is characterized by an all encompassing involvement by everyone who has anything to do with the final product. It involves those who plan, organize, design, build, sell, repair, and maintain the product. The theory being that a coordinated effort is what is required to bring diverse factors into an integrated whole.[10] Figure 1.1 shows the various stages of the Quality Control Evolution.

This report examines each stage of growth, noting both the advantages and disadvantages along the way. It will also compare the "quality circles" of Japanese industries with the quality methods used in this country. Finally, a brief evaluation of the quality control methods used in the successful operation of The Crom Corporation of Gainesville, Florida will complete this report.

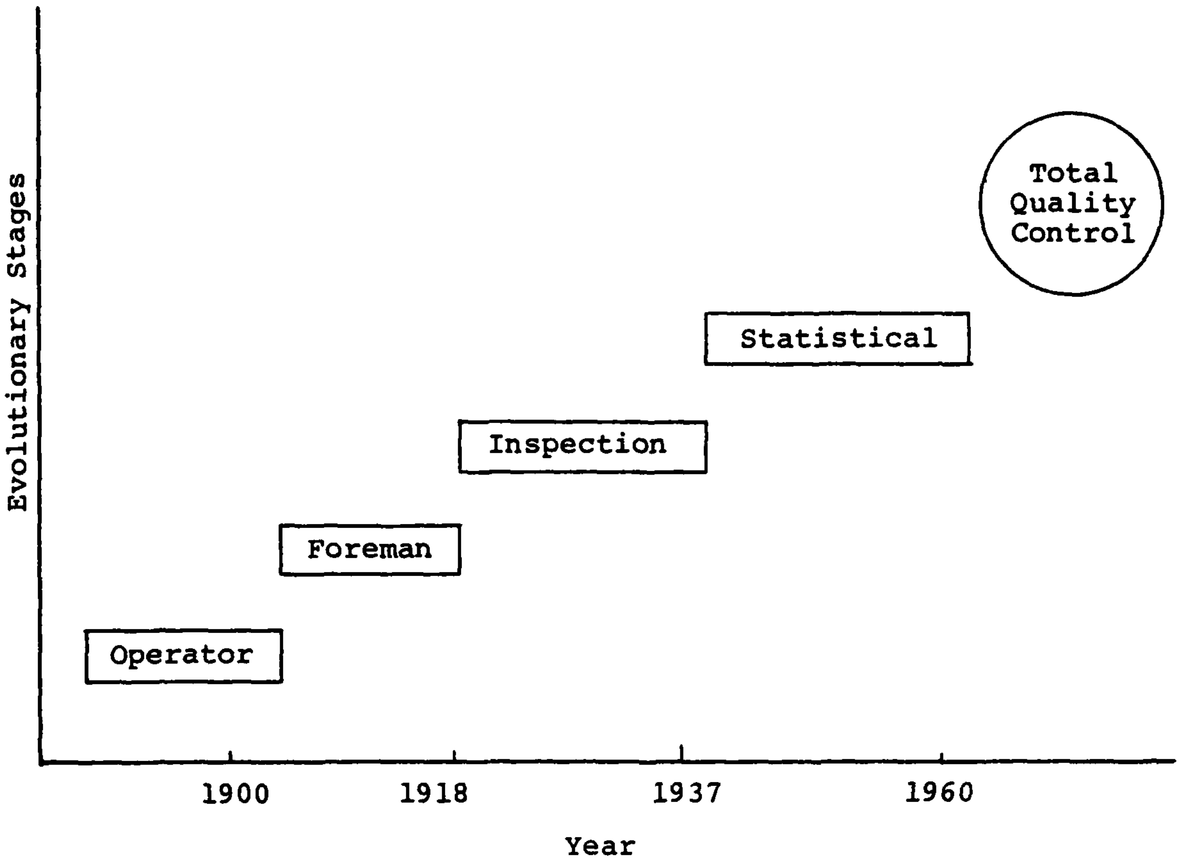

Figure 1.1 Quality Control Evolution
(Source: 11)

CHAPTER TWO

PAST QUALITY CONTROL METHODS

2.1 Craftsman's Pride

In the evolutionary growth of quality control as a science, its beginnings rested in the individual. For it was the individual who depended on his craft for his livelihood. If he produced products of inferior quality, he would soon be unable to sell his wares and talents in exchange for his own needs. Therefore it was incumbent upon the craftsman to reject poor quality work. The decisions facing him were much like those that face business leaders today. That is, "What is good enough?" In other words, how much effort should be expended in the control of quality before the point of diminishing returns is exceeded?

The non-sophistication of the age was one reason that quality control did not become a science but remained as an individualistic concept. The decisions which the craftsman made with regard to, "What is good enough?", were based on the worker's pride. The fruits of his labor and talents that bore his name were deemed to be worthy. Those products which did not meet his standards did not bear his name. Although pride was, and to some extent still is, a major factor in the establishment of quality standards, the market place was also a determinant in shaping acceptable standards. Those who were well-to-do could obviously afford to spend more than those who were less affluent. Consequently, the craftsman could be more painstaking in his work because he was to be adequately compensated for it. On the other hand, he could not be expected to be as skillful if he were to sell his product at a lower margin of profit.

In the past, the market place and the worker's self-esteem determined the standards of acceptable quality. Due to the increased tempo of civilization today, the craftsman has become nearly extinct and increasingly obsolete. For the most part, his role in establishing quality standards has been significantly diminished. The remaining factor is the needs of the market and how much consumers are willing to pay. Complicating the picture though, is the increasing use of technological breakthroughs. What once took a master craftsman months or weeks to produce can now be accomplished in minutes or hours.

The changing social and economic values of the country have also affected the strategy of consumers and hence the standard of quality which they are willing to accept. A long standing philosophy had been that products should last a lifetime. Regardless of whether the product was as complex as a building or as simple as a can opener, people used to purchase things that would last for generations. In today's society, goods are produced which reflect an attitude of "planned obsolescence." If it breaks or wears out, people tend to throw it away and buy a new one. This attitude has led to a degradation of the identification of workers with their products. Accordingly, with the removal of the first line of control, the responsibility for quality control is passed along to the next level.

2.2 Supervisor's Responsibility

As civilization became more sophisticated, so did the process by which products were made. The skill levels formerly required decreased to the point where untrained workers were used to meet the growing labor demand.[12] This was possible because of the growing trend of using machinery instead of the skills required in handicraft methods. Thus the pride in craftsmanship was replaced by an emphasis on quantity. Since work activities were reduced to simpler more learnable tasks, many persons performing similar tasks were grouped together so that they could be supervised by a single supervisor. This supervisor then assumed responsibility for the quality of their work.[13]

This approach met with limited success because the supervisor had only a second-hand level of control over the work being produced. Additionally, he was tasked with another pressing requirement; that is, meeting projected output goals. Balancing these two diverse requirements often resulted in conflicting decisions. For example, under the pressure of meeting the weekly output goals, a lowering of quality standards would have been one way of accomplishing it. It can be clearly seen that the next logical step would be to segregate the two opposing functions in order to ensure the enforcement of quality policies.

2.3 Quality Control Inspectors

As society became more specialized, so did the discipline of quality control. Organizations solely devoted to the inspection of quality were established in many industries. Their status as independent agents enabled them to determine whether or not a product was satisfactory without being anxious about the company's output schedules. Their only function was to insure that the work produced met the standards.

Another advantage of having people outside the production realm inspect the work is that the inspectors are more apt to notice irregularities and defects than those who are not as attuned to detecting them. Through proper training and education, their role may be instrumental in providing that watchful eye to insure quality work.

Despite the specialized skill of the inspection force, the fact remained that the level of control had surfaced to higher than practical levels. The laborer or worker who has the most control over what is produced was being farther removed from the problem. He had lost his identification with his work and his lack of responsibility for quality had insulated him from his true value in the world of quality control.

2.4 Statistical Methods

In the early 1900s, great progress was made in the management field. Scientific management concepts were being experimented with and put into practice. It was in this time frame, that quality control put down its roots and began to emerge as a bonafide science. Dr. Walter A. Shewhart, of Bell Telephone Laboratories, introduced the use of statistical methods, such as the use of statistical quality control charts, to help control quality in the early 1920s.[14] The use of these methods resulted in both improved quality and economy.

Statistical methods provided a rational approach and some quantitative answers to questions that were previously answered only by judgment or experience.[15] The effective use of these methods required an essential understanding of the basic principles of statistics. Misapplication of sound practices through insufficient knowledge often led to unsatisfactory results and a resistance to its widespread implementation. Those advocates who hurriedly urged their use created the impression that these methods were cure-alls that could miraculously solve every problem. The lack of full understanding of the basic principles and the aura created by its advocates caused many people to fear and avoid their use.

The advantages of a statistically based inspection and quality control program weighed far more than the initially perceived disadvantages. By providing a method of rational sampling, assurances could be made that only lots of known quality were being passed in the long run. This relieved the inspector of much of the judgment and experience requirements in selecting arbitrary samples. It also increased the efficiency of the inspection phase and hence the production output.

Many statistical tools and techniques are available in exercising quality control. Some of them are:

1. Frequency distributions
2. Control charts
3. Sampling tables
4. Special methods
5. Reliability prediction

This report will only briefly describe these tools so that a general understanding of their features may be obtained.

2.4.1 Frequency Distributions

A frequency distribution may be defined as a tabulation or tally of the number of times a given quality characteristic measurement occurs within the sample of product being checked.[16] Figures 2.1, 2.2, and 2.3 graphically depict a picture of the characteristic measurement of a stud length. These figures paint a simple picture of the frequency distribution without any algebraic analysis.

The frequency distribution concept underscores the inevitability of variation in produced goods. This variation may be caused by many factors. For example, the raw material may come from different sources with slightly different characteristics; the machinery used in production may have loose bearings or excessive vibrations, careless or untrained workers and changing climatic conditions all contribute to the variability of the end product. The absolute elimination of all factors is not a feasible goal nor would it be economical if it were possible. Therefore, the producer must base his operating philosophy on a tolerable, statistically predictable level of imperfection.[18] The variation in the end product generally takes

FREQUENCY DISTRIBUTION ON LENGTH OF STUD - .500$\pm$.005 in.

Length (in.)	Frequency	Freq. in %
.495		
.496		
.497		
.498	1	2%
.499	3	6%
.500	5	10%
.501	9	18%
.502	12	24%
.503	10	20%
.504	8	16%
.505	2	4%
Total	50	100%

Figure 2.1 Frequency Diagram
(Source: 17)

Length (in.)	Frequency
.495	
.496	
.497	
.498	X
.499	XXX
.500	XXXXX
.501	XXXXXXXXX
.502	XXXXXXXXXXXX
.503	XXXXXXXXXX
.504	XXXXXXXX
.505	XX

Figure 2.2 Frequency Distribution
(Source: 17)

