

**QUALITY MANAGEMENT
AND REWORK IN THE CONSTRUCTION INDUSTRY**

by:

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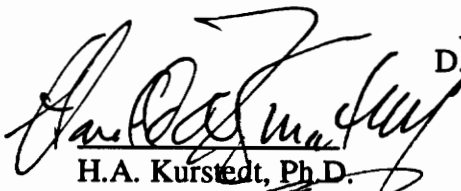
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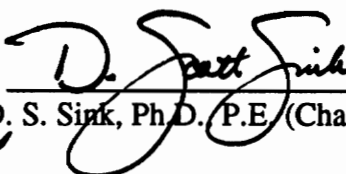
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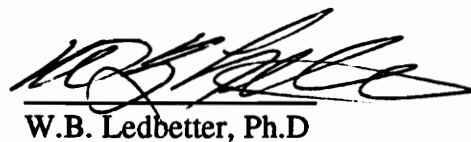
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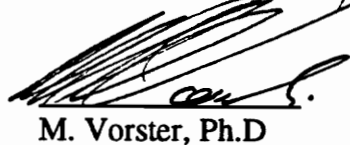
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ABSTRACT

Rework is an insidious problem in the construction industry. According to the Construction Industry Institute (CII) Source Document 29, the cost of rework is 12.4% of the total project cost. However, these costs are just the tip of the iceberg, because they do not represent schedule delays, litigation cost, and other intangible costs of poor quality. Therefore, the complete cost of rework is estimated to be much greater than 12.4%.

To effectively reduce the cost of rework, it is necessary to not only study the causes of rework, but also to study the effectiveness of activities designed to reduce rework. This research studied the relationships between rework activities and prevention and appraisal activities on four construction projects. This research addressed two questions: 1) What is the effect of prevention and appraisal activities on the reduction of rework, and 2) What is the effect of prevention activities occurring in the design phase on rework due to design errors in the construction phase?

Based on the project data collect by the Quality Performance Management System (QPMS), this research concluded there was a slight relationship between increasing prevention and appraisal activities and the reduction of rework. There was a direct relationship between the increase of prevention activities in design and the reduction of rework due to design errors in the construction phase. The relationships were stronger for both questions at the project level than at the discipline level. At the project level, the aggregation of all the disciplines appears to negate the biases created within the specific disciplines. This research helps to provide real-world data to emphasize the importance of prevention activity in the design phase of a construction project.

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Finally, I wish to dedicate this work to my parents Fritz and Marilyn Rudolph. Without their love and compassion, I would not be the person I am, nor could I have accomplished the things I have. I am incredibly fortunate to have great parents and blessed to realize how much they love me and how much I love them.

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SECTION 1: THE PROBLEM AND ITS SCOPE

1.1 Research Purpose

There is a need in the construction industry to improve the quality of operations and reduce the amount of rework that occurs to meet the required specifications. A Construction Industry Institute (CII) study of nine projects indicates that, on average, the cost of rework is 12.4%¹ of the total installed project cost (CII Source Document 29, 1987, p. 129). However, to improve quality and reduce rework, we must understand the root causes of the rework and the relative influence of activities designed to prevent rework (CII Publication 10-2, 1989)². The understanding of cause and effect relationships between rework and quality management activities will help construction organizations improve their processes to increase quality and reduce costs. Therefore, the purpose of this research is two-fold:

1. To demonstrate how quality management can be used to reduce rework.
2. To demonstrate how to reduce rework by properly timing prevention activity.

¹ The rework cost is only a portion of the project's cost of quality. CII defines the cost of quality as the sum of the cost of prevention and appraisal activities and the cost of rework.

² For the purpose of this research, the term quality management will be used interchangeably with prevention and appraisal activities, and the term rework with deviation correction.

1.2 Problem Statement

The amount of rework occurring in construction is not only a problem for the U.S. construction industry, but also for our nation which receives the construction industry's products. In 1989, the construction industry expenditures were nine percent of the U.S. gross national product (Oglesby et al, 1989, p.1). When considering that 12.4 percent of the cost is rework, one percent of the U.S. gross national product is spent on rework in construction.

This research will study the correlation between prevention and appraisal activities and the reduction of rework on construction projects. This research aims to 1) demonstrate the relationship between increasing prevention and appraisal activities and reducing rework and 2) demonstrate a relationship between prevention activities occurring in the design phase of the project life-cycle and their influence on reducing rework in construction due to design errors (i.e., the more prevention activity in the design phase, the less rework occurring in the construction phase due to design errors).

1.3 Importance Of Study

This research carries forward the CII Quality Management Task Force's efforts on Quality Performance Management System (QPMS), because this research defines, analyzes, and interprets some of the cause-and-effect relationships between prevention and appraisal activities and rework. CII emphasizes the need for knowledge about these cause and effect relationships with the following statement:

To manage and control the cost of quality properly, not only must we know the costs associated with correcting deviations and with quality management, but we must know the interrelationship between deviation cost and quality management costs (CII Publication 10-2, 1989, page 5).

When we have a better understanding of how quality management activities influence rework, we may begin to use longitudinal data for performance improvement. This knowledge may be used to stimulate improved methods of work to minimize the necessity for rework and unnecessary prevention and appraisal activity (Ledbetter and Wolter, 1992, p. 2-6).

1.4 Scope

The scope of this research is bounded by the Quality Performance Management System (QPMS) developed by the CII Quality Management Task Force (discussed in 2.4.2). QPMS is a measurement tool used to track the cost of quality which consists of the costs associated with: normal work, quality management activities, and correcting deviations/rework (CII Publication 10-2, 1989).

In developing QPMS, CII captured data from portions of one completed project, and W. B. Ledbetter, a consultant in quality measurement who developed QPMS, is currently capturing data from three construction projects in-progress. This research analyzes these four projects and looks for similarities and/or differences associated with the influence of quality management activities on the reduction of rework for each discipline. The disciplines studied by this research are electrical, instrumentation, mechanical, piping, tanks and vessels, and civil/architectural/structural. Further explanation of these disciplines will be discussed in section 2.4.2.

As indicated by Ledbetter and Wolter (1992), if we lived in a perfect world, we would only do normal work to accomplish the task. However, we do not live in a perfect world. Therefore, to understand why rework is happening, we need to study the root cause of rework. To understand how to effectively reduce rework, we must study the influence of prevention and appraisal activities on reducing rework.

This research continues work on QPMS conducted by the CII Quality Management Task Force to continually refine the answer to the following question: "Where must quality management efforts be placed in order to achieve the greatest benefit (i.e., result in the least deviation costs)?" (CII Publication 10-2, 1989, p. 3).

This research aggregates, analyzes, and interprets the data among the four different projects using QPMS. The study looks for trends and analyzes some of the trends occurring in the data to determine quality management's influence on reducing rework. The methodology (discussed in chapter three) was run within each discipline and at the project-level combining all of the disciplines. This study also analyzed the influence of prevention activities occurring in the design phases for their relative influence on reducing rework occurring in construction due to design errors.³

1.5 Delimitations

As with any research, there are certain relationships that will not be studied within this scope. However, it is possible for exogenous variables⁴ to influence the methodology and result in either a Type 1 or Type 2 error when analyzing the data. The following is a list of exogenous variables that this research will not evaluate:

- The length of time the company has used QPMS prior to the use on a current project⁵

³ There is an increased likelihood of a Type 2 error, involving failing to reject the null hypothesis when it is false due to the fact three of the two projects were not complete. However, an output of this research will be the model necessary to continue testing the relationships between projects after completion.

⁴ Exogenous variables are those variables considered to be outside the scope of the research. These variables will not be studied for their influence on the data.

- The data were "real-world" data and were not gathered from a controlled experiment
- Whether or not a company has used QPMS on more than one project
- The amount of quality management occurring within a company before the company implemented QPMS
- How much continuous improvement philosophies were visible throughout the company
- How QPMS was integrated into existing company procedures *⁶
- Contractual relationships *
- The effect of multi-party implementation *
- Philosophy and attitudes of owner and contractor *
- Specific differences of data processing, decision making, and evaluation among projects *

1.6 Research Questions

By studying the correlational relationships between quality management and rework for the purposes stated in section 1.1, the aim of this research was to develop an answer to the following research question:

- What is the effect of prevention and appraisal activities on the cost of rework?

This research also explored possible answers to the following question:

⁵ The historical data regarding QPMS is known, but will not be analyzed in the correlational studies being run on the data.

⁶ The * delimitations were also mentioned as items omitted from the Ledbetter and Wolter's QPMS course (1992).

- How do prevention activities occurring in the design phase of the project life-cycle influence the cost of rework occurring in the construction phase due to design errors?

1.7 Operational Research Questions

1. Will spending time doing quality management (prevention/appraisal) activities help reduce the cost of rework on a construction project?
2. If I spend more quality management time in the early stages of the project life-cycle, will I have a greater reduction in the project's overall cost of rework?

1.8 Conceptual Model

Figure 1.1 shows the conceptual model for the first research question and illustrates that this research will study correlational relationships between quality management and rework. As indicated in Ledbetter and Wolter (1992), if we lived in a perfect world, we would not need quality management activities or rework. However, we do not do things perfectly and therefore quality management activities and rework represent the cost of quality in the imperfect world. CII Publication 10-2 states the purpose of prevention and appraisal activities is to reduce rework in construction project. This research will help define the relationship between quality management activities and rework.

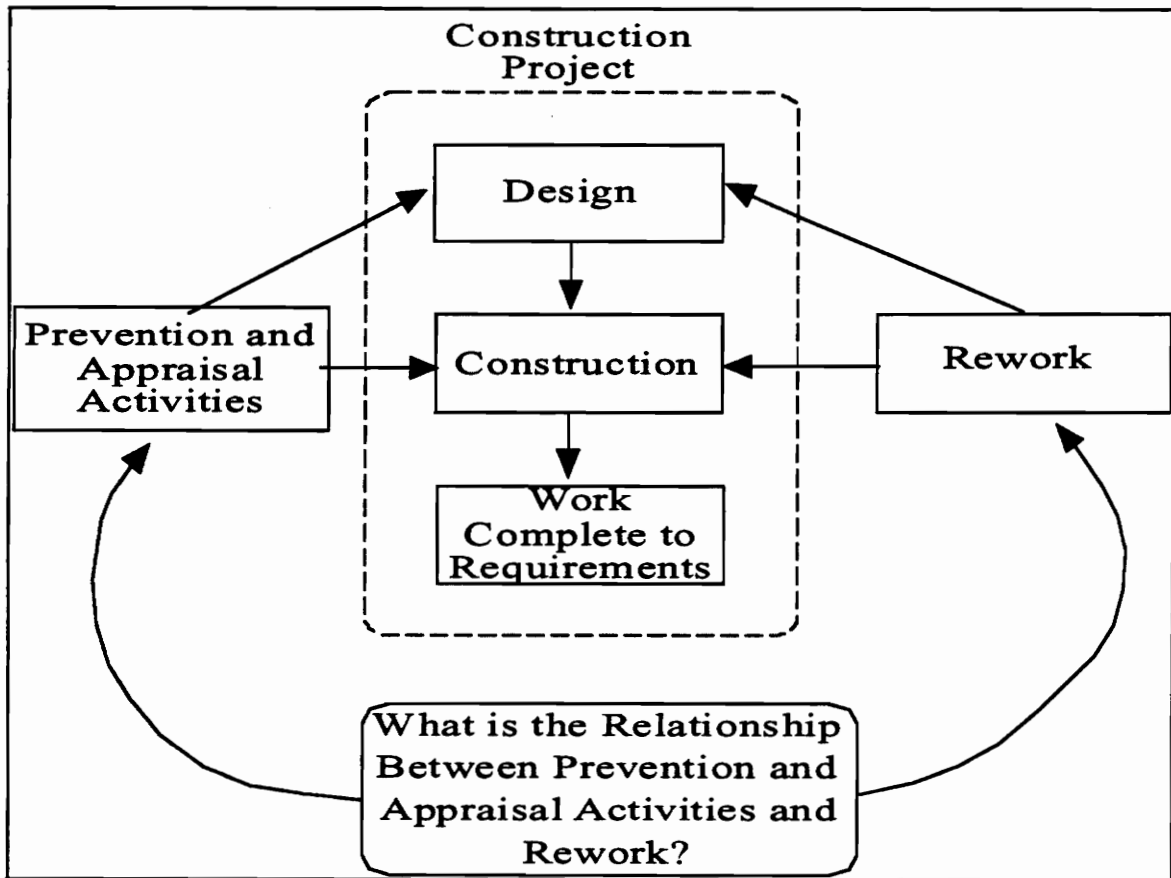


Figure 1.1: Conceptual Model for First Research Question

Figure 1.2 shows my conceptual model for the second research question and illustrates that this research will study correlational relationships between prevention activities occurring in the design phase and rework occurring in the construction phase due to design errors. The purpose of prevention activities is to keep rework from happening in the future. This research will help define the relationship between when the prevention activities occur and their impact on rework.