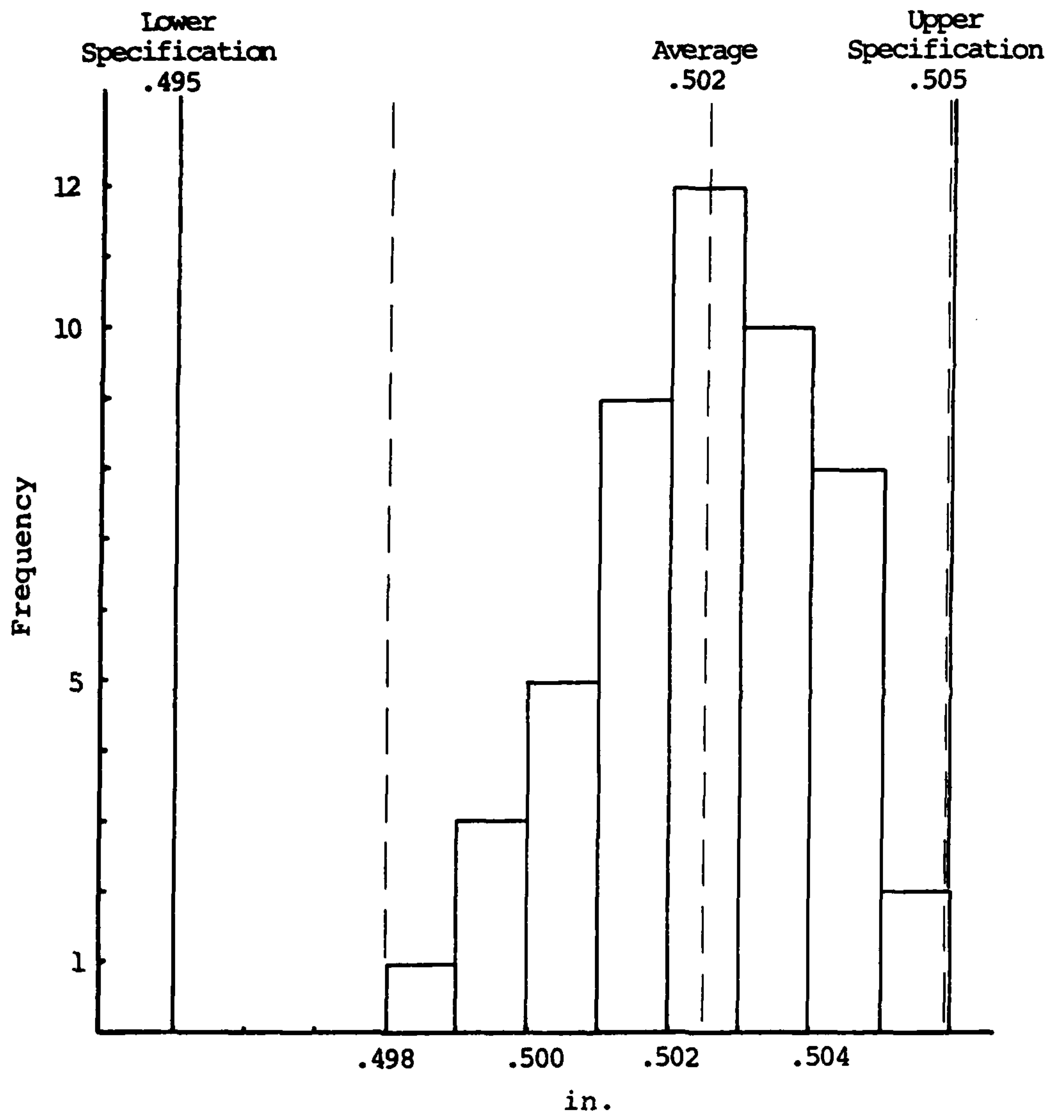

Figure 2.3 Length of Stud .500±.005 in.
Frequency Curve.
(Source: 17)

a definite frequency pattern. By analyzing enough samples a true representation of the particular quality characteristic is obtained.

The concept of adequate sample size is crucial to the use of frequency distribution as a control tool. In the determination of an adequate sample size, two practical considerations are taken into account. The first is the economics of the situation. How much will it cost to test each piece? Secondly, how much statistical accuracy is required? These two considerations are diametrically opposed to each other. On the one hand, the economics of the situation calls for the smallest possible sample size allowable. But statistics calls for a larger sample size to assure accurate results. What consequently happens is that a balance must be struck between both considerations. Figure 2.4 shows the relationship between sample size and cost of inspection. Even though we have moved into the realm of the scientific approach to quality control, past experience and judgment plays a very large role in this decision. Once the sample size is determined, the appropriate curves can be plotted and questions may be answered relating specification tolerances with variations in the goods produced.

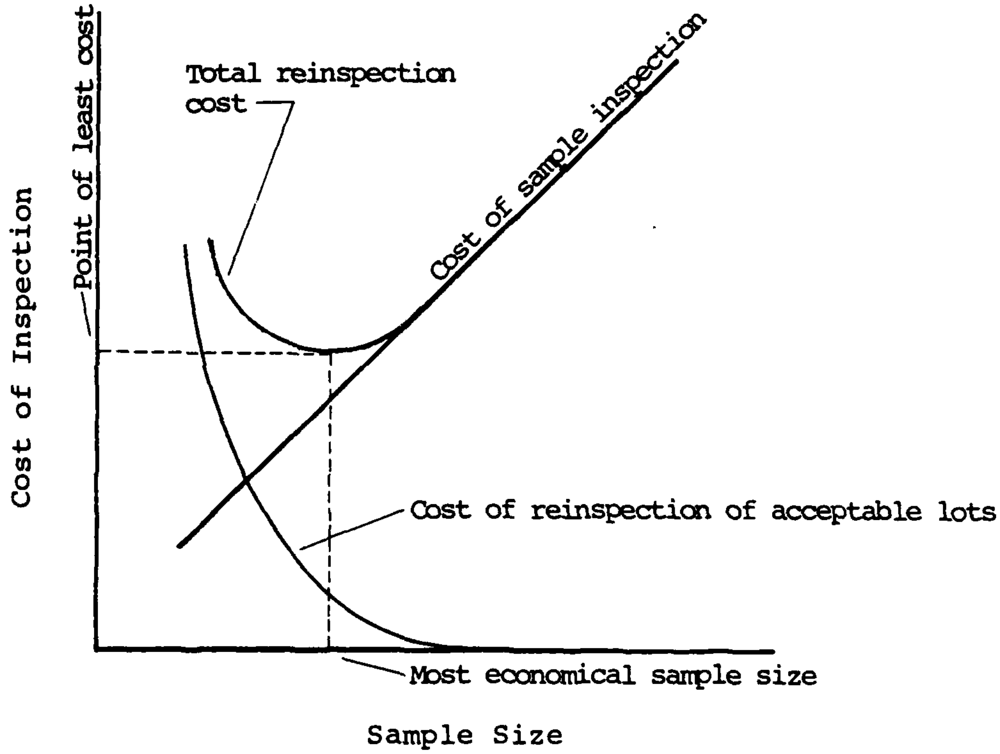

Figure 2.4 Relation Between Sample Size and Economy. (Source: 19)

2.4.2 Control Charts

Another statistical method used in quality control is the control chart. This is a tool that is designed to characterize the variability of a manufacturing or production process. Generally, this is determined by first categorizing the causes of variation into either chance variation or assignable variation.[20]

Chance variation is to be expected in any manufacturing or production process and cannot be completely eliminated. Hopefully, this random variability is such that it exhibits a somewhat stable pattern. On the other hand, assignable variations are "real" causes which may be due to poorly trained or careless workers, poor quality raw materials, improper machine settings, worn parts, and so on. The control charts are a method of systematically detecting whether or not a process is in or out of control.

Basically, a control chart consists of a central line and lines representing the upper and lower control limits. The central line corresponds to the average value at which the process should perform. Figure 2.5 shows a sample control chart. The upper control limit (UCL) and lower control limit (LCL) are chosen in such a way that values falling between them can be attributed to chance, while values falling outside them are signs that something is out of control. When values lie within the limits, the process

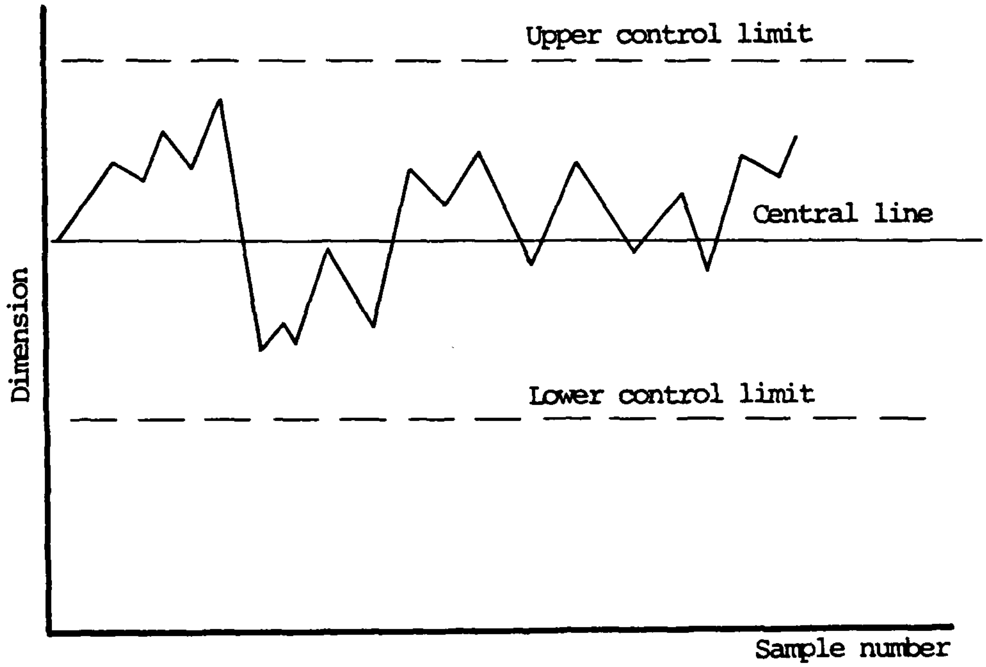

Figure 2.5 Sample Control Chart for Measurements (Source: 20)

is said to be stable and in statistical control. But even if all points are within the limits, a trend or other pattern may be a signal that action should be taken to avoid serious trouble. The ability to "read" these charts and obtain an accurate picture of what is going on requires experience and a developed sense of judgment. Even as more scientific and analytical methods are used, the exercise of human traits is still required to effect the proper results.

There are two fundamental types of control charts; there is a control chart for attributes and a control chart for measurements. The attribute chart measures the fraction of defectives per units inspected. The charts for measurements are concerned with a given dimensional tolerance range for a quality characteristic. The mechanics of creating these charts involves a rather lengthy and detailed discussion of statistical principles which is not deemed critical to the basic purpose of this report. Suffice it to say that this technique does exist and plays a more important role in manufacturing and industrial applications.

2.4.3 Sampling Tables

A sampling inspection method is a way of determining from a sample the quality of the whole. The advantages over a one hundred percent inspection are obvious in terms of economics. Sampling tables are used both as a basis for acceptance and for process-control. The logic behind the success of this method stems from the premise that variation in products usually conforms to a certain basic pattern for products that have come from the same source. This pattern may be sufficiently determined from inspection of only a certain number of units; or in other words, by sampling.[21]

2.4.3.1 Acceptance Sampling

The majority of acceptance inspections are conducted on a go, no go basis. That is, determining whether or not the items in the sample conform to the specification requirements. In performing this inspection objective there are two possible methods that can be used. One is the one hundred percent method and the other is the sampling method. The one hundred percent method has the advantage over sampling in that only by a thorough examination of each item can complete assurance be obtained that the lot is entirely free of defective units. However, there are certain disadvantages of the one hundred percent inspection as compared to an effective sampling plan. Some of these disadvantages are:

1. It is costly.
2. It may lead to false assurances about the completeness of the inspection job.
3. It actually involves sorting.
4. It may result in accepting some defective material.

5. It may result in rejecting some satisfactory material.
6. It may be impractical.[22]

Comparing these disadvantages to a reliable sampling procedure, it can be seen that sampling is relatively inexpensive. Other advantages of sampling are:

1. It can be applied to obtain a desired assurance of lot quality even in cases where available tests are destructive in nature.
2. Damage from handling during inspection is minimized.
3. As the production rate increases or decreases, it is readily possible to adjust the proportion inspected in such a way as to maintain a given level of quality assurance.
4. Rejection of an entire lot of material (rather than mere return of the defectives) is of sufficient consequence to a vendor or shop department to exert pressure for quality improvement.
5. Fewer inspectors are needed thereby simplifying the recruiting and training problem.
6. The inspector's knowledge that his results from the sample will lead to an important decision on an entire lot tends to have the psychological effect of increasing his importance, feeling of responsibility, and care.
7. Where batches of various products are received intermittently, as in an incoming inspection department, sampling inspectors examine fewer parts of a given kind before changing to a new type of work and are therefore less subject to errors due to monotony.[23]

Before statisical sampling tables came into being, the sampling method was already being practiced in industry. The procedures used were relatively crude and not based on sound statistical principles. Instead, sampling took the form of "spot checking." Spot checking posed problems because of the arbitrariness of procedures. It also could not answer important questions such as: What quality targets should be established for the plan? What should be the disposition of the lot that is rejected? Should another sample be drawn from the lot? Or, should the lot be one hundred percent inspected?

Obviously, the advantages of sampling versus one hundred percent inspection cannot be realized through the use of crude "spot check" procedures. Reliable and specific statistical sampling procedures are required to meet the stated needs. The needs that can be served by sampling tables fall into four general categories. They are:

Specification and Sampling Data

Protection Afforded

Disposal Procedure

Cost Required

The "specification and sampling data category" has to do with the size of samples to be taken, the conditions under which samples are taken and the conditions under which a lot will be rejected or accepted. The "protection afforded" category deals with the element of risk that the sampling schedules will reject good lots or accept bad ones. "Disposal procedures" are the set of guidelines which delineate what is to be done with the lots after the sampling inspection is completed. Sampling tables can also be used to determine the average inspection cost required to accept or reject a lot.