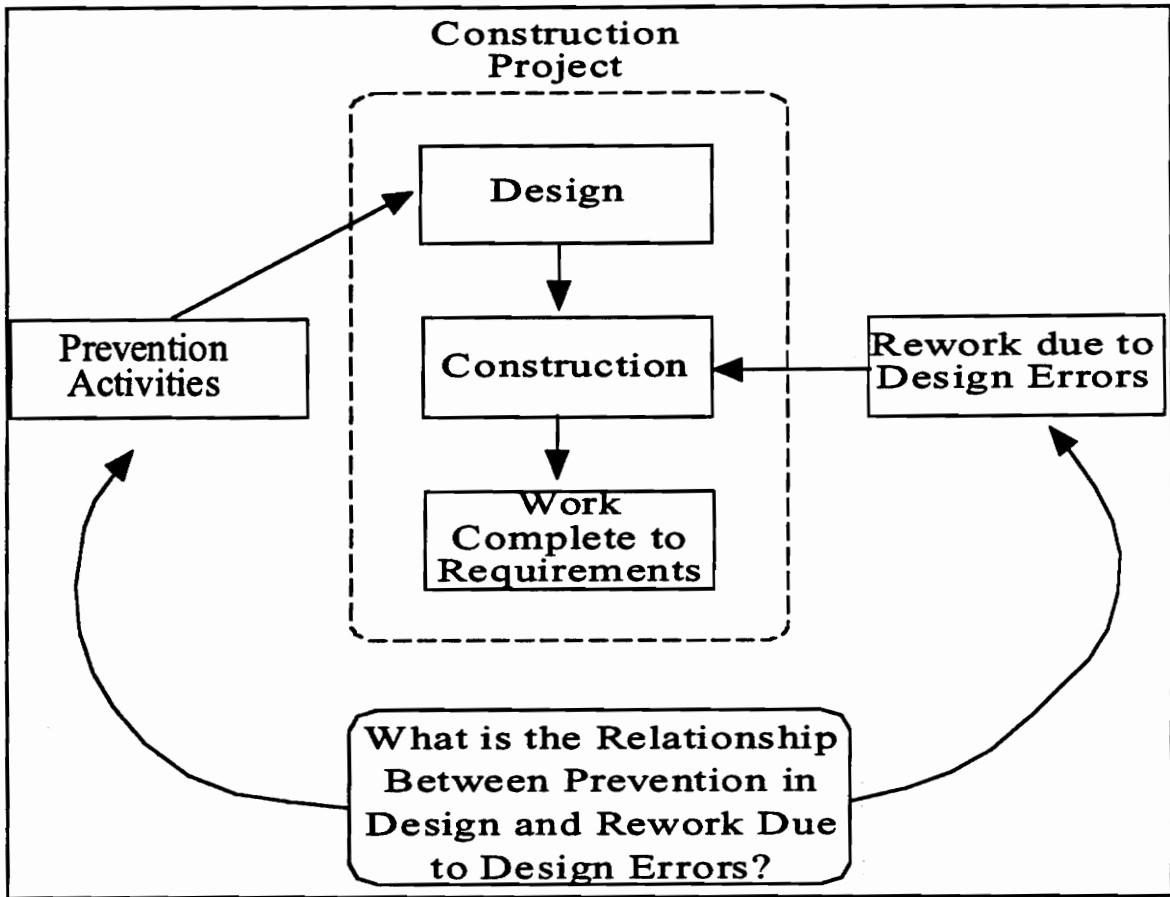


Figure 1.2: Conceptual Model for Second Research Question

1.9 Hypotheses

I will test the first hypothesis using correlational analysis.

For the First Research Question:

Null Hypothesis: Prevention/Appraisal Activity has no correlation with rework.

Hypothesis: Prevention/Appraisal Activity has a negative correlation with rework (i.e., the more prevention/appraisal activity, the less rework).

For the Second Research Question:

Null Hypothesis: There is no degree of correlation relating the prevention activity occurring in the design phase of the project life-cycle and the amount of rework occurring in construction due to design errors.

Hypothesis: The prevention activity occurring during the design of the project life-cycle has a negative correlation with the rework occurring in the construction phase due to design errors.

LITERATURE REVIEW

CHAPTER TWO

There is a great concern in the construction industry about the need for massive reforms to compete with the growing global competition. If major strides are not taken to improve the industry's performance, experts predict the construction industry may suffer the same fate as the US. automobile, textile, electronic, and steel industries (Matthews and Burati, 1989). But, in today's global economy, the paradigm of improvement is changing. It is no longer a matter of just getting better, but a competition of how much better and how quickly.

2.1 THE EXTENT OF THE QUALITY PROBLEM

In today's market, the quality of products and services has far-reaching implications for both business and society. The fierce competition in the global economy is continuing to produce goods and services of higher quality at lower prices (Deming, 1990, 1986; Juran, 1988; Feigenbaum, 1991; Crosby, 1989; Kearns, 1990; Marquart, 1991). Markets that used to be separated by national boundaries now transcend former geographic borders, reaching all four corners of the earth. Thriving organizations in the twenty-first century will provide the world's consumers with the products and services they need, when and where they want them.

Organizations losing the quality race often refute the success of foreign competition by claiming they have a cultural advantage. However, organizations competing well in today's dynamic environment recognize success has far less to do with national culture and far more to do with strong management, leadership, and continual study of how to meet your customers needs and wants (Deming p.5, Juran p. 445, Feigenbaum p. 3). Unfortunately, protectionist attitudes wanting to place higher tariffs on imports to protect domestic goods do little to improve the quality of domestic goods.

Even more disconcerting, is protectionist tactics do more harm than good, because they give management a false sense of security instead of the urgency to improve the products. International tariffs could expand the quality gap instead of closing it (Deming, 1990).

2.1.1 Closing The Quality Gap

Fortunately, several American companies have made significant strides in quality, but the race is a long way from being won. Although the organizations in the U.S. have achieved great accomplishments toward improving the quality of products and services, the need for improvement is severe. Studies of the foreign competition appear to show they are continuing to increase their rate of quality improvement (Cole, 1990). Figure 2.1 shows the impact of quality in the global marketplace according to Juran (1991).

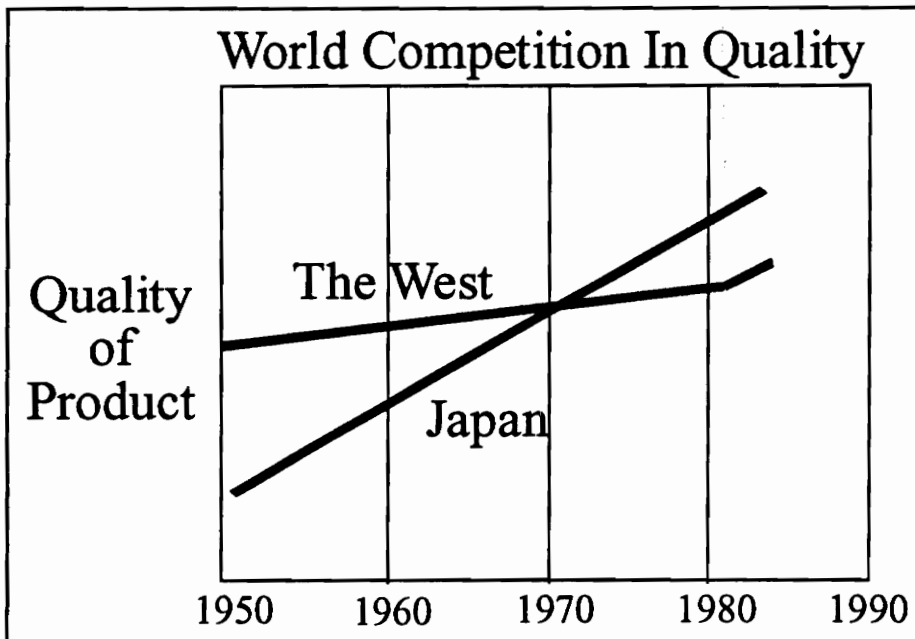


Figure 2.1: The Quality Competition in the Global Marketplace (Juran, 1991)

2.1.2 Quality Improvement Is Better for Society

In addition to benefiting the consumer with higher quality at lower prices, society as a whole benefits from improved products and services. The nuclear accident at Three Mile Island; the DC-10 crash in Sioux City, Iowa; the Kemper Arena roof collapse; and the Hyatt Regency walkway collapse have all had devastating impacts, of an immeasurable magnitude, to society. (Reddy, 1980; CII Source Document 30). These horrible accidents give significant cause to the growing concern regarding the dependability and safety of consumer goods and services in this country.

During the 1980's, newspapers were filled with announcements of plant closings, trade deficits, and languishing "smokestack" industries. These all-too-familiar news items indicated a more insidious malaise: the decline of American quality and productivity; thus, having a direct impact on our nation's ability to compete effectively in the global marketplace. Robert Reich of Harvard University compiled data on 16 industries for the U.S. Senate that showed the U.S. manufacturers' share of worldwide production fell by more than 50% between 1970 and 1979 (as discussed in Macieariello et al., 1989).

The underlying component of the widely-publicized competitive problem is the declining rate of productivity and quality in America, as compared to the foreign competition (Hayes & Abernath, 1980). According to the U.S. Bureau of Labor Statistics, from 1950 to 1983, the growth rate of U.S. manufacturing output per hour ranked seventh among seven advanced industrial nations. We trailed Great Britain, and were far behind Japan, West Germany, Italy, and France. Compared to Japan, the United States had a massively higher rework rate in the electronics industry (8%-10% vs. 0.5%-1%) and the U.S. industrial base is significantly older (17 vs. 10 Yrs.). These statistics clearly indicate the United States has a significant challenge ahead to compete globally.

The United States can no longer afford to be a society where a large percentage of the product's cost is devoted to rework (Loiselle, 1989). Deming (1986) estimates that 15-40% of the cost of goods or services is for waste, because low quality equals high cost.

Deming concludes it's a shame the country's economy must continue to suffer until management learns that by focusing on quality, organizations can reduce cost and increase productivity.

Significant quality improvement takes time, because it requires more than just implementing a program. An organization just beginning the quality race must first spend time studying itself to determine how it really meets the needs of its customers (Loiselle). As Deming puts it, there is no instant pudding in the quality game. It requires hard work and discipline, as with any true improvement effort. But, when realizing the potentially-devastating effects of allowing poor quality as discussed earlier, it's hard to imagine wanting to cut corners. Deming believes short-term profits are not an appropriate yardstick to measure good management, because anyone can learn to pay dividends by deferring maintenance, cutting out research, or acquiring another company. For management's efforts to be effective, they must move in the right direction.

2.1.3 The Importance of Management's Commitment to Quality

Cole's (1990) study compared the strengths in quality of the Japanese automotive firms versus American automobile firms. Cole found that the Japanese firms continue to drive hard for quality improvement, because they firmly believe strengths in quality will yield powerful results over the long term in the marketplace. Cole studied the underlying quality philosophies by the way the observers respond to the following argument:

The differences reported in J.D. Power's data compare the amount of defects in the U.S. cars versus the Japanese cars. The fact is that customers report the U.S. cars have 1.6 defects per car and the Japanese cars have 1.2 defects per car. This is only a difference of 0.4. (What is your response to this scenario?)

Cole asked the participants to discuss their opinions of this situation. Cole points out significant differences in how people emphasize cost of quality by comparing two opposing reactions. He quotes a *Wall Street Journal* writer who said, "So, what's the big deal? Customers aren't going to notice such small differences." Cole compared this viewpoint to quality management and to a response from Mr. Takagi of Honda (the head of the quality department at Honda). Mr. Tagaki's response was a most powerful reaction supporting the continual need for quality improvement.

I would answer that there is a world of difference between 1.6 and 1.2. Quality is based on customer satisfaction. In order for a customer of a certain country to feel satisfaction, he or she has to be buying the Number One product in that country. So, a necessary quality standard for a corporation is to have its customer ride in its cars with this kind of pride. This is our basic philosophy. Therefore, if ours was the company with 1.6, I would feel that it was a huge problem. I would immediately notify our top officers so that we could begin an analysis of the causes and aim for recovery. We would have a project on this up and running within a week. This type of thing is done all the time in our company.

Coming in first, being on top, only thinking of being Number One, not Number Two - this kind of racing spirit is what drives us in our business. These figures are extremely critical, and it is impossible for us to think that there is not much of a difference here. If J.D. Power announced these figures, we would start action as soon as they were announced if ours was the 1.6 company.

For us, it is not so much a matter of whether the consumer is aware of the difference between 1.6 and 1.2, but as a company, as long as this fact exists, we feel the need to rectify the situation toward customers who would buy Honda products. It is not a question here of what the customer thinks, but we work with the mind set that we will offer the best product in the world. So, in this context, we do not put very much weight on market research about the customer. If we took action with the thought that our customers probably wouldn't care about this difference, we would never beat the competition. I would think that if we behaved differently, there

would be something wrong with our management philosophy. And our top management thinks exactly the same as I do.

Top notch service helps to differentiate a company by generating new sales and increasing customer loyalty. The Takeuchi and Quelch (1983) study indicated that there is a perception in the United States that quality is declining. This study concluded in absolute terms this is not true, because the actual quality of the output is now higher than ever. Yet, the level of quality from the foreign competition has grown to an even higher level. However, the U.S. consumer perceives that the U.S. quality is on the decline. Perception is often considered to be reality, so when the consumer believes U.S. quality is low, closing the gap includes changing that perception.

Garvin (1986) studied two central issues to the quality improvement phenomenon: 1) the changing mix of problems with quality as quality improves; and 2) the interrelationships with quality and management commitment, work-force commitment, process to produce goods, and performance. Garvin's approach to studying quality was somewhat monumental, because most studies have taken a prescriptive approach that outlines the steps to be followed to correct problems with quality. Garvin went beyond that to analyze the causes of those problems. His results confirmed the previously descriptive approach to quality theory that the management commitment to quality is directly correlated to the level of quality performance.

As W. Edward's Deming states, "Best efforts are essential, but these efforts alone won't accomplish our goal." We need to continually work for the reduction of waste and transfer the man-hours spent in building defective material requiring rework to man-hours spent building good structures, thereby reducing the cost requirement to build a good structure. The management of quality is going to continue to grow as a critical strategic factor. As Peters and Waterman (1982) said in In Search of Excellence, "When

technology is everywhere and worldwide labor is cheap, the only way we are going to win is through Quality."

2.2 WHAT IS QUALITY ALL ABOUT?

Garvin (1988) concludes there is no sure-fire answer to the question: "What is quality?" This is partially because the environment is so dynamic that the requirements for the answer continue to evolve and develop. Garvin classifies the different approaches of quality ranging into five categories from those based on philosophy to those based on operations management. The five categories are: transcendent, product-based, user-based, manufacturing-based, and value-based. These approaches and their definitions are located in the table 2.1 below.

Table 2.1: Five Approaches to Defining the Quality Variable and the Underlying Disciplines (Garvin, 1988).

Approach	Definition Variables	Underlying Discipline
Transcendent	Innate excellence	Philosophy
Product-based	Quantity of desired attributes	Economics
User-based	Satisfaction of consumer preferences	Economics, Marketing and Operations Management
Manufacturing-based	Conformance to requirements	Operations Management
Value-based	Affordable excellence	Operations Management

2.2.1 Quality Expert's Opinions

The task of determining quality appears to be rather nebulous, however the need to continually reach higher and higher levels of quality is becoming ever-more apparent. Quality has been approached from many angles. The following section will discuss quality from the viewpoints of five well-known quality gurus: Feigenbaum, Deming, Juran, Crosby, and Taguchi. The intent of this section is to highlight some of the strengths the quality experts have to offer. The purpose is not to isolate one best method, but, instead to emphasize many of the important variables to be considered when striving for continuous improvement.

2.2.1.1 Feigenbaum

Feigenbaum (1991) believes the key to successful quality efforts is recognition that quality is what the customer, not the company, says it is. It results from strong customer-driven work and teamwork processes throughout all areas of the organization.

Feigenbaum defines product and service quality as:

The total composite product and service characteristics of marketing, engineering, manufacture, and maintenance through which the product and service in use will meet the expectations of the customer (p.7, 1991).

Therefore, the purpose of quality measurement is to determine and evaluate the degree or level which the product or service reaches the total composite to meet the expectations of the customer. Early in the 1950's, Feigenbaum wrote a book predicting how and why quality would be a determining factor in the competitiveness of the global market. This is when he first coined the term *Total Quality Control*. Feigenbaum (1991, p.835) defines Total Quality Control as:

An effective system for integrating the quality-development, quality-maintenance, and quality-improvement efforts of the various groups in an organization so as to enable marketing, engineering, production, and service at the most economical levels which allow for full customer satisfaction.

Feigenbaum gives four basic management fundamentals that are essential to implement total quality control. He concludes it takes relentlessly consistent and disciplined management leadership to direct the organization to continually meet the quality requirements of customers. The four management fundamentals are:

- 1) There is no such thing as a permanent quality level.
- 2) A hallmark of good management is personal leadership in mobilizing the quality knowledge, skill, and positive attitudes of everyone in the organization to realize making quality better helps to make everyone else in the organization better.
- 3) Quality is essential for successful innovation.
- 4) Quality and cost are complementary, not conflicting, business objectives.

The lifestyles of consumers and business effectiveness of companies in today's world depend upon the reliable, consistent performance of products and services with absolutely no tolerance for the lost time and cost of any failures. Therefore, quality is a fundamental strategy for competitiveness in today's market. For this reason, the rate of accelerating quality improvement is probably the most important task facing organizations. To accomplish this objective, organizations must accept and implement ten basic benchmarks of total quality control:

1. Quality is a company-wide process
2. Quality is what the customer says it is.
3. Quality and cost are a sum not a difference.
4. Quality requires both individual and teamwork dedication.
5. Quality is a way of managing.
6. Quality and innovation are mutually dependent.
7. Quality is an ethic.
8. Quality requires continuous improvement.
9. Quality is the most cost effective, least capital-intensive route to productivity.
10. Quality is implemented with a total system connected with customers and suppliers (Feigenbaum, 1991, pp. 828-829).

Total quality results from a long-term implementation oriented towards continuous improvement, based upon a systematic methodology that is progressively improved and relentlessly applied.

2.2.1.2 Deming

W. Edwards Deming is considered by many to be the architect of quality assurance in today's modern manufacturing environment. Deming is often regarded as the person responsible for teaching the Japanese about quality (Forker, 1991). In particular, Deming is noted for using statistical process control throughout the production process. Deming's interpretation of quality can be categorized into three areas: Quality of Design/Redesign; Quality of Conformance; Quality of Performance.

- 1.) Quality of Design/Redesign involves how well a prototype that has been developed from information gathered by consumer research, sales analyses, and service call analyses meets the consumers' needs.
- 2.) Quality of Conformance involves how well a firm and its suppliers meet the specifications of design to serve the consumers' needs.

3.) Quality of Performance involves how well the products or services perform in the marketplace.

Deming places a strong emphasis on using control charts, statistics, and a reduction in the number of suppliers to achieve a preferred level of quality. After these have been accomplished, the cost of quality can be measured by determining quality based on his three categories of quality of design, conformance, and performance (Forker, 1991). Deming (1986) strongly emphasizes the continuous nature of improvement through the use of a cycle developed by Shewart (1986) as shown in Figure 2.2.

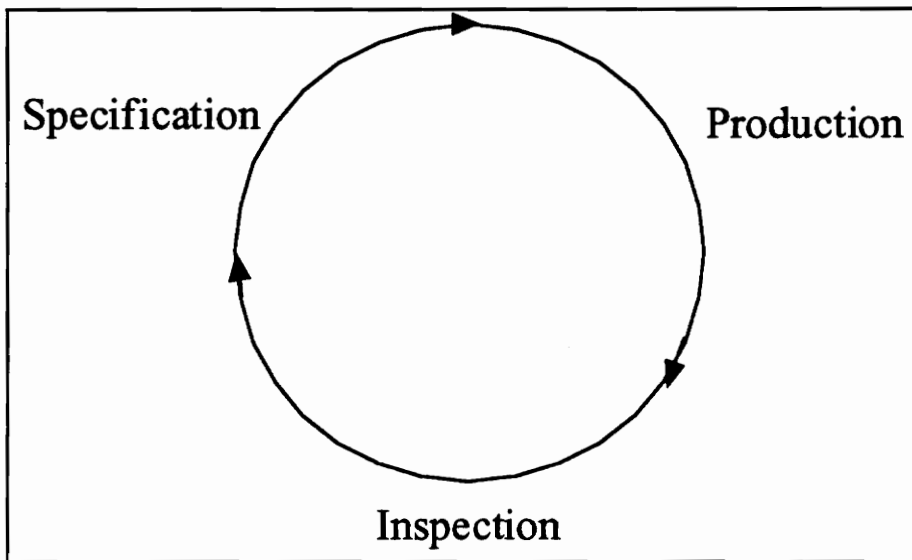


Figure 2.2 Continuous-Improvement Cycle (Shewart, 1986)

Scherkenbach (p.36, 1990) further expands the Shewart cycle by elaborating what each step entails:

- Step 1: Recognize the Opportunity
 - Step 1a: Operationally Define the Opportunity
 - Step 1b: Operationally Define the Theory
- Step 2: Test the Theory
- Step 3: Observe the Results
- Step 4: Act on the Opportunity

The cyclical nature of these steps is represented in Figure 2.3.

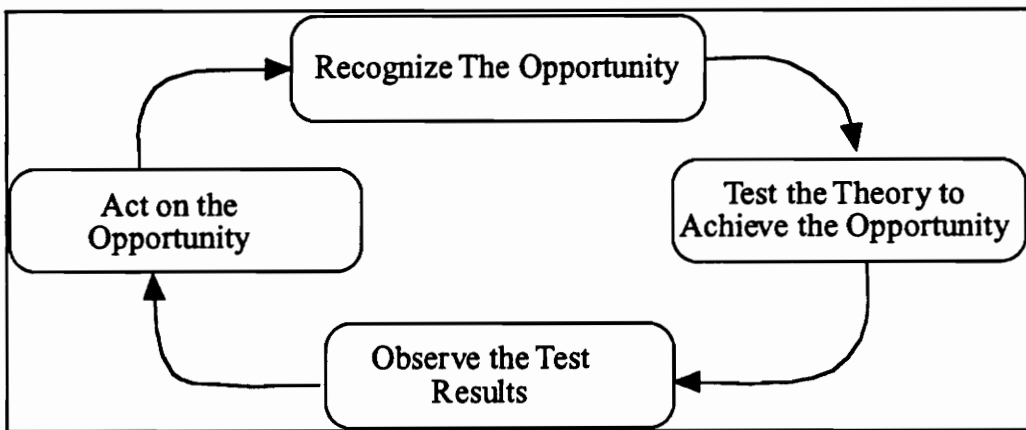


Figure 2.3 Scherkenbach's Continuous-Improvement Cycle (1990)

Deming gives fourteen management principles to guide the direction needed to lead the organization towards achieving the quality goal. The intention of the fourteen points is to form a framework surrounding the quality efforts to ensure the improvement interventions complement instead of conflict one another. Deming's points are listed in Table 2.2.

Table 2.2: Deming's Fourteen Points For Management To Improve Quality

1. Continually improve products and services in order to further the firm's competitive position.
2. Adopt the new philosophy; don't accept delays and mistakes.
3) Don't rely on mass inspection to detect defects; use statistical controls to assure that quality is build into the product.
4) Discontinue the practice of selecting suppliers based on price; reduce the supply base and establish long-term, trusting, single-source partnerships where both buyer and seller can pursue quality improvements.
5) Improve constantly and forever every process for planning, production, and service.
6) Institute training on the job.
7) Adopt and institute leadership
8) Drive out fear.
9) Break down barriers between staff areas.
10) Eliminate slogans, exhortations, and targets for the work force.
11) Eliminate numerical quotas for the workforce.
12) Remove barriers that rob people of pride of workmanship. Eliminate the annual rating or merit system.
13) Institute a vigorous program of education and self-improvement for everyone.
14) Put everybody in the company to work to accomplish the transformation.

This approach to quality requires top management to meet the needs of the customer by balancing employees, suppliers, communities, and investors over the long run (Takeuchi and Quelch, 1983). While striving to live by the guiding principles discussed above, management must also work to cure itself of the seven deadly diseases and remove obstacles to quality improvement. The removal of these problems will not

occur over-night. It requires a well-disciplined approach that takes time and patience. The seven deadly diseases and the quality obstacles are listed in Table 2.3.

Table 2.3 Deming's Seven Deadly Diseases and Quality Obstacles

Seven Deadly Diseases	
1.	Lack of constancy of purpose.
2.	Emphasis on short-term profits.
3.	Evaluation of performance, merit rating, or annual review.
4.	Mobility of management; job hopping.
5.	Management by visible figures alone, with little or no consideration of figures that are unknown or unknowable.
6.	Excessive medical costs.
7.	Excessive costs of liability, swelled by lawyers that work on contingency fees.
Obstacles to Quality	
1.	Hope for instant pudding.
2.	The supposition that solving problems, automation, gadgets, and new machinery will transform industry.
3.	Search for examples.
4.	Our problems are different.
5.	Obsolescence in schools.
6.	Poor teaching of statistical methods in industry.
7.	Use of Military Standard 105D and other tables for acceptance
8.	Our quality control department takes care of all our problems of quality
9.	Our troubles lie entirely in the work force

10.	False starts.
11.	We installed quality control.
12.	The unmanned computer.
13.	The supposition that it is only necessary to meet specifications.
14.	The fallacy of zero defects.
15.	Inadequate testing of prototypes.
16.	Anyone that comes to try to help us must understand all about our business.