The two basic types of sampling tables are:

1. Lot quality protection

2. Average outgoing lot quality protection

The lot quality protection system assures that only a specified percentage of lots containing a limited number of defectives will be accepted. In the other case, the protection afforded is based on the average quality of a large number of lots after inspection.

These two basic types of tables have relative advantages only in terms of their specific applications. For example, if a customer buys a large quantity of products over a long period of time, it may be more advantageous to assure the average outgoing lot quality. But on the other hand, if only an occasional lot is bought, it may be better to assure the quality of the particular lot. There are even more possible uses which may dictate which plan should be utilized. Each application has to be considered carefully to determine its requirements.

These two basic sampling tables may be used with:

1. Single sampling, that is, basing rejection or acceptance of a lot upon the units in one sample drawn from that lot.

2. Double sampling, that is, selecting one sample of units from a lot and, under certain conditions, selecting a second sample before accepting or rejecting the lot.

3. Multiple sampling, that is, basing acceptance or rejection of a lot upon the results of several samples of units drawn from that lot.

The most popular of these methods has been double sampling. Compared with single sampling, the idea of giving a lot a "second chance" has broad popular appeal. Also, double sampling permits a smaller first sample than that permitted by a corresponding single sample plan. When the percent defective is low or high in the first sample, it is frequently possible to accept or reject lots based upon those results. Therefore, double sampling can permit lower sampling costs. In comparison to multiple sampling, double sampling is easier to keep track of as the administrative requirements are much simpler. The choice of which to use, single, double, or multiple sampling depends on the conditions for which the sampling plan is being used. There is no absolute best method.

2.4.3.2 Sampling by Variables

Briefly, this technique seeks to determine not simply whether an item is "good" or "bad", but where in the tolerance band the item falls. An advantage of this method is that it may be less expensive than acceptance sampling on a go, no go basis. This is because information of equal value may be obtained from a smaller measurements sample than from a go, no go sample.

One of the most common forms of variables sampling combines the use of the frequency distribution concept. The measured parts are plotted on a tally card. The sample size may be kept flexible with sampling being stopped when sufficient data points are available to draw the distribution.

2.4.4 Special Methods

The objectives of statistical special methods is to solve problems that avoid solutions by way of the three previously mentioned techniques. Special methods help in the analyzing of problems with tool such as "tests of significance." Special methods are also useful in designing experiments that yield the maximum of information with the minimun of time and money and in determining whether there is an observable relationship between variables (correlation).

2.4.4.1 Tests of Significance

The purpose of tests of significance is to determine whether the quality of a lot, of the output of a given product type or of a batch of parts just received from a vendor, differs "significantly" from a standard value or from the quality of a second lot or more lots or sources.[24] They are used to compare material from two or more different sources to tell which of a number of factors affect the quality.

The two significance tests used the most are the "t" test and the "F" test. The "t" test is used to determine the significance of differences between measures of central tendency of two samples. The "F" test is used in determining the significance of differences among the spread of samples.[25]

2.4.4.2 Design of Experiments

Experiments, or tests, are extremely useful in the analysis of problems with quality. The designing of the tests though, would be impossible if it were not for the statistical tools that are available to us. There are two general conditions under which tests may be designed. The first is at the end of the experiment and the other one is at the start of the experiment. In the first case, all data and information is given to the analyst to sort out and decipher to reach accurate conclusions. This is done with tests of significance. This method is hampered by the fact that all data may not be available or in the appropriate format. However, when the analyst is asked to design an experiment or program before any tests are made, he is in a better position to insure that the required data will be available. Consequently, economies of time and expense are more favorable under the latter condition.

2.4.4.3 Mathematical Correlation

The coefficient of correlation, r, determines the strength of the relationship between a dependent and an independent variable. Mathematical correlation can also be used to derive a mathematical expression which can be used to predict the values of the dependent variable from values of the independent variable.

2.4.5 Reliability Prediction

Product reliability is one of the qualities of a product and is defined as: "The probability of a product performing its intended function over its intended life and under the operating conditions encountered."[26]

Two other terms often used in connection with the subject are inherent reliability and achieved reliability. The difference in meanings between the two terms is that inherent implies the highest degree of reliability possible in an item due to its design whereas achieved is the actual reliability demonstrated through real use. In all circumstances, achieved reliability is less than the inherent reliability.

Since reliability has been defined as a probability, the theories and rules of probability apply in the determination of the product's life before and/or between failures. To achieve product reliability, its failure rate must be controlled. Four basic activities in this effort are: (1) establish reliability requirements, (2) develop the reliability program to meet the requirements, (3) continue the control of reliability, and (4) continue the reliability analysis. Figure 2.6 shows how these activities are related to each other. Constant feedback should be reviewed periodically to insure optimization of the overall product reliability.

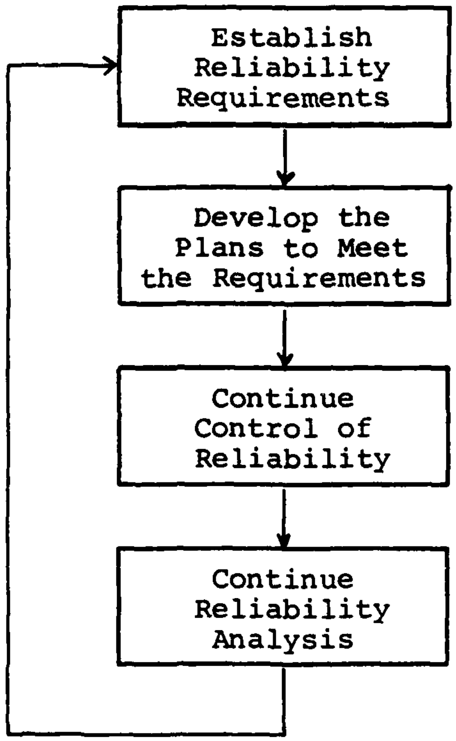

Figure 2.6 Activities of Product Reliability
(Source: 27)

CHAPTER THREE

THE QUALITY SYSTEM

3.1 Key Factors

The fundamental principle behind a quality system is the involvement of all of the activities required to produce a product to the customer's satisfaction. A quality system approach in the construction field treats as an integrated whole the activities of organizing, planning, designing, financing, building, and any other action needed to complete a structure for a specific use by society.[28] Compared with the traditional view of quality control, the quality system does not concentrate or emphasize any one conventional quality control method. For example, inspection is not relied upon, nor is design, nor statistical analysis, nor operator training. All methods are individually important yet it is the entire construction process that must be nurtured through to the end in order to effectively control the quality of construction.

Although it is one of the oldest fields of endeavor, construction operations lend themselves to relatively crude measures of quality control as compared to industrial and manufacturing operations. In construction, productivity is irregular and unpredictable, waste is high, labor costs have risen more, and the chances for extensive mechanization and standardization are remote because of the complex nature of each structure.[29] The system approach to quality in construction attempts to integrate both design and management functions. When the system is operating properly, better communications between these functions occur and feedback becomes a valuable element in project execution.

The key factors in a system for the control of quality in construction is diagramatically represented in Figure 3.1. Logically, the technical factors of the project quality start with the designer, who sets the level of quality and defines it in drawings and specifications. Quality then proceeds through the cycle with the advertisement for bids, preparation of estimates for bids by the contractor, awarding of the contract, establishing of field organizations by the contractor and by the owner or his engineer, training and indoctrinating the personnel of these organizations, setting up of control procedures and inspection by the owner, and eventually feedback to the designer to complete the cycle. Figure 3.1 also lists the non-technical or social factors which affect quality even before the technical factors come into play.[30]

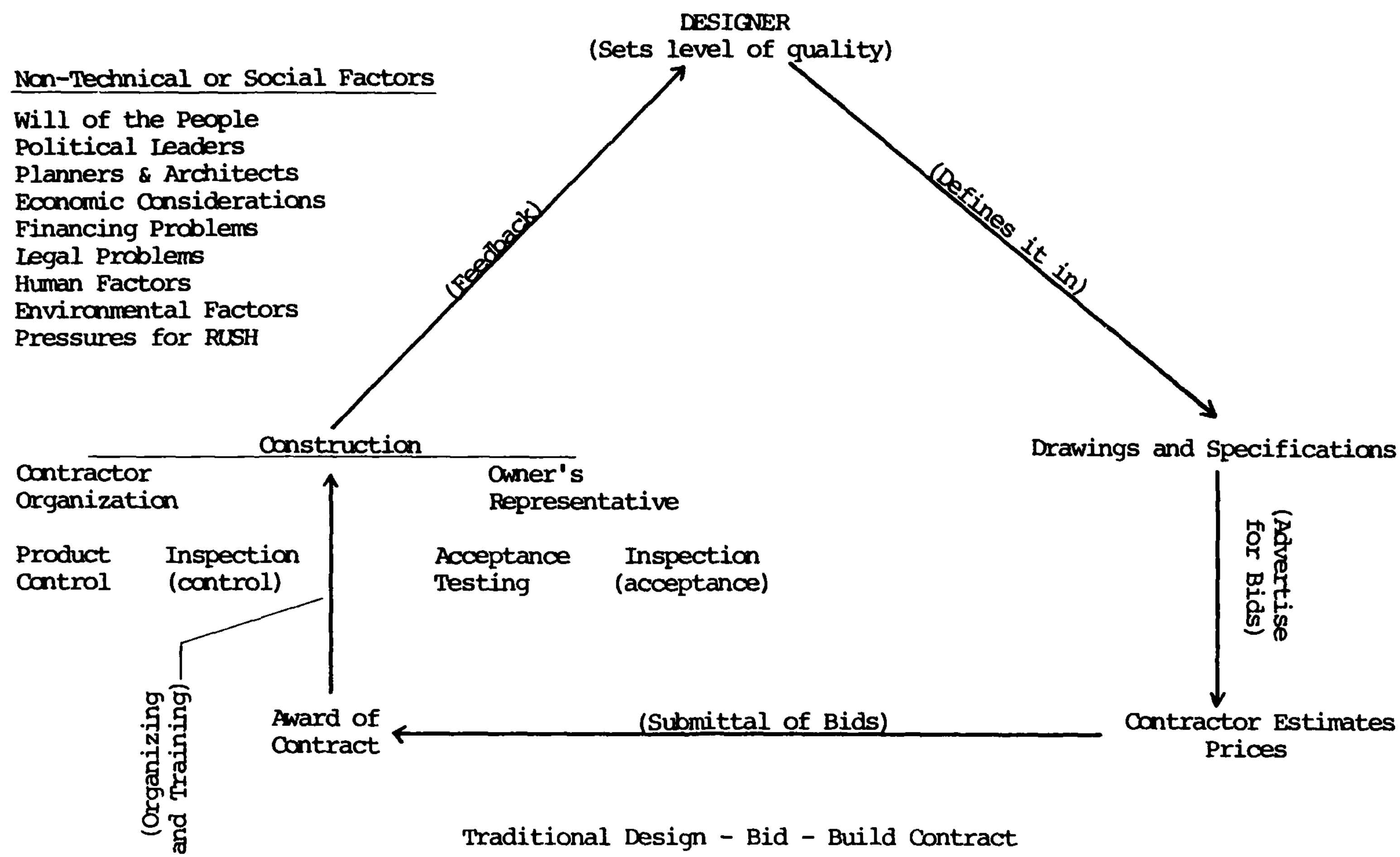

Figure 3.1 Diagrammatic Representation of Various Factors of System for Control of Quality in Construction. (Source: 30)

3.2 Interplay Within the System

It is extremely important that all of the elements of the quality system successfully interact to insure that the structure is "built right the first time." Corrective measures during and after the building process add time and expense to the project and are not consistent with the philosophy of providing the desired level of quality at minimum cost to the owner.

3.2.1 Design

The designer is chosen as the starting point for establishing the standards of quality to be obtained. He must work within the parameters of function, durability, safety, maintainability and cost in developing his design. His influence should also be felt in the actual construction aspects of the project. This is achieved by a careful review of the specifications for the job. The task of writing specifications has usually fallen on the shoulders of either inexperienced or over-worked individuals. Their attempt to get their work finished has led to "cookbook" approaches in specification writing. For the most part, specifications are assembled by copying from other documents which were used on other work, sometimes of a different nature. The specification writer is rarely cognizant of the details of the design and consequently includes inadequate or unrealistic requirements. But the blame should not be exclusively his because arbitrarily enforced specifications can produce results that are equally unwanted. Additionally, a prevalent tendency today is to avoid liability by over-specifying. This results in a pure waste of resources, and in the long run the owner pays for the extra cost.[31] So the designer must be attentive in defining the quality and characteristics of his design and satisfactorily communicate them through a set of drawings and specifications.

3.2.2 Preparing the Bid

The construction contractor first appears in the scheme of the quality system in the bid preparation phase of the cycle. His role is as critical as that of the designer in that his analysis of the drawings and specifications set the groundwork for the quality level that will be achieved. If the contractor understands all the requirements and potential pit-falls, not only will his bid be more accurate but his familiarity with the project will, in all likelihood, enable the quality required to be attained. However, if he fails to carefully study the bid documents, the chances are likely that he will encounter trouble in the construction phase of the project.

One way to help insure that bidders fully understand the drawings and specifications is to hold a pre-bid conference.[32] At this meeting the contractors and designer exchange information regarding any new construction technique or detail as well as the quality requirements. This opportunity could also be used by either side to ask questions or to clarify ambiguities. The designer may also issue addenda if necessary or desirable. Once the contract has been awarded, changes can only be effected through change orders or extra work orders. Both usually add to the cost of the project unless a compromise of quality is adopted to keep costs down.

3.2.3 Construction

The mainsprings of quality control are rooted in the truism that only the hands that actually do the work can control the quality during construction. Regardless of the intensity or level of supervision employed, it is only the workman who can determine the standard of quality of the finished product. It is for this basic principle that training plays a significant role in the control of quality. For it imparts not only the proper skills but also the proper attitudes that are required for attaining the desired goals.

It is also important that controls be of the "before the fact" variety. It is not feasible to judge whether or not adequate quality has been achieved after the project is completed. By then it is too late. When installing items or placing materials, the components must have the required quality. If it is inherently lacking then there is no choice but to reject the items or materials.

Adequate controls during construction can be broken down into two philosophies of approach. The first one is from the vantage point of the contractor. He must do everything he can to insure that his work will meet the requirements of the contract and be accepted by his client. The other approach is the one taken by the owner. The owner's only method of controlling quality is by either accepting or rejecting the work. He cannot tell the contractor how to do his work but he may accept or reject work at various stages in the construction phase. The owner's judgment of whether the work is acceptable must be based on sampling, testing, and inspection. If the contractor has an adequate program for documentation of quality control, the owner needs only to evaluate the data and conduct only enough additional tests to satisfy himself for acceptance. The owner's work effort is minor and simple if the contractor's records are found to be accurate and reliable. However, if the contractor has poor records or no control program at all, the owner must intensify his tests and inspection or reject work until the contractor sets up proper controls. So, it is evident then that the contractor should be concerned with testing and inspecting for control of work quality while the owner is in a position of testing and inspecting for acceptance.

In order to assist the contractor in his quest for quality in construction, it is desirable for there to be some other tangible rewards for high quality work aside from satisfactory fulfillment of contract requirements. The vehicles for providing these incentives are the specifications. By making it more profitable for the contractor to maintain a diligent eye on quality, the attitude for maintaining quality is reinforced in the minds of the contractors. Incentives may be built-in to the specifications by varying the intensity of tests and inspection depending on the success of the contractor's quality control program. It would behoove the contractor to make quality control a top priority otherwise he would risk the added burden and cost of tougher tests and inspection.[33] The attainment of consistent levels of quality has intangible rewards as well. Some of these benefits can come in the form of: (1) satisfied customers, (2) enhanced marketing and advertising, (3) a more competitive edge against other contractors, (4) an increased effectiveness in operations, and (5) a better and more respected business reputation.

The construction phase of the quality system is the most crucial. As it was previously stated, the hands that actually do the work are the only factors that directly affect the resulting quality. But its prominent role should not overshadow the interaction required between the designers and the builders. A rivaling relationship often exists between the two due basically to their individualistic traits and personalities. This is tempered by their common goal of project completion. Both sides must depend on the other in order to perform their present tasks as well as to improve their current skills and capabilities. These objectives may be achieved through the establishment of a standard pattern for regular and "as needed" feedback. Comments from field personnel can be used by designers on future projects to avoid difficulties that were encountered. Conversely, comments from the designers to the builders could result in less variation in quality and improved efficiency. But both parties must be open in their communications and receptive to the comments received.

3.3 Social or Non-Technical Factors

The non-technical or social factors shown in Figure 3.1, indirectly but sometimes dominatingly, have an affect on quality. These factors are distinguishable from the technical ones in that the owner, designer and contractor have no control over their influence on the project. This is not to say however that they are at the mercy of these factors because they are able to partially influence the direction that the factors move. This is achieved through active involvement and participation in these social forces. By being a part of these elements, the designer and or contractor becomes intimately aware of the desires of these oftentimes competing interests and may make appropriate adjustments in their project execution.

3.3.1 Political Leaders and Politics

People who are familiar with the construction industry should be well aware of the potentially enormous impact of politics and the will of the people upon project outcomes. A pulse should be taken of the feelings of the concerned public as early as during the conceptual phase of planning. A designer who is knowledgeable about the needs and sensibilities of the people is better equipped to serve the public. Oftentimes, the design professional discounts the validity of social and political pressures only to realize too late that they can greatly affect and shape the ultimate design of a project. The members of the quality team should also be aware of the political process in their own operating areas. Planning boards, county commissions, building codes, and the like, have to be treated properly.

3.3.2 Economic Considerations

A tremendously important parameter affecting quality is the economic consideration. Obviously it would be simple to enhance quality if costs were not a factor. But the challenge exists in achieving better quality at lower cost. Quality costs may be divided into three categories: (1) prevention costs, (2) appraisal or inspection costs, and (3) failure costs. The prevention costs are made up of quality planning, design, and training expenses. There is the greatest potential for payoff by investing in prevention of poor quality. By proper planning, designing, and training the overall concern for quality is established at the outset. An attitude of "doing it right the first time" is sufficient to minimize the inspection and failure costs.

3.3.2.1 Appraisal Costs

Appraisal or inspection costs cover the expenses of testing, equipment, materials, record-keeping and personnel. In the construction industry, the inspection function is carried out by various individuals. A good worker will judge and inspect his work as he installs or builds. Foremen and superintendents are constantly appraising work whenever they tour the project. The official field inspectors, those whose assigned duty is to inspect, may be selected from a variety of people.

Field inspection has traditionally been the responsibility of the design engineer. He performed tasks such as:

1. Inspection of construction materials to ensure that specifications are satisfied.
2. Inspection of construction processes to see that field conditions and as-built details conform with assumptions and design intent. Certain materials such as reinforced concrete, require regular and timely inspection, since the ability to perform visual inspection at a later time is greatly impaired. Special attention is also required with regard to execution of connection details.
3. Monitoring of required change orders to ensure that revisions during construction do not compromise design quality or safety.
4. Evaluation of initial performance of the structure during construction. This evaluation provides some indication of the adequacy of design.[34]

Over the last ten years or so, the role of the design engineer as a field inspector has been reduced significantly. In the interest of economy, the professional inspection services of the designer has given way to inspection by building officials, construction managers, and a contractor's own inspection forces. Building officials are knowledgeable professionals but they cannot and should not be expected to perform adequately to evaluate the blending together of construction activities and design integrity. Construction managers are relatively new professionals who have upset the balance of the equation. More often than not, their interests are in the business end of construction and not with the quality of construction. Even if the construction manager assumes the role as the inspector, his guidance will be more towards insuring that construction will be in accordance with the specified design. However, the opportunity to recognize and correct design errors is often beyond the construction manager's expertise and is hence wasted.

Inspection by a contractor's own forces is conflicting and may result in inferior quality, lack of control and lack of documentation.[35] The conflict which exists when meeting a construction schedule is a prime consideration. When this is the case, quality usually suffers. Maximum production is impeded when controls force quality standards to be met. Consequently, if a contractor is left to provide quality control for his work, he has the option of operating "by the book" or of trying to get away with what he can. Naturally, he is in business to make a profit. If greater profits can be made, he will choose to do so. What he must keep in mind though, is that short-term profits may lead to long-term failure. This could happen through gaining a reputation as a low quality contractor. Needless to say, if he obtains such a reputation, he may never be awarded any future projects.

It should be pointed out that a contractor may not be required to use his own forces as inspection personnel. Most likely he will have an option to subcontract this function. But even if an independent inspector is used, his objectivity and neutrality may be suspect since he is on the contractor's payroll. Additionally, it is usually subcontracted to the lowest bidder. So the excellence of inspection is of dubious quality. If a reputable inspection service was used, the contractor still has the final say-so regarding release of test and inspection reports that are not in his best interest.

3.3.2.2 Failure Costs

Failure costs are the most costly of the three categories of quality cost. In construction, the word "failure" immediately conjures up visions of great losses of life, property, money, and time. Structural collapses are sensational and potentially catastrophic in terms of loss of life. Liability due to these failures is great, often running into the millions of dollars. The usual response to this uncertain liability though, is the purchasing of additional insurance rather than improving the quality in planning and building. This is a trend which must be reversed if quality is ever to become a high priority in the construction industry.

Failure does not always refer to structural collapses. In the context of this report, failure may refer to any rejection of work or materials already performed or in place. For example, if the specifications call for concrete of 5000 psi compressive strength and the 28-day test cylinder breaks at 2500 psi, the concrete that has already been placed must be taken out and replaced with proper strength concrete. Needless to say, the example cited results in loss of labor, materials, time and money. All of which are undesirable in the eyes of all concerned.

In 1983, as a result of the Harbour Cay condominium collapse in Cocoa Beach, Florida, the state mandated that during the structural construction of a "threshold" or larger building, a "special inspector" must be present on site.[36] A "threshold" building is defined as any building larger than 2500 square feet or higher than 25 feet, or with a public meeting area greater than 5000 square feet or any of unusual design or construction as determined by the local building official.[37] The "special inspector" must be a Florida registered professional engineer or architect or a certified building inspector. This "special inspector" is required to be on site full-time during any structural construction phase. Other localities have also seen fit to mandate inspection to assure quality in construction and hence protect the safety of the public. Cities such as Ottawa, Canada and New York City, New York require inspectors to be on site to minimize construction errors and failures.

The costs of failures are so high that owners should reconsider the savings achieved from shaving inspection costs. All things considered, the cost of construction delays and rework may be far more than the money saved from skimping on inspection. Documentation of failure costs and warranty work can evolve into a convincing argument to invest in the cost of inspection or prevention. A balance must be struck however, between inspection and overall quality. Inspection that is hair-splitting on inconsequential points drives up the cost of inspection without any appreciable increase in quality construction. Therefore, one must be mindful of the inspection philosophy being used. In the quality system approach, the diversity of separate interests must be integrated to bring about a common goal.

3.3.3 Human, Environmental and Legal Factors

Through the legal aspects of construction, quality is affected by contractual relationships and the wording of specification clauses. The construction attorney must work to educate the other members of the construction team in order that claims and litigation can be avoided.[38]

Both internal and external human factors influence the resulting quality of the project. By internal human factors, reference is made towards the people who actually build the facility. External human factors refer to the social pressures of the surrounding neighborhood. Internal factors affect quality in that a somewhat direct correlation may be made between the skills of the workers and foremen to the actual quality produced. On the job skill levels are also affected by management style and technique. For example, an overbearing and dictatorial-type superintendent may find it difficult to get people to work for him. Incessant demands and harsh working conditions may drive his good workers away. While quality standards might be maintained, the cost in terms of discontented workers is high. On the other hand, an attitude that is too carefree may result in shoddy work because of inattentiveness to details.

External human factors and environmental concerns are brought to bear through pressures for rush, pressures for controlling dust, noise and traffic congestion, and pressures due to climatic conditions. Pressures for rush are often caused by an anxiety to get the job done in order to gain the full benefits of the investment. Avoiding excess financing costs is another incentive to finish as soon as possible. The disadvantages of rushing project completion may be overcome by planning for speed in the execution phase. But the problem is still present and usually detracts from quality and increases cost.

The integration of social and non-technical factors with the technical aspects of a project must be effected if the quality system is to work. This can only happen if involvement in the social areas is made in the early stages of project development.

CHAPTER FOUR

QUALITY CIRCLES

4.1 Origins

Most people regard the concept of quality circles to be a uniquely Japanese innovation. The truth of the matter though, is that quality control circles (QCC's) were conceived as the result of the suggestions of an American quality expert. In the 1950s, General MacArthur sent a quality control expert, Dr. W. Edwards Deming, to work with the Japanese people on improving their quality control.[39] The Japanese objective of improving the quality of their produced goods was crucial to the economic stability of their country. Inferior product quality would make their goods unsellable in the world market.