2.2.1.3 Juran

Juran defines quality from a user-based perspective as "fitness for use." Juran's definition of fitness for use includes four areas of categorization: Quality of Design, Quality of Conformance, Availability, and Field Service (Forker, 1991).

- 1) Quality of Design involves the quality of market research, concept and specifications of the consumer requirements.
- 2) Quality of Conformance involves a product that meets the design specifications and is determined by technology, manpower, and management.
- 3) Availability involves the reliability of the product working, maintainability, and logistical supports.
- 4) Field Services involves the warranty and repair/replacement services of the product after sale to the consumer.

There are two dimensions to his definition of quality: satisfying the consumer needs and wants with the appropriate product features and free from defects. Every unit of the organization is involved in value-adding processes and produces products or services to its customers. Juran calls each of these users a *processor team*, and each

processor team carries out three quality-related roles shown in Figure 2.4. This diagram shows the interrelationships among the following three roles:

- **Customer:** The processor team acquires various kinds of inputs which are used in carrying out the process. The processor team is a customer of the suppliers who provide the inputs.
- **Processor:** The processor team carries out various managerial and technological activities in order to produce its products.
- **Supplier:** The processor team supplies its products to its customers (Juran, 1991, pp. 23-24).

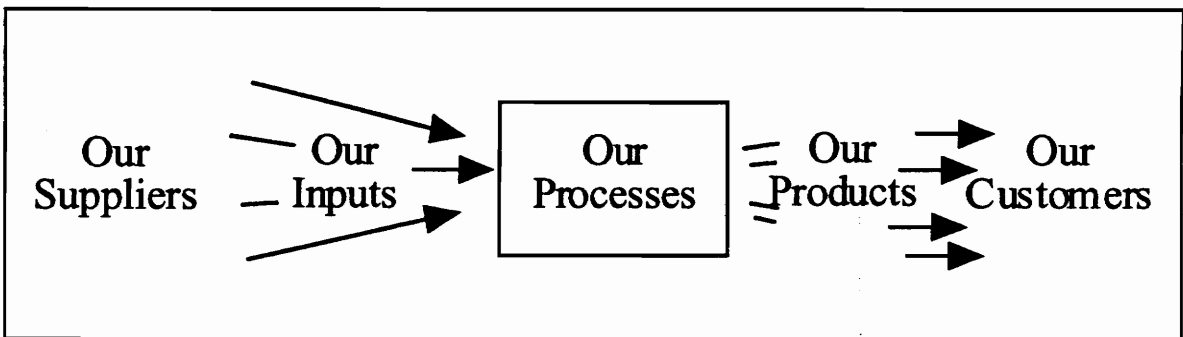


Figure 2.4: Quality Roles for the Processor Team, (Juran, 1991)

Juran is perhaps best known for his quality trilogy for organization quality based on the managerial process for *quality planning, control, and improvement* (Forker, 1991).

Quality Planning involves:

- 1) Identify the customers, both external and internal.
- 2) Determine customer needs.
- 3) Develop product features that respond to customer needs (Products included both goods and services).
- 4) Establish quality goals that meet the needs of customers and suppliers alike, and do so at a minimum combined cost.
- 5) Develop a process that can produce the needed product features.
- 6) Prove process capability-prove that the process can meet the quality goals under operating conditions.

Juran considers strong quality planning to form the road map to successful continuous improvement efforts.

Quality Control involves:

- 1) Choose control subjects-what to control.
- 2) Choose units of measurement.
- 3) Establish measurement.
- 4) Establish standards of performance.
- 5) Interpret the difference (actual versus standard).
- 6) Take action on the difference.

Quality Improvement involves:

- 1) Prove the need for improvement.
- 2) Identify specific projects for improvement.
- 3) Organize to guide the projects.
- 4) Organize for diagnosis-for discovery of causes.
- 5) Provide remedies.
- 6) Prove that the remedies are effective under operating conditions.
- 7) Provide for control to hold the gains

The trilogy is not merely a way to explain quality, because it also acts as a unifying concept extending throughout the company. The three processes of the Trilogy are interrelated in their effectiveness. Figure 2.5 is a graph displaying time on the abscissa and cost of poor quality (quality deficiencies) on the ordinate. This shows that, over time, the chronic waste was driven down to a level far lower than originally planned. The chronic waste was an opportunity for improvement.

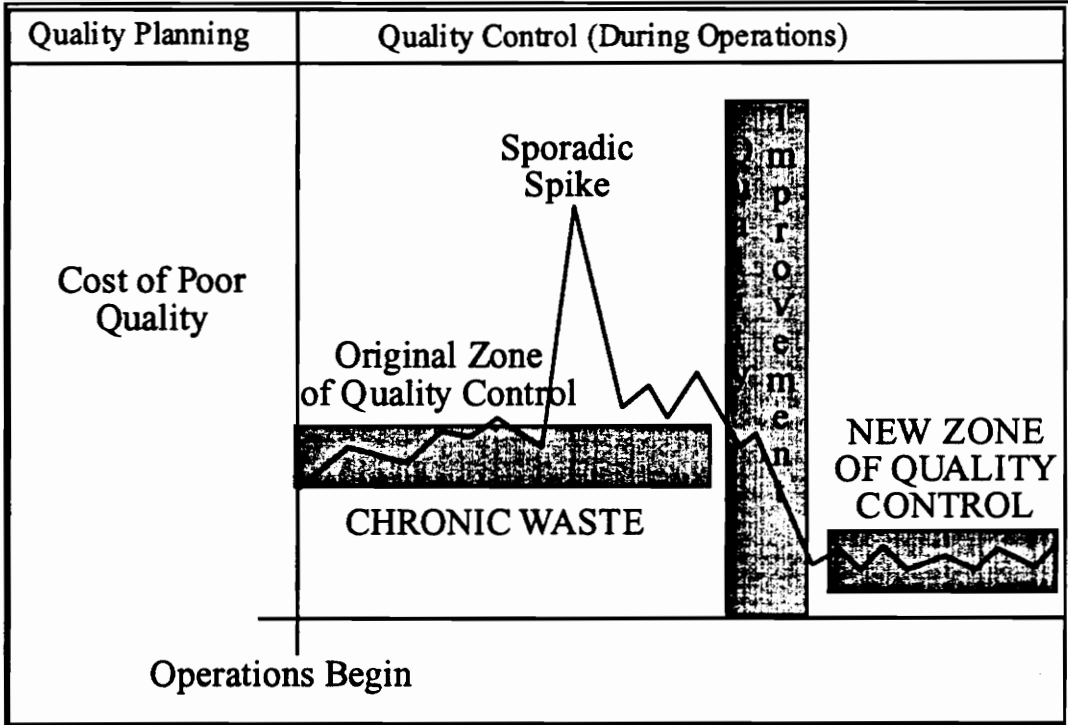


Figure 2.5: The Juran Quality Trilogy (1991)

Chronic waste is best described by the plight of the fabled manager up to his waist in alligators. Each alligator is a chronic waste and has potential for quality improvement. As the quality improvement project is completed, the result is a dead alligator. Once the management exterminates all the alligators, the quality improvement would be complete - but just for the moment. The reason is the quality planning process still must be in operation generating new alligators to be exterminated.

2.2.1.4 Crosby

Crosby used an engineering or operations management viewpoint with his definition of quality as being, "conformance to requirements." Quality should conform to engineering tolerances for every product and strive for zero defects. Top management must be committed to quality and lead systematic implementation of quality throughout the firm with the following responsibilities:

- 1) Stating its standards regarding quality. Employees must know what requirements they are expected to meet.
- 2) Supplying the education and tools that employees need to meet the requirements set by management. The role of the quality department also must be clarified.
- 3) Encouraging, assisting, and training employees to meet the state quality requirements (Forker, p.67).

Crosby (1989) highlights fourteen steps that leading to the achievement of conformance to requirements. These steps are listed in Table 2.4.

Table 2.4: Crosby's Fourteen Steps (1989).

1. Management Commitment
2. Quality Improvement Team
3. Quality Measurement
4. Cost of Quality Evaluations
5. Quality Awareness
6. Corrective Action
7. Establish an Ad Hoc committee for the Zero Defects Program
8. Supervisor Training
9. Zero Defects Day
10. Goal Setting
11. Error Cause Removal
12. Recognition
13. Quality Councils
14. Do It Over Again

Crosby stresses prevention as the key to establishing long-term quality. It should be noted that some of Crosby's terms, such as "zero defects," approach quality from a different angle than other experts such as Deming.⁷

⁷ Deming's dissonance with the term "zero defects" is based on his belief it is an exhortation. He believes these slogans could actually damage morale, because they force the exhortation on the line-worker who must deal with problems of the system beyond his control. For example, poor planning on the part of management may cause problems that are beyond the worker's control. The term "zero defects" during assembly is impossible for the worker to accomplish due to system flaws. As an eventual goal, "zero defects" is understandably admirable, but it should be remembered it can only happen when all special causes of variation are removed.

2.2.1.5 Taguchi

Genichi Taguchi's interpretation of a high quality product or service is one that operates as it was intended for use without variability and without causing the consumer any harm. Taguchi measures quality as a loss to society by using as an evaluation of "the loss a product's poor quality causes society after being shipped, other than any losses caused by its intrinsic function." The loss is caused either by variability in the product's function or by side effects that have an adverse effect. An example of the loss done to society could be when a product fails (such as a roof collapsing), society pays a much higher price for the failed product than the manufacturer did in producing a poor product.

Taguchi's approach goes beyond the traditional interpretation of quality that is measured as the percent of items that fail to conform to the predetermined product interval. According to Taguchi, those specifications imply that the consumer has no preferences among the value of performance within the specification limits, but becomes completely unhappy when the performance measurement falls outside the tolerance interval (Roslund, 1989).

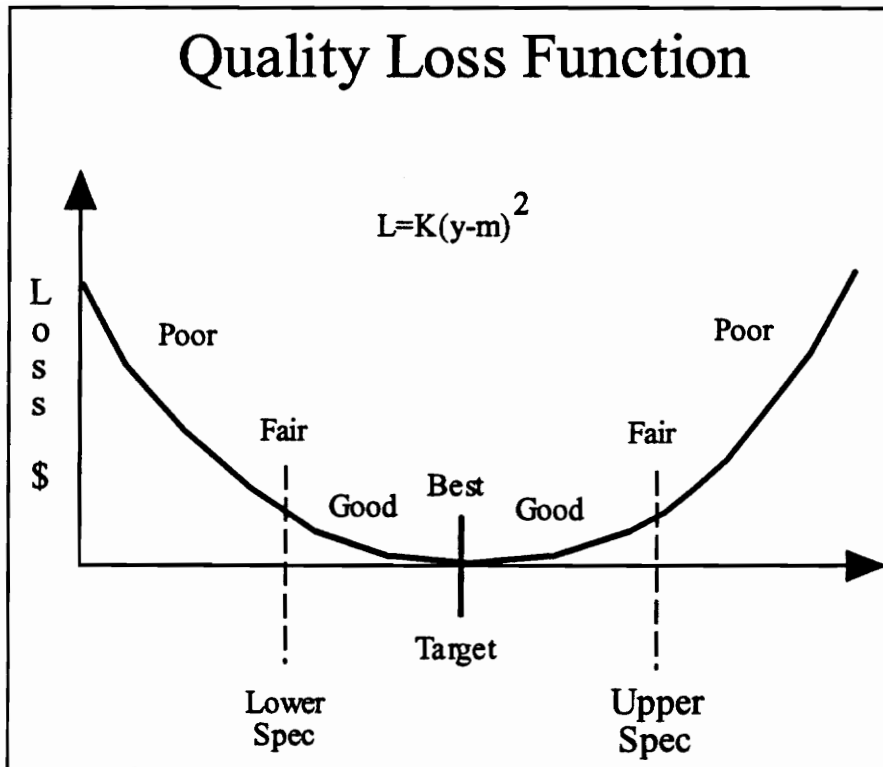


Figure 2.6: Taguchi's Loss Function (Roslund, 1989)

Taguchi's method determines the quality by calculating the performance variation of individual characteristics from the targeted values during the product life cycle at varying conditions. Taguchi concludes that quality is best when on target, and quality decreases as products deviate. Customer's unhappiness grows with deviation of the products, and this can be expressed as a loss of dollars. Taguchi evaluates this dissatisfaction with his quality loss function as shown in Figure 2.6. The variables influencing performance are divided into controllable and uncontrollable. Controllable variables can be manipulated easily such as the product's manufacturing process design. The uncontrollable variables are considered noise factors that are either impossible or very difficult to regulate. Noise factors are separated into three categories:

1. Outer noise: Variables external to the product's design, components, and manufacturer process.

2. Inner noise: Variables brought about by decay of product's parts and material.
3. Between noise: Variable that are too difficult to pin-point, but that show up among the product units.

Taguchi strongly emphasizes the importance of a solid design quality. He states that the quality of design is contingent on the success of three components of design: systems design, parameter design, and tolerance design. During systems design, the engineers determine the most appropriate technology for use in the value-adding processes. After selecting the materials, components, and production equipment, parameter design is used to make product or process increasingly insensitive to environmental conditions. The intent of parameter design is to concentrate on optimizing a performance characteristic by manipulating certain product parameter values and process factor levels. An example of manipulating parameter variables would be to study how the product performs at 30 degrees Fahrenheit and at 90 degrees Fahrenheit. Tolerance design that is aimed at controlling error factors and keeping them in limits. Setting the appropriate process tolerances helps to establish optimal performance (Forker, 1991).

All three of the design components need to be emphasized to continually ensure high levels of performance in the product or services. In Forker's comparison of different approaches to design quality, she found significant differences in the amount of time spent in the three design components. In particular, the Japanese appeared be strongly emphasizing the importance of parameter design. Emphasis in this area recognizes that the external environment continually influences the variability of product performance. The relative differences in time spent on elements of design optimization are shown in Table 2.5.

Table 2.5: Percentage of Time Spent on Each of the Three Elements of Design Optimization in the U.S. and in Japan (Forker, 1991).

Design Element	U.S.A	Japan
Systems Design	80%	40%
Parameter Design	2%	40%
Tolerance Design	18%	20%

The emphasis on parameter design helps the product obtain a much tighter variability around the target value as shown in Figure 2.7.

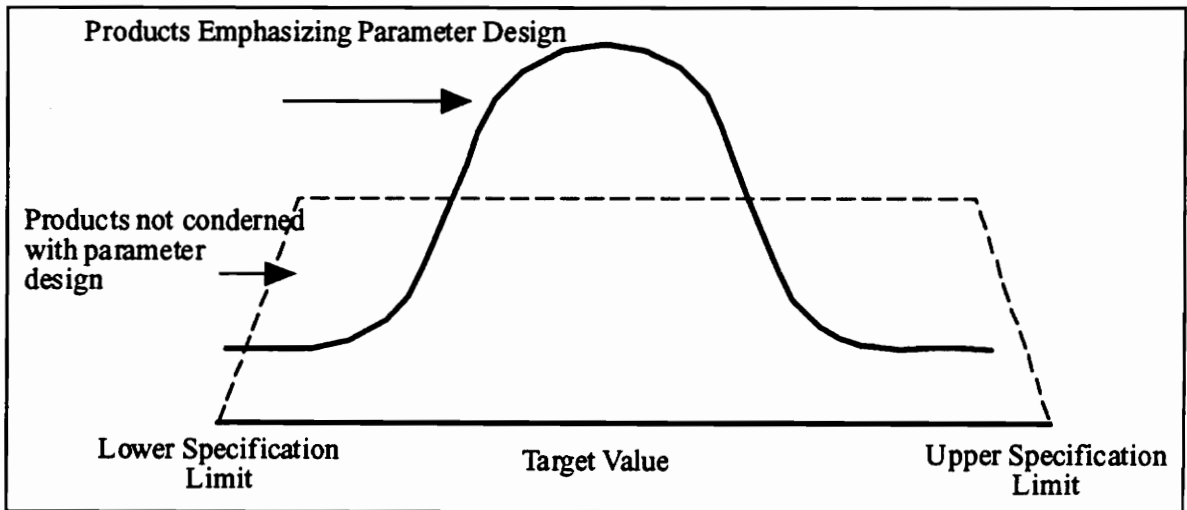


Figure 2.7: The Distribution of Acceptable Product Quality (Forker, 1991).

The summary of the various approaches to quality is located in Table 2.6.

Table 2.6: Summary of Various Approaches to Quality (Forker, 1991)

Expert	Approach	Major Focus of quality Definition
Deming	User-based	How well a good or service meets consumers' needs
Juran	User-based	Fitness for use
Crosby	Manufacturing-based	Conformance to requirements
Taguchi	Value-based	Operation of product in intended manner without variability
Feigenbaum	User-based	Full-filling the customers' needs and expectations

There is no clear cut approach or entirely-accurate definition for quality. It is very similar to the term being physically fit. You have to continually work toward a never-ending goal, but each person requires a slightly varied approach depending on his or her individuality. As with many nebulous problems, the solutions evolve from studying patterns of the big picture. Refusal to acknowledge a holistic or systems approach to any improvement venture probably will evolve into developing more problems than solutions (Hill, 1977).

2.2.2 Systems Approach to Quality

One common theme among all of the experts is the significant role the customer plays in determining quality. Each expert may have his or her own interpretation of how to best serve that customer, but they all recognize the importance of the customer in

quality management. Quality must be designed into the product or service by determining the customers' needs and wants for product (or service) utility. Market analysis must be used within the design-phase by planning and brainstorming customers' desires. These desires should be translated into requirements. Simultaneously, continued benchmarking of best practices should be maintained to ensure the quality of processes. Meeting the customers needs by using the best possible process to develop new and innovative products is a continual cycle (Plsek, 1987).

The overall view of this value-adding approach can be seen in Deming's production system as shown in Figure 2.8. The customer is the ultimate judge of quality and his or her influence needs to be carried throughout this production process.

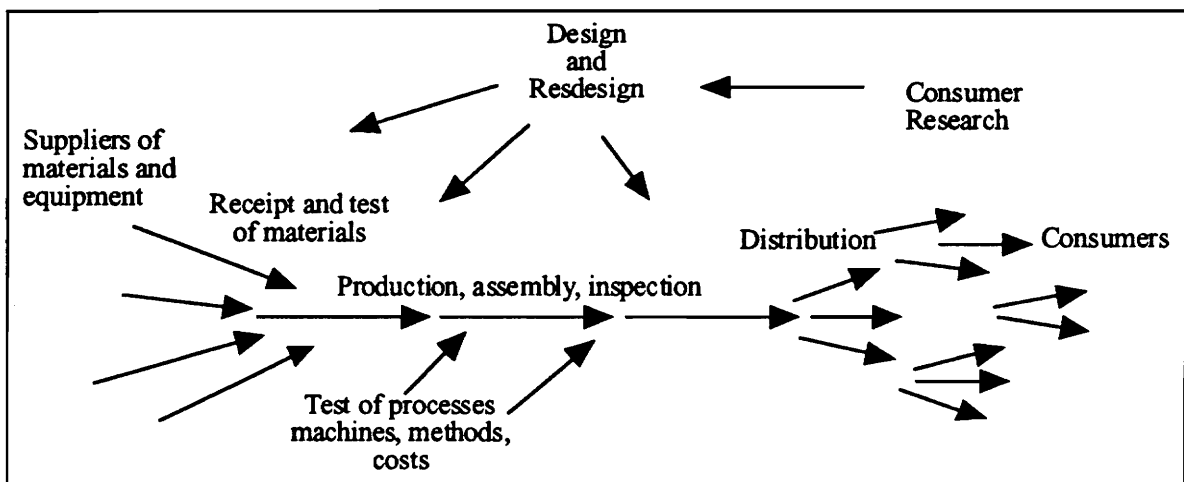


Figure 2.8: Deming Production System (1986)

Garvin (1986) researched the varying levels of success contingent upon where the organizations place their emphasis on quality. He found that successful quality companies emphasized quality as their primary objective. The successful quality companies developed policies that were communicated to strongly focus on quality, and the workers in these companies displayed a strong commitment to the quality goal. Garvin's study found quality to be the most important area of emphasis. His studies found that managers

in strong quality organizations were more likely to view their operations as open systems. The open systems approach considers the impact on performance involving external factors such as vendor selection, statistical control of incoming parts and materials, along with reliability of the design of products to varying external conditions.

The strong quality companies had significantly stronger and more rigorous training programs emphasizing total quality control of the entire production system. His findings confirmed his hypothesis that high levels of quality are directly correlated to the organizational commitment to the quality goal. He also concluded that just mimicking practices without internalizing the overall quality approach was often unsuccessful.

2.2.2.1 Five Quality Checkpoints

When attempting to comprehend the systems approach to managing quality, Sink (1989) discussed the importance of considering each stage of production as a quality input. Juran emphasizes that every unit is a value-adding process that converts inputs to outputs. The inputs come from an upstream supplier and the outputs go to a downstream customer. Sink's interpretation of total quality management is the systematic planning, organizing, measuring, controlling, and continual improvement of five quality checkpoints for this value-added process as shown in Figure 2.9 (1989).

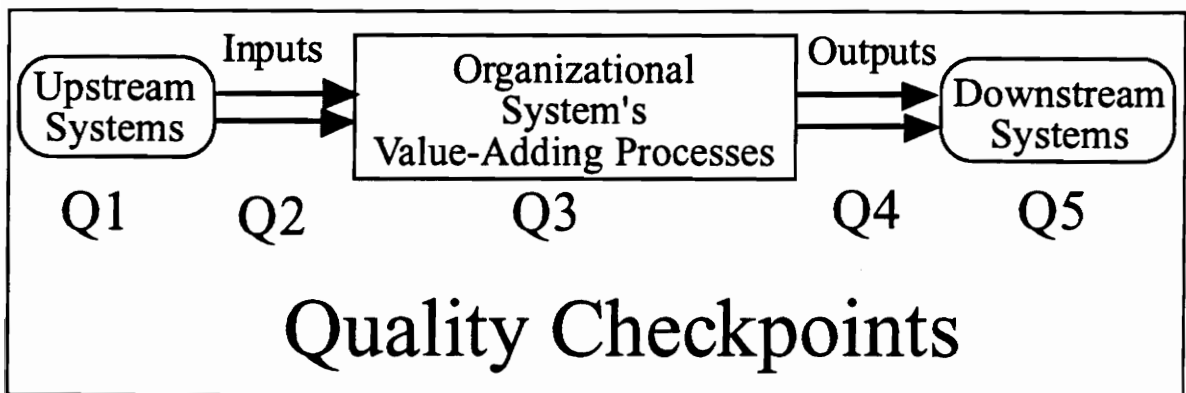


Figure 2.9: The Five Quality Checkpoints (Sink, 1989)

Quality Checkpoint 1: The selection and management of upstream systems

Quality Checkpoint 2: Focuses on confirming the system is receiving the inputs from the upstream systems that it needs, wants, and expects.

Quality Checkpoint 3: Focuses on building quality into the product or services.

Quality Checkpoint 4: Determining the assurance that what the organization is producing meets the specification, requirements, and established expectations.

Quality Checkpoint 5: Understanding the downstream systems by determining what your customers want, need, expect, and demand. (Sink, 1989).

2.2.2.2 Achieving Company-Wide Quality Control

To achieve stellar performance in the quality of management, the quality of human behavior, the quality of work being done, the quality of work environment, the quality of product, and the quality of service is no easy task. Management will have to work diligently studying the process and removing barriers to improve the long-term quality of products and services. Sullivan (1986) describes seven stages for company-wide quality control:

- 1) Inspection after production
- 2) Quality control during production
- 3) Quality assurance involving all departments (systems oriented)
- 4) Education and training (humanistic aspect of quality)
- 5) Product and process design optimization for more robust function (society oriented)
- 6) The Taguchi loss function (cost oriented)
- 7) Quality function deployment to define the "voice of the customer" in operational terms (consumer oriented).

Figure 2.10 shows the progression of the stages of company-wide quality control.

According to Sullivan, what many people consider to be total quality control is just a

subset of the large transformation to company-wide quality control that is necessary to achieve stellar performance for the customer. He believes organizations need to consider ever-present subliminal references such as the quality of society, the quality of industries, the quality of the national economy, and eventually the quality of world trade. The ultimate progression for quality management is to improve the world in which we live.