The prominent feature of the effort to improve Japan's quality was an enormous training program for directors, managers, supervisors, and technological specialists. The form and commitment to training was based on a combination of Dr. Deming's suggestions and the theories of several eminent behavioral scientists. In 1962, Dr. Kaoru Ishikawa gave shape to the form of training which featured intradepartmental groups of ten or so workers seated around a table; hence the name Quality Control Circle.[40] Dr. Ishikawa was an engineering professor at Tokyo University, and the circles were sponsored by the Union of Japanese Scientists and Engineers (JUSE).[41]

In reviewing the past thirty years or so, it has become evident that a significant improvement in the quality of Japanese products has occured. Consequently, business leaders everywhere are interested in finding out what Japan has done to achieve its remarkable success. The answer that has been pointed to most frequently has been the worker's participation in problem solving in quality circles.[42] This concept is now sweeping through other industrialized nations of the world. It has met with mixed success largely because of differences in management and implementation philosophies.

4.2 How Quality Control Circles Operate

Quality control circles consist of members, leaders, the facilitator and the steering committee. Membership in the circles should be voluntary. The underlying principle behind the concept is to maximize the contribution of the worker by utilizing his education, experience, and creativity in improving company performance.[43]

4.2.1 Circle Members

For the workers, participation in a quality control circle provides a source of job interest that was not previously present in their routine work. The sense of participation in planning and decision making has resulted in improved worker motivation. This increased interest has in turn led to an elevation of the worker's sense of self-worth. The overall result has been a "win/win" situation typified by the quote, "You do something for the company, you're doing something for yourself."[44]

A properly functioning QCC program must begin with a comprehensive training program for the members. This training should address four important skill areas: relating skills (group dynamics), discovery skills (information gathering and problem analysis), advocating skills (decision-making and presentation), and supporting skills (implementation and reinforcement).[45] This training is only the first step in getting circle members to function effectively as a group. The key to the success of QCC's is the development or presence of trust. Trust must come from within the organization otherwise programs will be slow to move and be stunted.

The relating skills are often the most neglected. This may be due to the presumption that people know how to deal with one another. However, experience has shown that

Americans tend to concentrate on areas that are procedural and technical in nature. Consequently, the interpersonal skills required to successfully execute any endeavor are virtually ignored. In this way, the most important resource available, that is the human resource, is inefficiently utilized. Proper quality control circle training aims to overcome this.

Both discovery and advocating skills have been traditionally stressed in our society. But supporting skills have been neglected almost as much as relating skills. This becomes evident when a great solution is voted down only because the implementation strategy was faulty. Skills in this area are geared towards surmounting the implementation barriers. Oftentimes the barriers are interpersonal or intergroup in nature and have little to do with the solution itself. Training in this area helps circle members develop strategies for implementing their solutions based on an understanding of the people and groups they are dealing with.[46]

Once members of a quality control circle are trained, they identify a number of problems and select one they want to work on first. Circle members meet regularly and apply their training to achieve a solution to the problem. When a solution is reached, they prepare a presentation to management outlining both the problem and their recommendations.

4.2.2 Circle Leaders

In the beginning, the leader of the circle should be the supervisor. As members become more comfortable with the concept, the circle will eventually elect its own leader. The leader's main job is to involve each member to their fullest extent. An effective leader does not dominate the group but rather asks questions of the quieter members, seeks their opinions and involves everyone in the "brainstorming" process. The leader is responsible for the smooth and effective operation of the circle.[47]

4.2.3 Facilitator

The facilitator, or program coordinator, usually handles about ten QC Circles. He attends all meetings and helps the circles stay on the right track as well as interface with other groups.[48] For example, if data collection from another department was necessary in the analysis of a problem, the facilitator would help the circle in obtaining that information. As the title implies, he facilitates the process that the circle undergoes in order to make them more effective.

4.2.4 Steering Committee

The steering committee is composed of three to eight members (depending on the size of the organization) who are managers from major departments of the company, as well as the facilitators. The committee is tasked with implementing quality control activities, to set goals and objectives for the activities, to establish operational guidelines, and to control the rate of expansion. Presiding over the committee is the chairman. The decisions of the committee are made by voting.

4.3 Evaluation of Quality Control Circles

Since the introduction of quality control circles in Japan in 1962, the controversy surrounding their universality has continued even until today. Many industrial leaders and managers in the West believe that the circles are the key to Japan's astounding success. Consequently, they believe that they can purchase that same success by introducing the quality control circle concept in their own operations. The wide disparity in results between Western circles and Japanese circles bears closer scrutiny.

4.3.1 Japanese Ingredients of Quality

The founder of quality circles, Dr. Kaoru Ishikawa, gives six features of quality work in Japan:

1. Company-wide quality control (CWQC) - refers to the involvement of all departments and divisions of the organization in a systematic quality control effort. This concept refers not only to all functional areas but to all levels of personnel as well. An integral part of this ingredient is the long range commitment of management to the quality improvement program. This is also known as "total QC."

2. Quality control audit - monitors the effectiveness of execution of all quality policies and quality control programs.

3. Industrial education and training - must be given to everyone in the organization if CWQC is to require everybody's participation. These training programs must be specifically developed for each company and represent a substantial undertaking. For a large firm, it may take more than three years before any leadership in product quality can be achieved. The process starts with upper management and works its way down to the non-supervisory level.

4. Quality control circle - according to the QC Circle Koryo (General Principles of the QC Circles), is a "small group to voluntarily perform quality control activities within the workshop to which they belong. This small group with every member participating to the full carries on continuously as a part of company-wide quality control

activities, self-development and mutual development, control and improvement within the workshop utilizing quality techniques."

5. Statistical methods - for quality control are used to a great extent by many workers from all departments.

6. Nation-wide quality control promotion activities - are mainly organized by JUSE and climax in November, the Quality Month. Activities include conferences and presentations of the Deming Prize to individuals and companies.

These ingredients are basic to the proper working of quality control circle programs. Western managers who believe that the success of the Japanese in product quality leadership is the result of only one quality activity are badly mistaken.

4.3.2 Significance of Quality Control Circles

There are two schools of thought with regard to the effectiveness of QC Circles. For some, they are the most significant quality improvement method that has come along since F. W. Taylor's concept of specialization. For others, they are nothing more than a passing fad. Arguments for both sides will be presented here.

Discussions with Japanese experts indicate that QC Circle activities accounted for only a small percentage of the total quality improvement. That is, not more than 10% of the overall improvement was due to the workings of quality control circles.[49] This can be explained by the fact that the workers can only attack the "trivial many" vice the "vital few" problems that face them. This is because the "vital few" problems are caused by an absence of management policies, poor coordination, insufficient training and so on. Hence, the "vital few" problems are beyond the capability of the workers to tackle. The "trivial many" represents most of the 10% contribution of quality control circles activities.

Dissidents of the sweeping movement to introduce QC Circles in the West point to the division of product defects into worker-controllable defects and management-controllable defects. The criteria which differentiates between the two are three-fold. The worker must know what he is supposed to do, know the result of his work, and have the means of influencing the result. If any of these three criteria is not met, then the worker cannot be blamed; and hence, it would be a management-controllable defect. These defects fall into the "vital few" category of problems.

Proponents of QC Circle programs maintain that success can only occur if the true focus is on quality improvements rather than just on productivity gains.[50] This has been the key to the self-sustaining nature of Japanese quality programs. The quality control circles are looked upon as people building programs instead of as methods to increase productivity and quality.[51] The concept viewed in this perspective has been successful as evidenced by the branching out of QC Circles into areas such as safety, job enlargement, cost, environmental concerns, and so on.

What probably fuels the debate the most is the manner in which quality control circles are presently handled by companies in the West. Many articles have been published cautioning against imprudent adaptation of QC Circle principles. It must be remembered that Japan underwent an evolutionary process in attaining the leadership role that it enjoys today. The transformation from a defeated country after World War II into a world leader today was motivated by a national need to be able to export goods so as to earn the foreign exchange necessary to buy materials for its growing industrialization.[52] No such urgent stimulus exists today for the United States.

4.3.3 Obstacles to Success for QC Circles

During the early 1900s, the rapid expansion of U.S. industry quickly outran the supply of trained craftsmen. As a result, unskilled labor had to be used. In order for this to work, compensation for the low education level of the workforce had to be made. It was at this point that

Frederick W. Taylor proposed his concept of "scientific management."[53] Taylor's solution separated the work of planning from the work of execution. This gave rise to the line-staff distinction and the dawning of the age of specialization. What resulted was a spectacular increase in productivity.

Although productivity improved dramatically due to Taylor's contribution, the vast differences between today's workforce and that of the early 1900s, made "scientific management" outdated. The underlying premise of the Taylor system was the low level of education of the workforce. The present day workforce has dramatically increased its level of education from that of its predecessors. Consequently, workers are now able to plan and make decisions as they pertain to their work. No longer are these functions the sole territory of managers and engineers. Unfortunately, the specialization of work that was started through Taylor has continued to the point where tasks have become highly repetitive and short-cycle. The result has been job monotony, boredom and underemployment of the most valuable asset available - people.

Before this underemployed asset can be tapped for greater utilization in problem solving, management must strive to recognize the fact of underemployment, foster an atmosphere of collaboration, and promote the acceptance of change.

4.3.3.1 <u>Underemployment of Workforce</u>

Much of the talent, education, experience and creativity of the American workforce is wasted in the name of productivity. The premise assumed is that highly repetitive short-cycle tasks result in more efficient and productive work output. Many managers in this country are smug in believing that the American way of doing business is best. While they are aware of the presence of foreign competition, they fully believe that foreign competition is a threat only because of price advantages through low wages and unfair pricing. American managers are also largely unknowledgeable about the competitive advantages inherent in QC Circle programs. This lack of awareness of need to respond positively to this challenge extends from management to workers and union leaders.

The underemployment of the workforce has, in some instances, resulted in complacency. But in some cases, the workers exhibit an interest in job enlargement as a means of reducing job monotony and boredom. So the opportunities are present for QC Circles to come in and channel some of the under-utilized talent towards mutually beneficial ends. However, management and the workforce must be aware of the need to fully utilize the resources available to them.

4.3.3.2 Atmosphere of Collaboration

The usual relationship between management and the workforce is that of an adversarial nature. This has long been the case, especially since the existence of labor unions. Both sides usually vie for a greater share of the company's profits. This is understandable and occurs even in Japan. Where the workforces differ is in the treatment of roles with respect to company performance. In this country, workers view an improvement in company performance to be a sole responsibility of management. On the other hand, Japanese workers feel that they must share in the responsibility for improving company performance. A joint agreement in this area will enable an atmosphere of collaboration to prevail. This is vital to the success of any QC Circle program.

4.3.3.3 Acceptance of Change

The perception of managements' authority and freedom to act in the United States, is a major stumbling block to the acceptance of any quality enhancement program. Most managers regard the sharing of authority with the workforce to be an erosion of their own position. Naturally, they will meet with resistance any program that threatens them in that regard.

The resistance on the part of the workforce stems from the fear of job "speedup." That is, if improvements are actually realized, management will come to expect and demand that greater improvements be achieved. Additionally, it is feared that these improvements may actually result in the number of jobs being reduced.

Union leaders are concerned with changes as well. If QC Circles succceed, a natural tendency will be for workers to change their allegiance of loyalty from the union to that of the company. This would result in a degradation of their ability to wield power over management.

The attitudes toward change must be modified so that they will not be viewed as a threat to any one faction. It appears evident that the only way that this can happen is through a slow evolutionary process.

4.3.4 Requirements for Success of QC Circles

A key element in the long-term success or failure of QC Circles is the philosophical readiness of the organization.[54] Viewing QC Circles as a panacea for poor quality and productivity is short sighted and dangerous. If management is unwilling to allow and support employee intervention, the introduction of a quality control circle program may produce negative consequences rather than positive results. Therefore it is critical to ascertain the organizational readiness of a company before implementing and sustaining quality control circles.

As a minimum, the following areas should be assessed.[55]

1. Organizational Structures - in order to determine the extent to which people feel compelled to protect and maintain their functional "turf." If interference in a functional area would be perceived as a threat, the organization is not yet ready for the QC Circle concept.

2. Management Philosophy - a compatible philosophy of management throughout all levels of the organization enhances the opportunity for success of employee involvement and participation. A critical element in this area is the necessity of a long term management commitment to QC Circles. Another important element is the capacity of management to act on the recommendations of the QC Circles; either by acceptance and implementation or by rejection with

explanations to the circle members. Data collected in this area by interviews, surveys and observation can determine the readiness in this area.