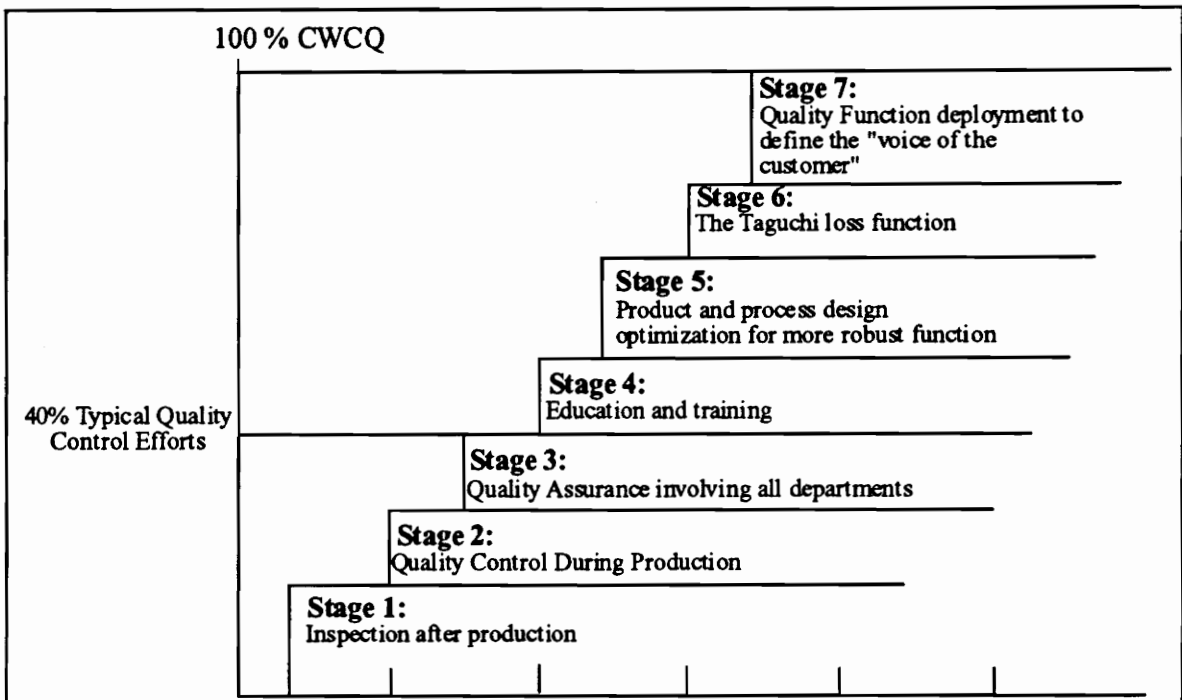


Figure 2.10: The Build Up of Seven Stages to Company-Wide Quality Control (Sullivan, 1986)

Part of the dilemma, when trying to achieve the highest level of quality and sophistication in meeting the customers requirements, is the labyrinth of complexity in which all the variables must work together to achieve a certain level of performance. It is often confusing and very complex to understand all of the working relationships that need to be understood to actually achieve this level of commitment necessary to be successful in today's global economy. Successful interventions must understand how the management systems work together in forming the complex structure of the environment.

2.2.2.3 The Management Systems Approach

To truly optimize the performance of the overall system, quality is dependent upon how well the management systems are aligned to meet the goals of the systems (Senge, 1990). Figure 2.11 displays a simple relationship of two forces. When the forces are aligned in the same direction to accomplish a common purpose, they work together. However, when the arrows oppose each other, they accomplish nothing but working against one another. The nature of directing the management systems for performance improvement follows the same pattern as the mechanical forces. To accomplish the quality objective, all of the management systems must be going in the same direction to optimize the overall system.

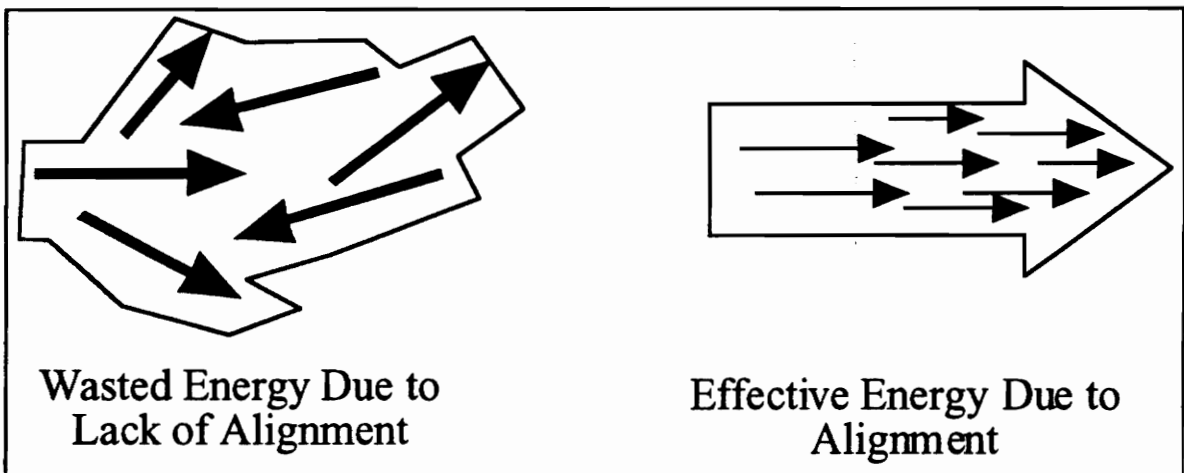


Figure 2.11: Organizational Forces Need to be Aligned toward the Same Direction (Senge, 1991).

Marcieariello et al. (1989) list five management systems that need to work together towards the transformation: style and culture, infrastructure, rewards, communication systems, and formal control processes. An explanation of each management system is described in Table 2.7.

Table 2.7: Management System Descriptions (Marcicariello et al, 1989)

<p>Corporate Culture: The composite of shared values, common perceptions, common decisions premises that people of the organization use in activities or to solve problems of the organization. If a system requires behaviors that are counter to the culture of the organization and the style of management, the system will likely prove unsuccessful.</p>
<p>Infrastructure: Management designs the formal organization so various units in the organization are linked together so they can communicate and coordinate with each other. A critical aspect of infrastructure is the amount of autonomy people have in their positions. Autonomy refers to the amount of freedom that he or she has in making a decision and the constraints placed on the decision by the organization.</p>
<p>Rewards: Management must be able to elicit employees to participate if the formal organization is going to exist. The reward system should emphasize both individual and group performance. The system should also emphasize long-term (strategic) objectives along with short-term (operational) objectives. Market rates should determine the reward structure.</p>
<p>Communication Systems: Management needs vehicles of communication within the organization. These are necessary for building an identity with the organization and its goals, for coordination and conflict resolution, and for resource allocation in decision making.</p>
<p>Control Process: Two distinct but interrelated control processes. one for long-term and one for short term are put into place to assist the decision-making processes of the organization.</p>

Figure 2.12 displays the interrelationships between the management systems. Each system influences and is influenced by the other systems. The arrows on the model demonstrate that if you change one element of a management system, simultaneously you will change how that system interacts with the other management systems. The systems displayed in this figure represent a summary of flaws that are typical in many U.S. Firms (Marcicariello et. al., 1989).

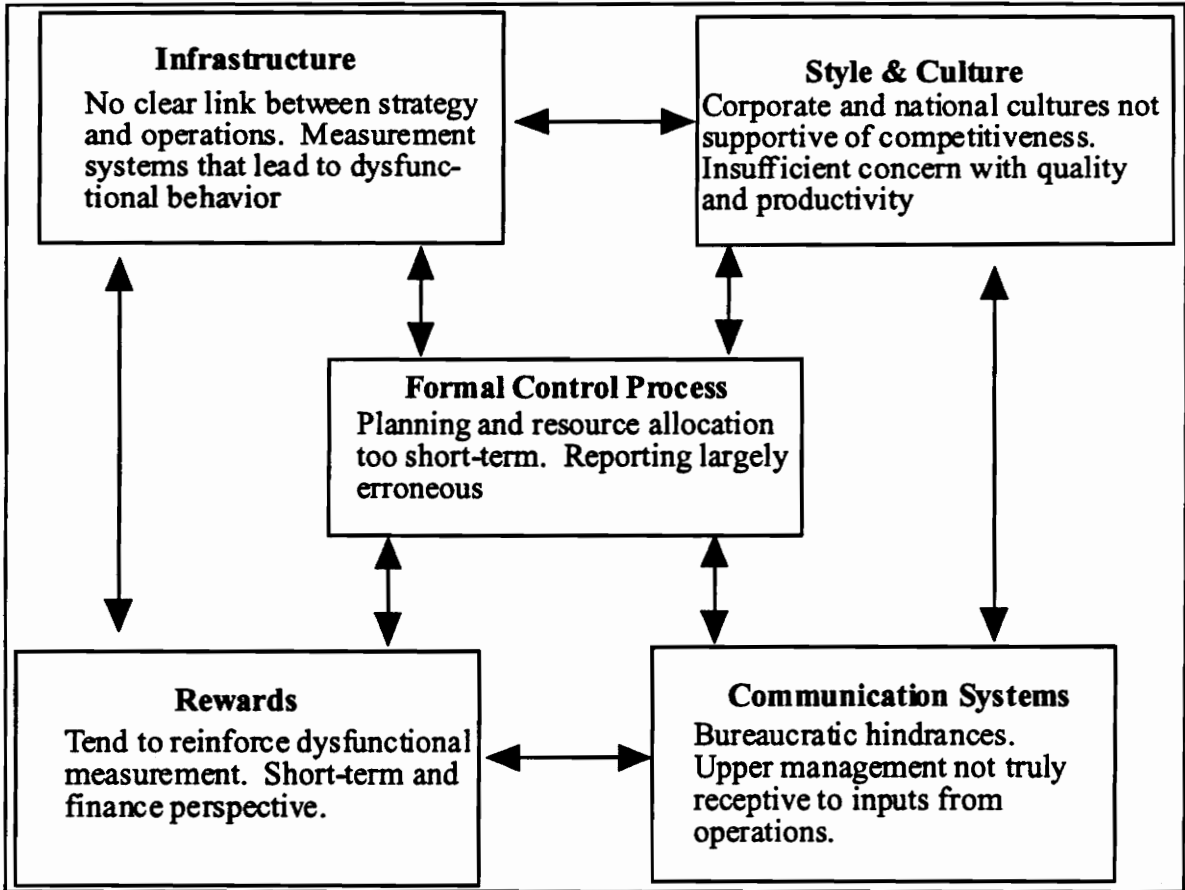


Figure 2.12 Summary of Flaws in Management Systems in U.S.
(Marcicariello et al., 1989).

Unfortunately, the directions of the management systems have been poorly aligned for quite awhile. The state of the American economy is a good example of what can happen to poorly aligned management systems. Norman Jones puts downfall of infrastructure this way:

By the 1950s, manufacturing had ceased to be a factor in strategic planning. Factories had been handed over to caretaker managers in dead-end jobs. Their assignment was simple: don't do anything risky, just keep the production lines moving. More and more factory jobs were reduced to boring, repetitive chores that anyone could do, and the pool of skilled machinists withered. The upshot: By the time Japan emerged as a serious challenger in the late 1960s, the U.S. was saddled with an alienated work

force and moribund factory managers. They didn't have a prayer against Japan's dedicated workers and energetic engineers.

Performance measurement that has been the subjugation of management accounting practices and financial reporting practices inherently gives rise to short-term myopic thinking. Thomas Johnson and Robert Kaplan say it this way:

During difficult times, when margins were being squeezed, and innovative products were not forthcoming from the company's laboratories, executives found it easier to generate earning through creative financial transactions than through innovative products and efficient production processes...But perhaps the most damaging dysfunctional behavior induced by a preoccupation with short-term profit center performance as the incentive for senior managers to reduce expenditure on discretionary and intangible investments. The immediate effect of such reductions is to boost reported profitability but at the expense of sacrificing the company's long-term competitive position.

Marcieariello et al., give an example of how properly aligned management systems should appear to complement each other and optimize the overall system. Figure 2.13 shows this interrelationship.

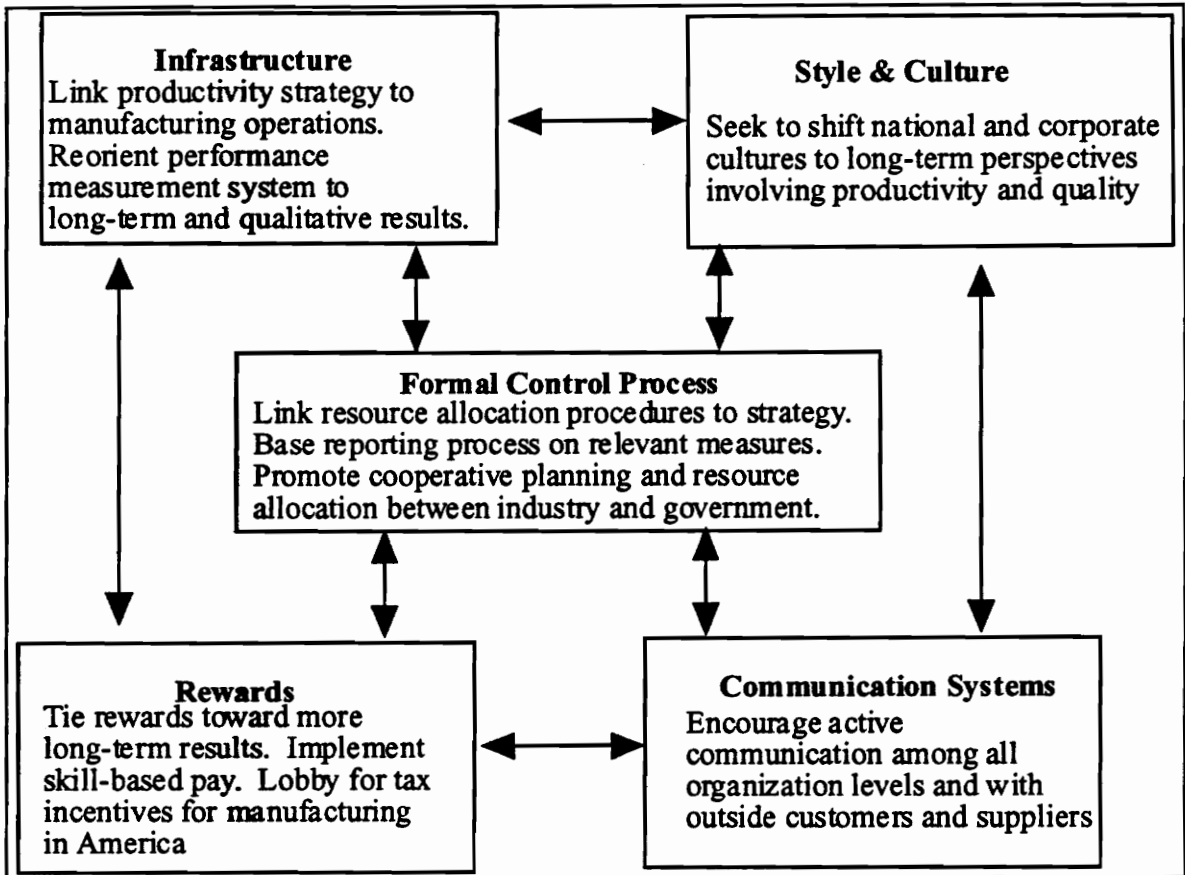


Figure 2.13 Summary of Recommendations to Management Systems (Marcicariello et al, 1989)

2.3 MEASUREMENT AND ITS USE IN REDUCING REWORK

How does a company systematically acquire knowledge about how or what to improve? This question is not new; quite frankly, it has been a perplexity for the industrial world for most of this century. In 1915, Frederick Taylor profoundly concluded the success of management will be based on their ability to become more scientific, because in science, knowledge is gained by systematic observation, experiment, and reasoning. He concluded it is necessary to begin substituting scientific investigation and knowledge instead of individual judgment or opinion.

The key to continued success in quality management is the ability to collect information that will improve the performance of a product or service and incorporate this knowledge into the design of a new product. Peter Senge concludes that an organization's ability to learn collectively will largely impact its long-term success. Properly designed measurement systems help provide the feedback systems necessary to transfer learning from one project to another or one product to another.

2.3.1 Why Is It Necessary to Measure Quality?

Mary Follett (1927) emphasizes that Taylor's scientific method of management consists of two parts 1) research and 2) the organization of knowledge obtained by research. Measuring quality in construction adds value by systematically collecting data and converting that data to information regarding the level of quality. When the measurement system accurately aggregates the information, managers are able to reduce uncertainty about the cause and effect relationships within their domains (Thompson, 1967).

When managers make decisions about their domains, they are hoping for positive outcomes based on their interpretation of the cause and effect relationships. Chester Barnard (1938) concludes knowledge of the past cannot change the past, only the future. He claims the purpose of the organization bridges the gap between the past and the future by focusing on what can be done in the present. Measuring quality helps to formulate knowledge about what can be done in the present to help increase the probability of positive consequences for the organization in terms of the quality of its product. However, the right knowledge about the cause and effect relationships only takes place when the correct measures are taken. The next section will discuss balancing measurement with the strategy and actions of the organization.

2.3.2 Striking The Balance In Measurement

Dixon et al. (1990) stress the need for balancing strategy, actions, and measures. The primary decision in managing the construction company lies in its choice of strategy. The strategy chosen works to determine the strategic and tactical objectives leading to actions the construction company takes toward improvement. The strategy chosen also impacts the necessary measurements used to reduce uncertainty. The triangle shown in Figure 2.14 represents the interrelationships between these three components.

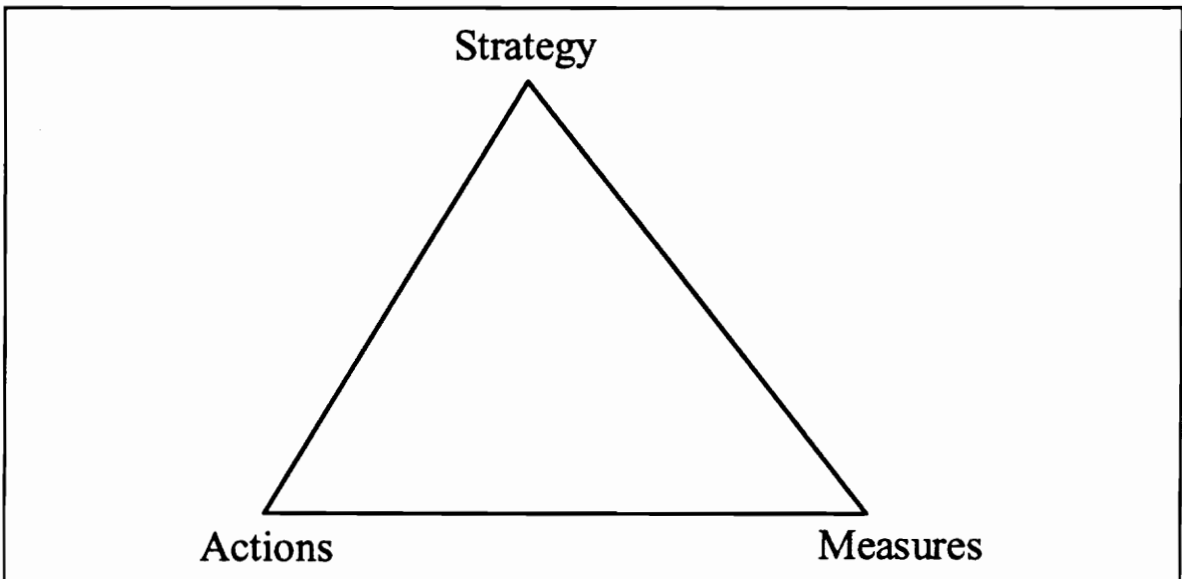


Figure 2.14. The Strategy is Balanced by Actions and Measures (Dixon et al., 1990).

For example, when a construction company develops the strategy to improve quality, it must take action to develop a working definition of quality. It is also necessary to train employees to use quality assurance techniques to take proper measurements. The performance improvement plan depicts the strategic goals for the organization, and these lead to actions that need to be measured to determine the impact on the organization. Each construction company needs to develop its own unique balance of these three

components. There are certain characteristics of the construction industry that must be considered to accurately measure quality, as described in the next section.

The organization's performance plan needs to focus on continuous improvement if the organization intends to survive. Edmonds et al. (1989) describes a set of emerging "principles" for organizations: an organization should strive to achieve operating excellence, eliminate waste, do it right the first time, shorten cycle responses, improve control over production processes, discipline, and adhere to commitments. Edmonds et al.'s requirements for excellence require more than just achieving a certain rate of return. They require a comprehensively, integrated measurement system to ensure the continuous improvement of all processes in the organization.

2.3.3 Characteristics of the Construction Industry

To better understand cause and effect relationships between quality management and rework, it is necessary to understand some of the characteristics specific to the construction industry (adapted from Thompson, 1967). This section will address some of the unique characteristics of the construction industry.

2.3.3.1 Parties in Construction

As we think about measuring quality in construction, it is useful to look at the parties involved and the roles they play. In essence, construction is comprised of four major parties who all can influence quality (Oglesby et al., 1989). These are:

1. Owners: Conceive the projects and operate the completed facility.
2. Designers (usually engineers or architects): Translate the owner's ideas into detailed directions through drawings and specifications.

3. **Constructors (contractors and subcontractors):** Manage the efforts of converting the designers' directions into completed facilities.
4. **The labor force (particularly foreman and craftsmen):** Use their skills and efforts to transform the directions in the plans and specifications into a physical structure.

When designing, developing, and implementing quality measures for construction, it is important to understand the system in which the construction industry exists.

2.3.3.2 Considering the System of Construction

Construction differs from the repetitive processes of manufacturing in many ways (Oglesby et al., 1989), and therefore the techniques of planning and the methods of implementation of quality measurement must recognize the unique characteristics of this industry.

Oglesby et al. (1989, pp. 26-27) have identified a few of the characteristics common to the construction industry:

1. Most projects are of relatively short duration.
2. On-site work stations are not permanent.
3. The final product is usually of unique design and differs from work station to work station so that no fixed arrangement of equipment or aids such as jigs and fixtures is possible.
4. Because construction is a preliminary step leading to a completed facility, the layout and arrangements may make access for construction difficult and permanent provisions for safety impossible.
5. Because construction often needs highly skilled craftsmen rather than unskilled workers, individual crews, whether union or nonunion, usually do specialized operations.
6. Operations are commonly conducted out of doors and are subject to all the interruptions and variation in conditions and other difficulties that rain, snow, heat, and cold can introduce.

7. Construction often involves large-scale, cumbersome, and heavy assemblies of vessels or other components that are difficult to handle and fasten in place.
8. The owner is deeply involved in the construction process while the purchaser of manufactured goods is not.

Since the projects tend to be unique in design, looking at the project as the unit of analysis is useful when considering quality improvement interventions. Matthews and Burati (1989) applied Juran's Triple Role Concept to construction as shown in Figure 2.15.

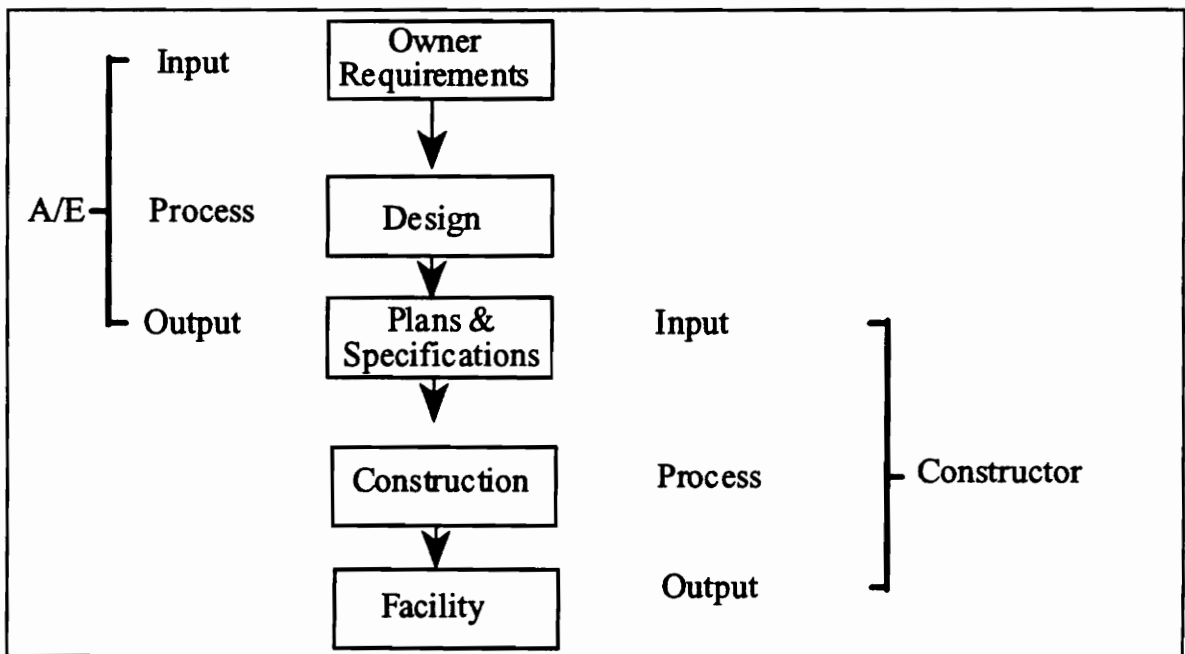


Figure 2.15: Juran's Triple Role Concept Applied to Construction (Matthew's and Burati, 1989)

2.3.4 Quality Management In Construction

Quality Management in construction must consider all of the stakeholders in the project as shown in Figure 2.16 (i.e., the project team, subcontractors, suppliers, customers, etc.). When managing quality of a construction project, it is essential to consider all of the project stakeholders. The span of the project domain is quite large, when considering all of the project stakeholders. All of the project stakeholders are affected by how well quality is managed on the construction project (Cleland, 1986).