3. Overall Knowledge of Concept - even a thorough training program to educate all members of an organization in the knowledge and importance of the QC Circle process may not remove all doubts from everyone's mind. If some of the key people in the organization still question the usefulness of the concept, readiness for implementation may be questionable.

4. Implementation Plans - a thorough and detailed plan (including plans for contingencies) that has the approval and support of the key managers and supervisors is a sure sign that the organization is ready to proceed.

Any major roadblocks in any of these four areas may move the prudent manager to "fall back and regroup" before proceeding.

CHAPTER FIVE

QUALITY CONTROL IN THE CROM CORPORATION

5.1 Overview of The Crom Corporation

The Crom Corporation is an engineering and construction firm that specializes in prestressed composite tanks. It was founded in the early 1950s and has grown today to assume a prominent role in composite tank design and construction. Since its inception, The Crom Corporation has built over one thousand tanks ranging in size from 25,000 gallons to 10 million gallons. The wide range of applications include water reservoirs, wash water tanks, clarifiers, reactivators, sedimentation basins, digesters, trickling filters, lime slurry tanks, thickener and softener basins, aeration tanks and stock charts.[56]

The growth and success of The Crom Corporation may be attributable to several factors. Primarily, they enjoy an excellent reputation due to their favorable history, successful design, broad experience, high degree of responsibility, and standing behind the guarantee of quality in their product. As a specialty subcontractor, The Crom Corporation assumes total responsibility for tank construction. There is no further division of responsibility beyond them. For this reason, their guarantee is effectively the best in the market today. The written guarantee warrants the workmanship and materials for a period of five years from date of acceptance of the tank. If leakage or other defects occur within the warranty period, they will make the required repairs promptly upon written notification from the owner. These repairs are made at no cost to the owner with all expenses borne by The Crom Corporation. To make this guarantee even better, The Crom Corporation has essentially backed up its written guarantee with an unwritten service lifetime guarantee. This is how confident they are with the quality of their product. This commitment and dedication to complete customer satisfaction is a major selling point in their favor.

5.2 Quality Methods in Practice

Since The Crom Corporation specializes in only one type of product, experience has enabled it to become extremely proficient in its design and construction. A unique facet of the Crom philosophy is that anyone who aspires to a management position in the company must undergo field training for approximately two years. The objective of this field training is to educate the individual concerning the product that the company sells. A secondary benefit is derived whereby a greater empathy with the workers is achieved. As a result, The Crom Corporation has an inner strength of perceptive managers who are attuned to the needs of the workers. This mandated kinship of management and workers has produced a company that is characterized by its closeness and loyalty. Everyone in the organization realizes that the issue of job security rests in the success of the company. Therefore, a genuine attitude of desire for excellent quality and productivity is present.

5.2.1 Personnel

The most important resource in any organization is its people. Skilled, hard working individuals significantly determine the quality of construction. The Crom Corporation cultivates skilled craftsmen through a well defined training program. Advancement from one level to the next is controlled in large part by the individual's own motivation and abilities. The problem exists not with its own full-time workers, but with the local hires at the various job sites. Although they are hired only for manual type labor, the quality of men and women available is often lacking in all respects. "Down-and-outers", alcoholics and malingerers are frequently referred to the project superintendent from the local unemployment agencies. From this poor selection, the superintendent must put together a workforce capable of performing quality construction. This is not to say however, that only the dregs of society are referred, but the point is that Crom's own quality workforce is weighed down by the introduction of outside personnel. Only the keen eyes of the superintendent and foremen can weed out those workers who do not contribute to quality.

The retention problem of experienced tankbuilders and nozzlemen has been overcome by the company's management philosophy of treating their workers as part of a family. During lean construction periods, valuable men are kept employed even though they may be working out of their area of expertise. It is felt that it is in the company's better interest to keep them on the payroll even though the work is not there. It also has the added benefit of familiarizing the workers with other aspects of the company's operation. Better educated workers pay big dividends in the potential for higher quality work.

5.2.2 Construction in the Field

A basic hindrance to product uniformity in construction is the myriad of complexities inherent to different construction sites. However, uniformity may be approached through a standardized system of construction. The Crom Corporation builds prestressed composite tanks that are basically similar in design. The use of a standard design allows workers the opportunity to gain proficiency in various construction techniques. The routine nature of these techniques places absolute quality almost within the reach of the company. This is evidenced by their ability to offer the best guarantee in the industry.

Notwithstanding the enviable position of The Crom Corporation as a quality leader in its field, construction problems do crop up and persist. For example, the watertightness of the tank is critically dependent upon the integrity of the steel diaphragm and its interface with the tank floor. Any error in the installation or material condition of either could result in leaks. A special epoxy is used to compensate for any irregularities between the extruded rubber gasket and the steel diaphragm sheets. Epoxy is also useful in assuring a watertight seal.

5.2.2.1 Vertical Joints

During two field trips to a Crom Corporation project site in Tampa on February 21st and March 22nd of 1984, several recurrent construction difficulties surfaced through interviews with field personnel. One difficulty inherent in any Crom tank is the treatment of each vertical joint between sheets of diaphragm material. Presently, a pre-formed hole at the bottom of the panel is used to pump epoxy up through the joint to achieve watertight integrity. Problems are encountered when the pre-drilled hole is off the mark or when shotcrete makes its way into the void thereby creating an obstacle to the smooth flow of epoxy. The Crom Corporation has met these difficulties by developing specialists. A "pump joint" crew will come on board and perform the function of pumping the joints full of epoxy. This specialization of task may be a natural consequence of the company's growth. The vertical joints are a multi-faceted problem. The holes may not be aligned correctly, the nipples may be installed at the wrong angle or too far through, joints may be inadequately cleaned or taping may be improper. A specialized crew would concentrate their efforts in assuring that these facets were correctly performed.

5.2.2.2 Shotcrete Application

Proper dry-mix shotcrete nozzling is one of the keys to insuring a watertight tank. To this end, The Crom Corporation is a leader in its field. The application of shotcrete is performed by workers who have been specially trained in this skill area. His or her training includes theory on sandpockets, overspray, rebound, reinforcing placement, weather conditions, curing, and all other items required for a satisfactory application.[57] The extent of this training is so comprehensive that a broad foundation is laid for quality awareness. Figures 5.1 and 5.2 are examples of the training aids used. The nozzlemen are experienced and certified by independent testing agencies in accordance with guidelines established by the American Concrete Institute (ACI).[57]

The control exercised over the shotcreting operation is considered to be more effective because of the wide range of topics covered in the nozzleman training course. Operators are taught to notice whether proper conditions are present before the shotcrete can be applied. In this way, they perform a check on the work completed by others. Crews that work immediately ahead of the shotcrete crew must perform in a quality manner, otherwise negative attention will be drawn toward them.

5.2.2.3 Diaphragm Integrity

The Crom Corporation policy on checking for diaphragm leaks during construction, calls for the tank to be "shined." To "shine" a tank means to light the interior at night and to check for holes in the diaphragm. Light leaks are marked and patched with epoxy. Although this is the company policy on checking diaphragm integrity, some superintendents have, and

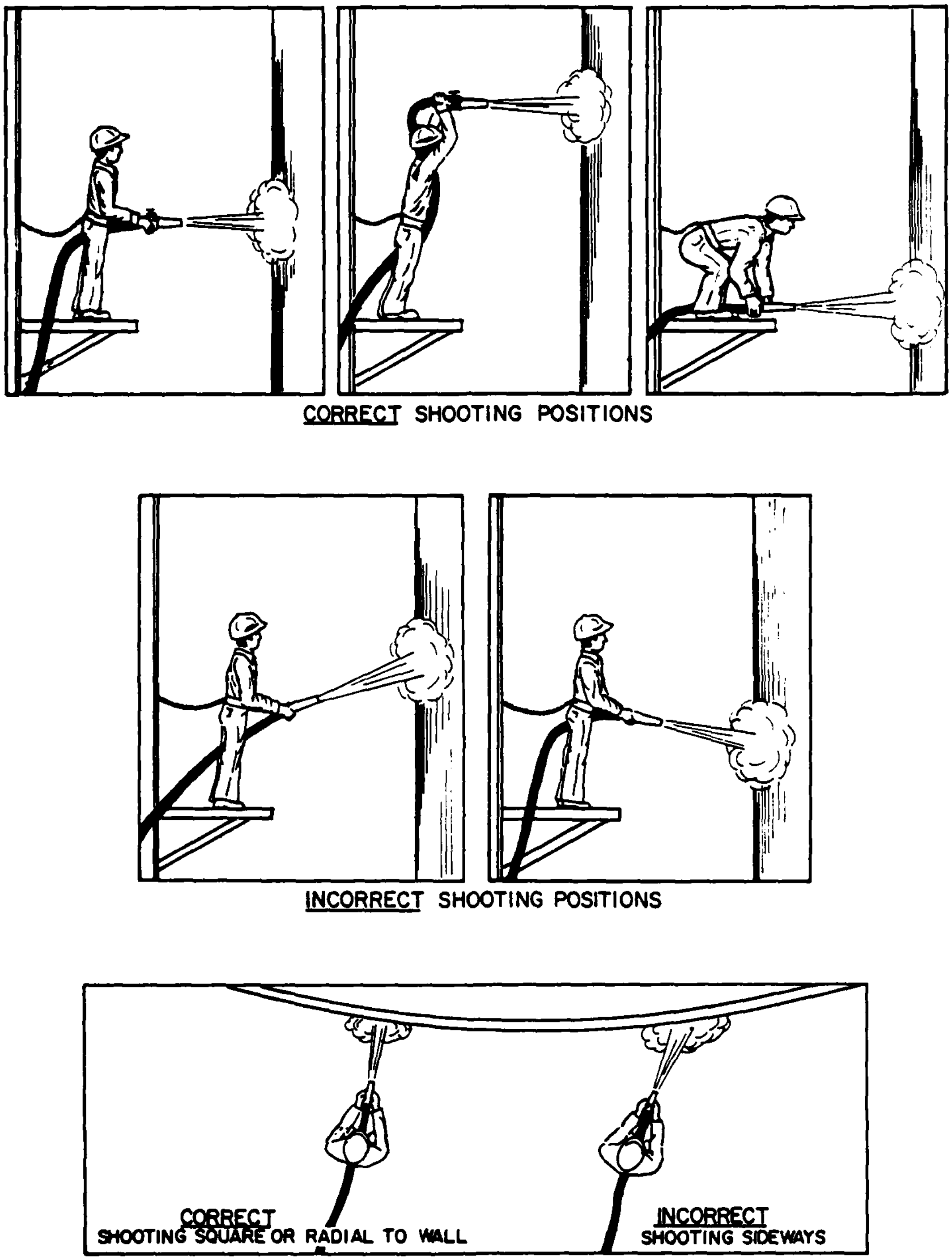

Figure 5.1 Training Aid Depicting Proper Shotcrete Application Technique (Source: 57)

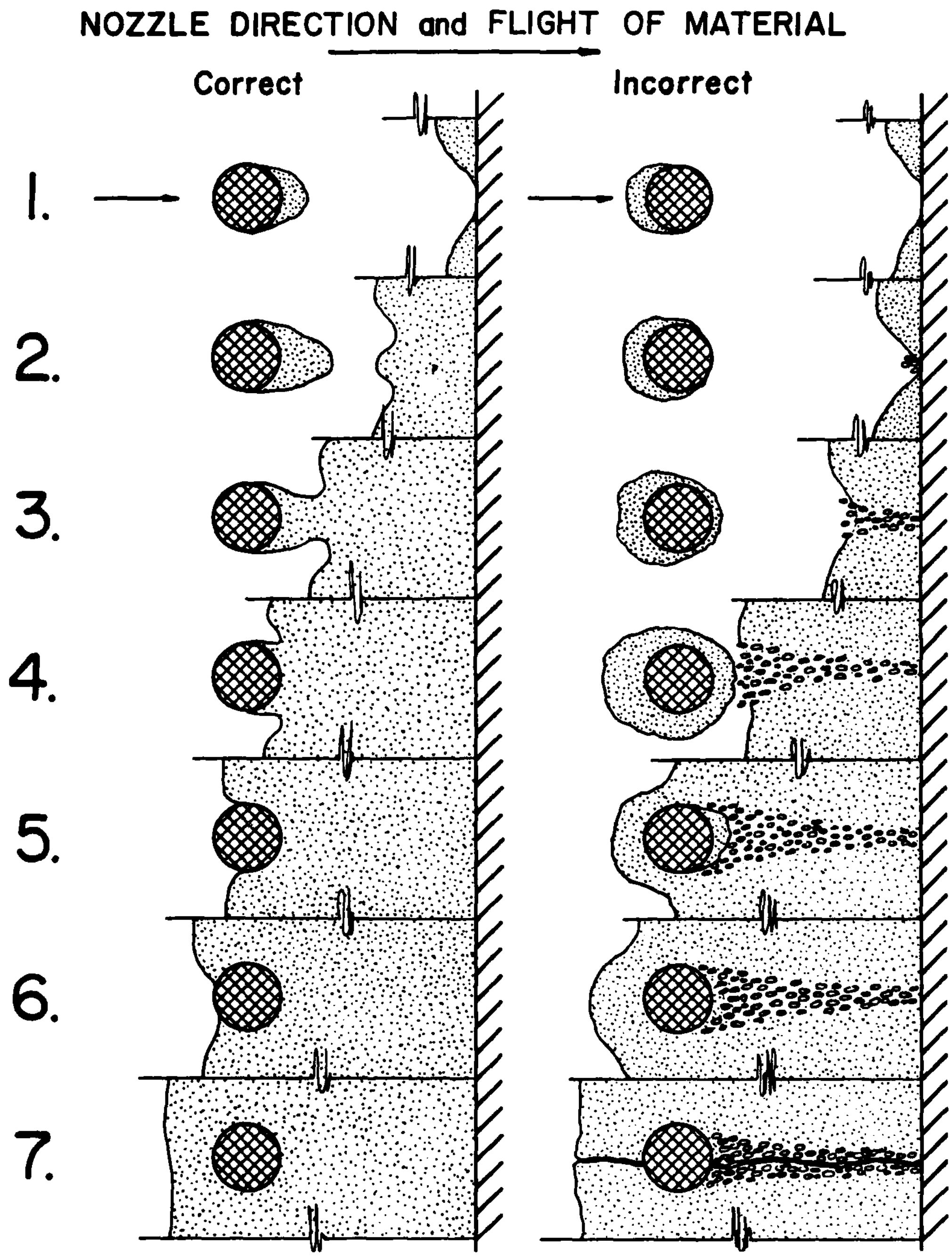

Figure 5.2 Training Aid Depicting Proper Encasement of Reinforcing Steel (Source: 57)

use, their own methods. The latitude afforded to the project superintendent is considerable as he must answer only for failures in the final analysis. Some superintendents believe that leaks or holes can be better detected after shotcreting the exterior. They maintain that the velocity of the shotcrete material is so great that it is able to find even pin holes that penetrate the diaphragm through them. These areas are then marked on the interior by patches of shotcrete that have gotten through.

5.2.3 Summary

The overall objective of constructing a watertight tank affects all areas of operation. Not only must the floor joint be impermeable, but the diaphragm itself must be free of penetrations as well. The shotcrete encasement must be applied properly as well as the prestressed wire winding. Every phase of construction is dependent upon the other in order for a quality product to be built. Field quality is affected by the materials received and the way in which they are installed. It becomes evident that the entire organization plays a part in and affects the overall quality of the finished product.

5.3 Quality Incentives

The incentive mentioned the most in interviews with Crom Corporation employees is the project bonus. While the dollar figure differs for each project, the bonus awarded to the job superintendent is considered sizable. The amount of the bonus is determined by way of a complicated formula with parameters for time, budget, safety and aesthetics. This bonus amount is computed by the project manager and awarded only after the tank is accepted and leakproof for the first ninety days. The assumption made here is that if the tank is going to leak, it will leak within the first ninety days. Obviously, this is a strong driving force for meeting the constraints of quality, timeliness, budget and safety.

Other incentives are not as dramatic as the bonus. For the individual worker, proficiency in his skill area leads to greater productivity and improved chances for advancement. Recognition of the worker as a quality conscious person could result in an enhanced self-image and serve as a positive example for others.

The initiative of workers is never restrained. This creates an atmosphere of cooperation between the workers and management. During the concrete placement of a dome roof, some workers wanted to experiment with a vibrating screed. Such a screed was jury-rigged and in operation during the placement. While perhaps not an overwhelming innovation or success, the important thing to remember is that the workers were not stifled in their attempts to look for a better way to do things.

5.4 Quality Guarantee

During the past five years (1979-1983) The Crom Corporation has spent over $777,000[58] in repair work for defective tanks. This was the cost to the company of backing up its guarantee. The dollar amount cited includes not only work that falls under their written guarantee, but also work on tanks that are out of warranty. As an operating philosophy, the company strives to maintain continued customer satisfaction. The extra cost involved in repairing tanks whose guarantee has expired results in a reputation as a dedicated, responsible, and pride-in-quality minded company. This pays dividends in terms of advertising and in new jobs that come their way.

The guarantee is also a tool by which quality may be checked and improved. If costs of repairs are excessive or too high, this would indicate that the tanks are not being built properly the first time. It is less expensive to make it right the first time than to try to correct mistakes. The purpose of a quality guarantee is to put the purchaser in the position he would have been had the product been good in the first place.[59] It is remarkable to note that during

1983, The Crom Corporation made $2859 worth of repairs on a tank that it built in 1959. Some twenty-four years later, the company is still concerned about satisfying its customers.

5.5 Quality Documentation

During the construction phase daily reports are maintained by the job superintendent. These reports record weather conditions, materials used, labor, equipment, activities performed and any other data pertaining to the construction of the project. Proper documentation during construction is useful in determining causes for problems encountered later on. Typically what happens is that these reports are very sketchy. This is due in large part to most superintendents' aversion for paperwork. Being men of action, the passivity of filling out forms is unappealing to them. Hence, minimal attention is given toward proper project documentation. This was most evident during field trips to project sites in February and March 1984.

5.6 Recommendations

The successful operation and growth of The Crom Corporation may be traced to its commitment in providing a quality product. This is supported by its emphasis of "cradle-to-grave" management of projects by their project managers. When a single person is dealing with a customer in all phases of product delivery, that is marketing, design, contracting and construction, the customer gets more than his money's worth because of the continuity of his relationship with the company. It is this philosophy of quality and service to the customer that causes The Crom Corporation to be a prominent leader in the tank building industry. But there is always room for improvement.

5.6.1 Bonus

As an incentive for job superintendents to complete projects expeditiously, a bonus is given upon satisfactory completion of the job. The amount is computed based upon the parameters of cost, time (ahead or behind scheduled completion date), safety record, and aesthetic appearance. Although this bonus has worked well, opponents argue that it damages the quality effort.

By providing such a strong motivator as a sizable bonus, the opportunity exists for abuses to occur if proper safeguards are not in place. On the job, the superintendent has virtually absolute authority. The company depends on him to see that a quality tank is constructed. So with his tremendous responsibility, he carries with him the commensurate authority. However, circumstances may occur whereby the project falls behind schedule. Or perhaps the project is pushed by impending detrimental weather conditions. Whatever the cause, the superintendent oftentimes faces the decision between degree of quality and size of bonus.

While The Crom Corporation employees are highly qualified and motivated, the lure of bonus money can sometimes blind people. Bonuses routinely given soon become things to be expected. Before long, the bonus becomes the preeminent factor in a job. The constraints of safety, cost, time, and quality upon the size of the bonus are recognized but only indirectly influence the execution of the construction phase. This is due to the complexity of the formula by which project managers determine the bonus amount.

A major change is recommended in the administration of the bonus program. Presently, the bonus is awarded to the superintendent if, after the first ninety days in service, the tank does not exhibit any leaks. In this context, the risk of the superintendent is short-term. The tank need only remain watertight for the first ninety days. But because of the almost unlimited guarantee, the company should investigate a method by which long-term quality can be achieved. The traditional methods of training the workforce is effective. But an added reinforcement of the technique taught is needed in the field. This is the foremen and superintendent's function. But due to the pressures of the job, they often are unable to be quality inspectors as well.

What is recommended, is a delayed bonus program. In this program, the bonus is computed as it is presently done, but the bonus is paid out in increments over the lifetime of the written warranty. There are two advantages to this proposal. First, it increases the risk of the superintendent from short-term to long-term. In this way, he should become more concerned about the details of quality methods in construction. For it is the details that determine the overall quality of a tank. Secondly, by placing the unpaid portion of the bonus in an interest earning escrow account for the superintendent, he has more of a stake in his own performance and in the performance of the organization. Any expenses incurred due to repairs on the tank would first be taken from the unpaid portion of the bonus. By making his bonus contingent upon time and lasting quality, the retention of quality superintendents is made easier as well. The benefits to the superintendents are an increased awareness of the importance of quality in construction, the accrual of interest on the unpaid portion of the bonus, and a lower taxable income per year.

5.6.2 Specialization

The trend toward specialization in tasks evidenced by the pump joint crew is somewhat disturbing. The workers are trained in the overall process involved in tank construction. With the training should go proper execution in the field. If problems occur and persist on site, then the deficiency should be corrected by more or better training. By bringing a specialized crew in to perform a task which the on site crew should be able to properly perform but cannot or will not, is felt to be a step in the wrong direction.

This division of labor into specialized tasks may lead to a solution to the problem, but it may also create other problems. For example, if problems do arise later, finger pointing and a reluctance to accept responsibility may result. This is contrary to the philosophy of "cradle-to-grave" delivery as far as the construction crew is concerned. It is recommended that The Crom Corporation re-evaluate this area of concern.

5.6.3 Repair Costs

The accounting and cost control of repair work is accurately kept on computer files as well as on backup hand cards. The repair costs cited in section 5.4 of this report were extracted manually from volumes of data cards. Manual extraction from cards that were updated by hand seemed to indicate an underutilization of resources.

The numbering system of cost accounts is relatively simple. A sample account number of 6425 contains two basic pieces of information. The first two digits refer to the year in which financial activity first began to appear on that particular job. The last two digits refer to the number of the job opened that year. In the sample number given, 6425 refers to the twenty-fifth job opened in 1964. Repair costs are appended as a .09 suffix cost account. Therefore, all repair costs to any particular tank are available. Difficulties arise because repair costs may accrue in differing fiscal years. So, in order to determine the cost of repairs for the tank built in 1964 (6425), one would have to search for cost account 6425.09 for every year beyond 1964. It would appear logical that a computer would be able to retrieve this information without any problem. However, such is not the case according to the head accountant of The Crom Corporation.

It is puzzling to perceive of a computer program or system that requires as much manual backing up as this particular one. While this line of questioning was not pursued, it is recommended that The Crom Corporation review its utilization of the computer in the accounting function. Along with this review, it is also suggested that a person knowledgeable in statistical analysis determine what types of data should be maintained for further business applications.

5.6.4 Construction Documentation

The area of construction documentation in the field has been a bane for managers for a long time. In order to establish adequate controls for quality, painstaking attention to documentation must be given. All required reports must be filled out properly, tests performed on schedule, and all prerequisites documented in order that doubt is not cast during audits on otherwise acceptable construction. A thorough and detailed system of documentation would be helpful in providing a basis for study, feedback, and decision making. It is recommended that The Crom Corporation review the adequacy of their construction documentation with respect to a comprehensive approach to quality control. That is, documenting for the purpose of advancing measures of quality control rather than for purposes of protection from liability.

5.6.5 Training

In the new organization assumed by The Crom Corporation in January 1984, the Field Services Division is responsible for Safety, Training, and Quality Control. As it just so happens, the final recommendation is closely intertwined with training and quality control.

The training program that is established is an excellent one. A well defined path of progression for its full-time workers is marked by plenty of training aids and encouragement. At this time it should be recalled that quality control circles were hailed as the savior of Japan. It was through a massive quality training effort that the Japanese industries achieved their leadership position today.

From the author's viewpoint The Crom Corporation is ripe for the proper introduction of QC Circles. Its management is enlightened to the need for quality and is capable of focusing on it vice productivity. They also pride themselves on the fact that "people make the company".[60] So, the company would look upon QCC's as a people building program as well. It is recommended that The Crom Corporation seriously assess itself with regard to its readiness for Quality Control Circles. They should research the principles of how they work and ascertain for themselves the probabilities of success in their own corporation.

CHAPTER SIX

RECOMMENDATIONS AND CONCLUSION

6.1 Summary of Recommendations

Recommendations to improve the level of quality in The Crom Corporation are made in five distinct areas. The delayed bonus program is seen as the one immediate area that will return both instant and long term dividends. However, before any action is taken to change the bonus program, management must thoroughly study all the possible ramifications of such a change. Once a decision is reached, successful implementation will depend on how well it is "sold" to the superintendents. Participative management actions in this regard would be beneficial if any changes are to be made.

The second area for re-evaluation is the trend toward specialization in tasks. The Crom Corporation has always been proud of its self-sufficiency in the field. But division of tasks in the field is seen as an initial step in separating the worker from identification with the product. Introduction of specialists enhances the tendency to abdicate responsibility on the part of work crews. This area of concern should be closely examined in order to prevent complete alienation of the worker from the product.

Thorough construction documentation must be emphasized if quality control is ever to become rooted in scientific and statistical principles. Realizing the aversion to paperwork that is present in the field, an incentive to achieve proper documentation may be realized by relating it to the size of the bonus amount.

In a similar area of documentation, the accounting and cost control aspect of project execution has a substantial margin for improvement. Only by analyzing real costs over time, can a quality management program be properly evaluated.

The final recommendation is in the area of training with respect to implementation of QC Circles. Training cannot be over-emphasized in the development of a successful QC Circle program. It should also be remembered that QC Circles are a long term investment in higher quality products, higher quality work environments, and higher quality workers. The Crom Corporation appears to be in a perfect position to embark upon this well documented and successful concept.

6.2 Conclusion

The field of quality control in construction has been largely ignored. Sophisticated control techniques exist in industrial and manufacturing worlds but their uses are limited in construction. In construction, quality control is emphasized in materials testing and evaluation. However, the discipline of quality control must still be considered as an art when it comes to the building process.

All things considered, the approach that appears most effective for controlling construction quality is the "total quality system" or "company-wide quality control" (CWQC) approach. The involvement of all members of the construction team is considered crucial in affecting quality. The important point to remember in this approach is the requisite foundation of establishing and maintaining good working relationships with other members of the team. While everyone should be on the lookout for construction defects or errors, they should never take a self-righteous attitude if and when they do find mistakes and alienate others. By dealing honestly and fairly with others, an atmosphere of mutual respect and cooperation would be achieved.

It can be seen then that the foundation for an effective quality control program stems from proper management of human resources. Essentially, this is the premise from which the Japanese rebuilt their country and

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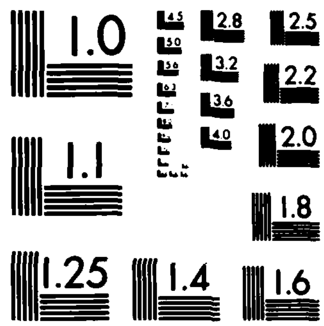

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

economy. It should be noted that the Japanese theory on quality control is not built around quality control circles. The use of QC Circles works effectively only because of the company's vital "quality infrastructure".[61] So, it becomes obvious that before a company can successfully use QC Circles, it must have a properly developed "quality infrastructure". This can only come about through a massive training effort.

The construction industry can benefit from the total quality system approach. Difficulties would occur due to the fragmented nature of the team members. But in firms that are still self-sufficient, such as The Crom Corporation, this approach has enormous potential for less repair work (higher quality) and increased company harmony and loyalty within its workforce.

Construction companies should be cautious though about implementing the concept of quality control circles without first counting the cost with respect to training, man-hours invested, and commitment to the program. It is said that it normally takes approximately three years after introduction of the concept before any noticeable improvements can be realized. So, the commitment required is considerable especially when one stops and recalls that the average business lifespan of a general contractor is approximately five years.

Much has been done in the field of quality control during this century. Advances have been great especially in the aerospace industry. Twenty years ago, space travel was stuff that dreams were made of. But because of the tremendous progress and development of quality control techniques, space travel may become common place and available to all of those who dare. The quality control efforts in construction have lagged behind primarily due to its inherent nature. Today, construction professionals are only beginning to realize that the same type of space-age quality of product is possible. What it takes is a whole new perspective. We must begin where the Japanese began thirty years ago. Only by dedication to this purpose, can the construction industry enjoy the same advances in quality that other industries have long enjoyed.

REFERENCES

1. Carrubba, Eugene R., Ronald D. Gordon, and Adril C. Spann, Assuring Product Integrity, D. C. Heath and Co., Lexington, 1975, p. 2.

2. Halpern, Siegmund, The Assurance Sciences: An Introduction To Quality Control and Reliability, Prentice-Hall, Inc., Englewood Cliffs, 1978, p. 65.

3. Carrubba, op. cit., p. 4.

4. Halpern, loc. cit.

5. Juran, J. M., Leonard A. Seder, and Frank M. Gryna, Jr., Quality Control Handbook, McGraw-Hill Book Company, Inc., New York, 1962, p. 1-2. Hereafter referred to as QC Handbook.

6. Ibid.

7. Halpern, op. cit., p. 66.

8. Hartstern, Robert F., "Quality Control During Construction of Power Plants", Journal of the Construction Division, American Society of Civil Engineers, Vol. 108, No. CO1, Proc. Paper 16896, March 1982, p. 57.

9. Ibid.

10. Abdun-Nur, Edward A., "Control of Quality - A System", Journal of the Construction Division, American Society of Civil Engineers, Vol. 96, No. CO2, Proc. Paper 7576, October 1970, p. 119.

11. Feigenbaum, A. V., Total Quality Control, McGraw-Hill Book Company, Inc., New York, 1961, p. 18.

12. Carrubba, op. cit., p. 3.

13. Feigenbaum, op. cit., p. 17.

14. Carrubba, op. cit., p. 4.

15. Rutherford, John G., Quality Control in Industry, Pitman Publishing Corporation, New York, 1948, p. 65.

16. Feigenbaum, op. cit., p. 207.

17. Ibid.

18. Halpern, op. cit., p. 66.

19. Rutherford, op. cit., p. 99.

20. Miller, Irwin and John E. Freund, Probability and Statistics for Engineers, Prentice-Hall, Inc., Englewood Cliffs, 1965, p. 336.

21. Feigenbaum, op. cit., pp. 308-310.

22. Ibid.

23. Juran, QC Handbook, p. 13-69.

24. Feigenbaum, op. cit., p. 390.

25. Feigenbaum, op. cit., p. 391.

26. Feigenbaum, op. cit., p. 406.

27. Feigenbaum, op. cit., p. 416.

28. Abdun-Nur, op. cit., p. 119.

29. Clough, Richard H., Construction Contracting, John Wiley & Sons, Inc., New York, 1981, p. 2.

30. Abdun-Nur, op. cit., pp. 121-123.

31. Ibid.

32. Clough, op. cit., pp. 80-81.

33. Abdun-Nur, op. cit., p. 130.

34. Carper, Kenneth L., "Limited Field Inspection VS. Public Safety", Civil Engineering, May 1984, p. 52.

35. Isaak, Merlyn, "Contractor Quality Control: An Evaluation", Journal of the Construction Division, American Society of Civil Engineers, Vol. 108, No. C04, Proc. Paper 17507, December 1982, pp. 481-484.

36. Godfrey, K. A., "Building Failures - Construction Related Problems and Solutions", Civil Engineering, May 1984, pp. 61-63.

37. Ibid.

38. Simon, Michael S., Construction Contracts and Claims, McGraw-Hill Book Company, Inc., New York, 1979, preface.

39. Moskowitz, Joyce, "Quality Control Circles: Will They Work in the U. S.?", Mechanical Engineering, March 1982, p. 72.

40. Juran, J. M., "International Significance of the QC Circle Movement", Quality Progress, February 1983, p. 20. Hereafter referred to as QC Circle.

41. Moskowitz, loc. cit.

42. Sandholm, Lennart, "Japanese Quality Circles - A Remedy for the West's Quality Problems?", Quality Progress, February 1983, p. 20.

43. Juran, QC Circle, p. 22.

44. Moskowitz, op. cit., p. 73.

45. Sedam, Scott M., "QC Circle Training Process Should Cover Relating, Supporting, Problem-Solving Skills", Industrial Engineer, January 1982, pp. 72-74.

46. Ibid.

47. Moskowitz, op. cit., p. 73.

48. Kusayanagi, Shunji and B. Philip Hatley, "Look Again At Quality Circles", Civil Engineering, April 1984, p. 67.

49. Sandholm, op. cit., p. 21.

50. Rieker, Wayne S., "QC Circles and Company-Wide Quality Control", Quality Progress, October 1983, p. 14.

51. Babbit, Robert C., "One Company's Approach to Quality Circles", Quality Progress, October 1981, p. 28.

52. Juran, QC Circle, p. 19.

53. Gordon, George J., Public Administration in America, St. Martin's Press, New York, 1982, pp. 181-182.

54. Brooke, Keith A., "QC Circles' Success Depends on Management Readiness to Support Workers' Involvement", Industrial Engineer, January 1982, p. 76.

55. Ibid.

56. Crom Prestressed Composite Tanks, The Crom Corporation, Gainesville, undated pamphlet.

57. Crom, Theodore R., Dry Mix Shotcrete Nozzling, The Crom Corporation, Gainesville, undated report, p. 30.

58. Research conducted at The Crom Corporation, Accounting Division, Gainesville, March 28, 1984.

59. Juran, QC Handbook, p. 1-27.

60. Shafer, Willard G., A Civil Engineering Management Research Study for the Crom Corporation, xeroxed report, Department of Civil Engineering, University of Florida, January 1984, p. 8.

61. Sandholm, op. cit., p. 22.

BIBLIOGRAPHY

Abdun-Nur, Edward A. "Control of Quality - A System." Journal of the Construction Division, American Society of Civil Engineers, Vol. 96, No. C02, Proc. Paper 7576, October 1970.

Babbit, Robert C. "One Company's Approach to Quality Circles." Quality Progress, October 1981.

Brooke, Keith A. "QC Circles' Success Depends on Management Readiness to Support Workers' Involvement." Industrial Engineer, January 1982.

Carper, Kenneth L. "Limited Field Inspection VS. Public Safety." Civil Engineering, May 1984.

Carrubba, Eugene R.; Gordan, Ronald D.; Spann, Adril C. Assuring Product Integrity, D. C. Heath and Co., Lexington, 1975.

Clough, Richard H. Construction Contracting, John Wiley & Sons, Inc., New York, 1981.

Crom Prestressed Composite Tanks, The Crom Corporation, Gainesville, undated pamphlet.

Crom, Theodore R. Dry Mix Shotcrete Nozzling, The Crom Corporation, Gainesville, undated report.

Feigenbaum, A. V. Total Quality Control, McGraw-Hill Book Company, Inc., New York, 1961.

Godfrey, K. A. "Building Failures - Construction Related Problems and Solutions." Civil Engineering, May 1984.

Gordon, George J. Public Administration in America, St. Martin's Press, New York, 1982.

Halpern, Siegmund The Assurance Sciences: An Introduction to Quality Control and Reliability, Prentice-Hall Inc., Englewood Cliffs, 1978.

Hartstern, Robert F. "Quality Control During Construction of Power Plants." Journal of the Construction Division American Society of Civil Engineers, Vol. 108, No. C01, Proc. Paper 16896, March 1982.

Isaak, Merlyn "Contractor Quality Control: An Evaluation." Journal of the Construction Division, American Society of Civil Engineers, Vol. 108, No. C04, Proc. Paper 17507, December 1982.

Juran, J. M.; Seder, Leonard A.; and Gyrna, Frank M. Jr. Quality Control Handbook, McGraw-Hill Book Company Inc., New York, 1962.

Juran, J. M. "International Significance of the QC Circle Movement." Quality Progress, November 1980.

Kusayanagi, Shunji and Hatley, B. Philip "Look Again at Quality Circles." Civil Engineering, April 1984.

Miller, Irwin and Freund, John E. Probability and Statistics for Engineers, Prentice-Hall Inc., Englewood Cliffs, 1965.

Moskowitz, Joyce "Quality Control Circles: Will They Work in the U. S.?" Mechanical Engineering, March 1982.

Rieker, Wayne S. "QC Circles and Company-Wide Quality Control." Quality Progress, October 1983.

Rutherford, John G. Quality Control in Industry, Pitman Publishing Corporation, New York, 1948.

Sandholm, Lennart "Japanese Quality Circles - A Remedy for the West's Quality Problems?" Quality Progress, February 1983.

Sedam, Scott M. "QC Circle Training Process Should Cover Relating, Supporting, Problem-Solving Skills." Industrial Engineer, January 1982.

Shafer, Willard G. A Civil Engineering Management Research Study for the Crom Corporation, mimeographed report, Department of Civil Engineering, University of Florida, January 1984.

Simon, Michael S. Construction Contracts and Claims, McGraw-Hill Book Company, Inc., New York, 1979.

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