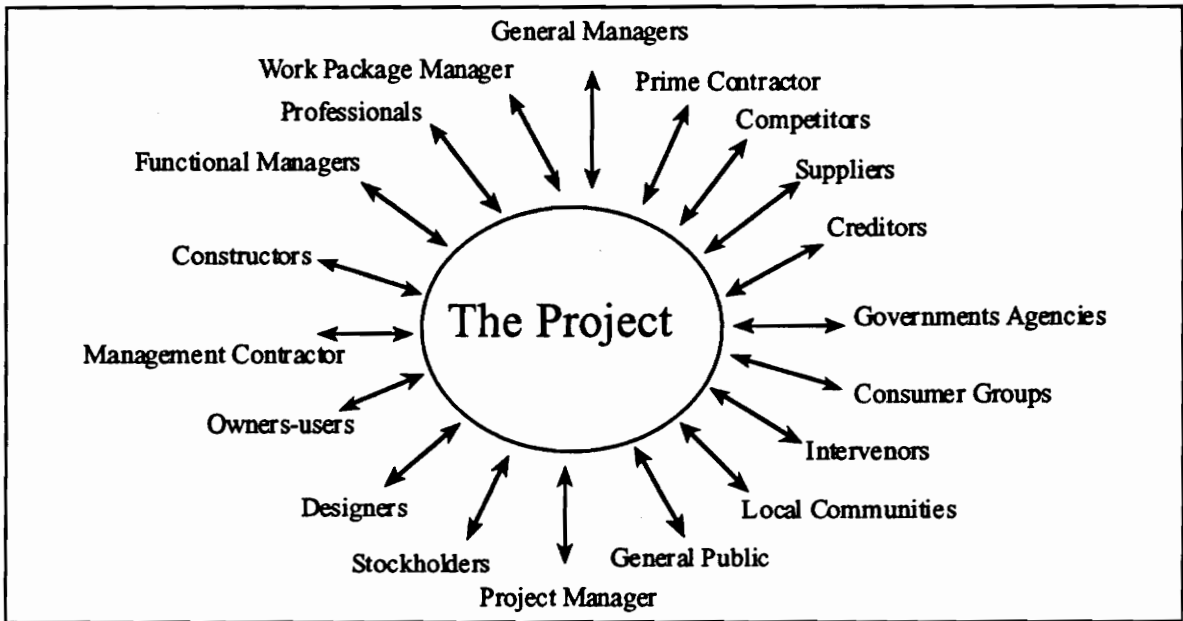


Figure 2.16: Construction Project Stakeholders' Network (Cleland, 1986)

There are a number of reasons why the quality of a project is not easily or automatically achieved as the project is being built. First, the requirements of the project aren't always adequately described. Designers say it is very difficult to anticipate and detail everything in the construction requirements. Second, the construction environment is very dynamic. The size, complexity, and location of projects vary from one to another. The working conditions change from one project to another, and the labor force changes in size and composition. Third, construction projects are often heavily driven by cost or time, and management doesn't place enough emphasis on quality (CII Source Document 30). With the inherent variability of the construction industry, it is a considerable challenge for organizations to perform consistently with high levels of quality. Unfortunately, when poor quality occurs, there can be devastating consequences.

Poor quality management in concrete construction leaves behind a horrible memory. Fifty-one people were killed when a concrete cooling tower collapsed at the Willow Island West Virginia Power Plant. The forms were supported by concrete that hadn't reached an adequate strength to support the load. Unfortunately, this type of

failure demonstrates the extreme consequence of what can occur when quality is poor in construction (Ledbetter and Ledbetter, 1985).

For example, in concrete construction, common everyday mistakes result in excessive cracking, shifting, flaking, or weak concrete. The construction industry can no longer afford to correct these problems after they occur. Rather than waiting to correct the problem, quality management must be implemented at the beginning of a project to help prevent them from ever occurring. The quality management program should be defined as all quality assurance and control activities necessary to achieve the specified project requirements.

Ledbetter and Wolter (1992) define quality management in construction to be the optimization of prevention and appraisal activities to meet quality objectives. To effectively transfer this throughout all phases on the construction project, there needs to be company-wide efforts involving everyone in the organization in the performance improvement efforts. CII (Source Document 29, 1989) defines prevention and appraisal work as all of the activities associated with defect prevention and product appraisal to determine if a defect has occurred. In short, it is everything done to assure that quality is delivered to the customer. The purpose of quality management in the construction industry is to help the project management prepare and perform their work according to the design based on customer requirements (Hong, 1989).

Construction in the nuclear industry is known to place an extremely high emphasis on quality due to the nature of its technical operations. However, quality construction in the nuclear industry is also known to be very expensive and rather uncompromising. There are several aspects that are important to quality control in this type of building: organization consideration, program selection, procedures, planning and schedules, documentation and records, filing, turnover, communication, and training. Part of the reason behind the extreme expense for quality in the nuclear industry is that most of the quality management activities are focused on inspection during the construction stage.

When something is built incorrectly, it requires both disassembly and reconstruction (Bayless, 1986).

The level of quality management is somewhat dependent on the level of owner involvement in design, procurement, and construction phases. The nuclear industry, in general, is very strict with quality, but construction quality tends to be based largely on inspection, at a very high cost. Florida Power and Light is one of the few firms that has been somewhat successful with incorporating quality management into the design phase of the projects. They analyze what measurements need to pass nuclear inspection, and work closely with the designer and constructor to ensure these quality elements are built into the project working to prevent rework in the future (Burati et al., 1981).

Takenaka Komuten (an architecture and construction firm) also won recognition for their systematic improvement to the building industry. They accomplished this objective in all types of buildings and with a large reduction in cost. Takenaka was successful in this improvement effort by studying the needs of the users (in offices, hospitals, factories, hotels) and incorporated their findings into the design of their projects. The improved design focused on accurately meeting the requirements of the customer; thereby, reduced the costs of rework in drawings and in the actual construction (Deming, 1986).

2.3.4.1 What Makes Projects Successful

According to Ashley et al., the success of the planning of a project is largely an indicator for the success of the project as a whole. They place this strong emphasis on the planning effort for both the design and construction phases of the project. He believes this to be the single most important variable for successful construction projects. He lists other critical attributes for a successful construction project. Each project should have strong management commitment to a common goal, strong project team motivation,

project managers with good technical capabilities, a good scope and unequivocal work definitions, and strong measurement systems in place to support the project with feedback through its life-cycle.

When these project management attributes are aligned accurately towards accomplishing the goal, there is a higher probability for solid performance for a successful project. Ashley et al. give six criteria to measure the success of a project. The six criteria for success of a project are budget performance, schedule adherence, client satisfaction, functionality, contractor satisfaction, and project manager satisfaction.

2.3.4.2 The Dilemma of Failing to Meet Requirements

When studying the value-adding processes of the construction industry, the analysis primarily involves the interpretation, translation, and actual construction of owner requirements as depicted by Matthew's and Burati's portrayal in Figure 2.16 on page 48. Therefore, it is logical for the CII Quality Management Task Force to define quality as "conformance to requirements". The CII Quality Management Task Force's use of this operational definition of quality allows CII to use quantitative data when measuring and evaluating projects to the degree that the work either conforms or does not conform to requirements (CII SD-29, CII SD-30, CII Publication 10-2). The inability of the construction industry to always conform to requirements illustrates the industry's deficiency to add value to the full potential to the customer.

CII estimates that the failure to maintain quality (failure to conform to requirements) is costing the U.S. construction industry over \$15 billion a year to correct these deviations from requirements (CII Publication 10-2). CII also concludes that \$15 billion is just the cost of correcting these deviations; other hidden quality failures may increase that number by several fold. Dr. Deming (1986) concludes that rework is only part of the overall cost of poor quality. He says:

The cost of rework is only part of the cost of poor quality. Poor quality begets poor quality and lowers productivity all along the line, and some of the faulty product goes out the door, into the hands of the customer. An unhappy customer tells his friends. The multiplying effect of an unhappy customer is one of those unknown and unknowable figures, and likewise for the multiplying effect of a happy customer, who brings in business (Deming, p.12, 1986).

The Construction Industry Institute study supports Deming's conclusion that it is impossible to track all of the unknown cost for poor quality. They expand on his theory by offering some examples of extra expenses that were not captured in the tracking system:

The extra expense and lost profits incurred by the contractor as a result of changes, errors, and omissions were not specified in deviation reports and thus could not be included as deviation costs. All of the aforementioned costs have an impact on the total project cost. The lack of identification of these costs serve as an additional reason to consider the percentages reported herein to be conservative estimates of the true values (Burati and Farrington, 1987).

The cause of structural failures is typically due to design errors. These errors involve a lack of understanding between dead and live loads such as in the Kemper Arena roof collapse and in the Hyatt Regency walkway (Ledbetter and Ledbetter, 1985). The construction errors typically are due to misinterpretation of drawings and specifications. There has also been an increase of litigation due to failures in the construction industry. (Gross, 1984). There are many vague measurements that partially represent the damaging effects of not meeting the quality requirements. When considering the declining portion that construction plays in terms of the gross national product, as shown in Figure 2.17, it

is possible to conclude that this is a long-term consequence of poor performance (Godfrey, 1984).

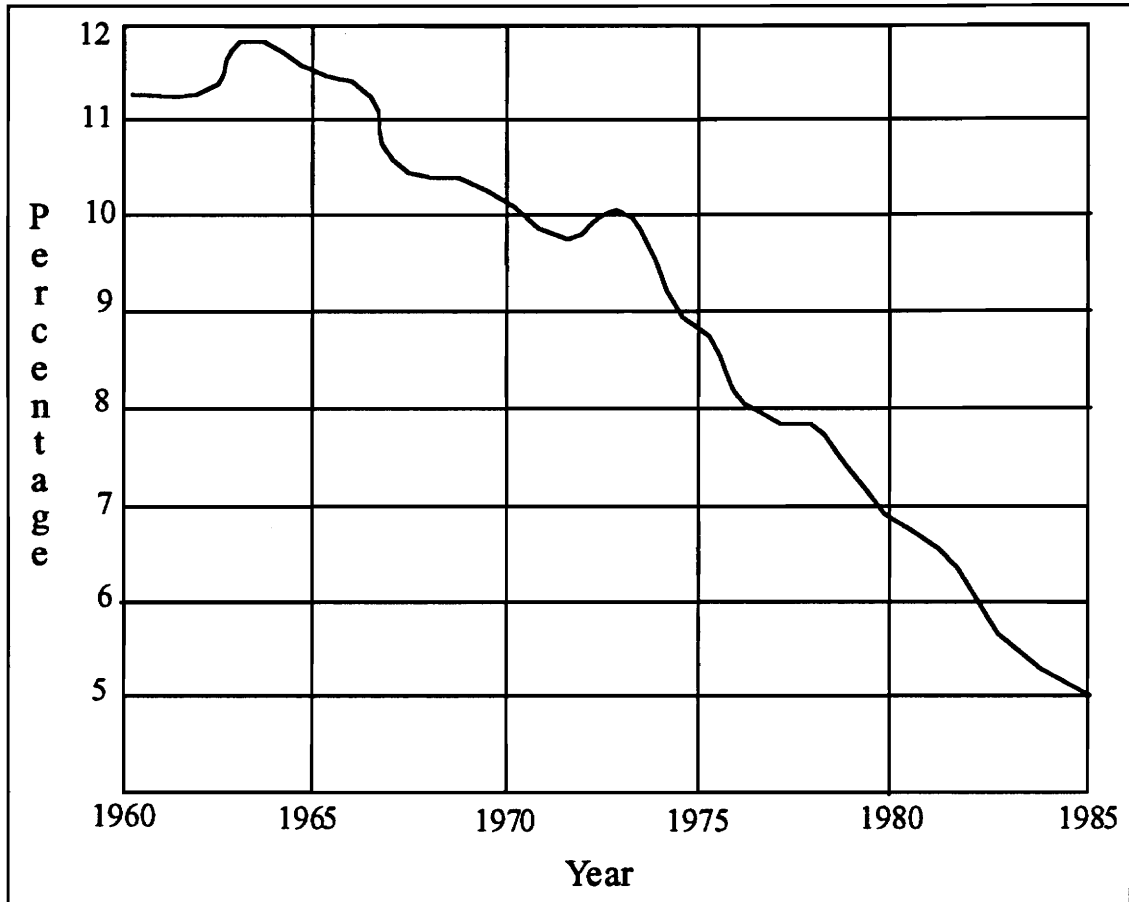


Figure 2.17: Construction Drop in the Gross National Product (Godfrey, 1984).

Tucker (1986) estimated that construction costs have risen 50% higher than inflation. In terms of construction productivity, it is believed that only 20% of the theoretical labor hours are actually used in putting the work into place. All of these items represent that the failure to meet requirements is much greater than the currently reported figures. But how does a construction project manager know where to begin? Thus, here lies the need for measurement feedback. An accurately designed measurement system helps highlight where to place emphasis for quality improvement efforts to have the most effectiveness.

2.3.4 What Is Measurement?

Deming (1990) suggests managers make decisions as a prediction of the future. When managers make these decisions, they are hoping to have positive outcomes as a result of their actions. Chester Barnard (1938) concludes knowledge of the past cannot change the past, only the future. He claims the organizational purpose bridges the gap between the past and the future by focusing on what can be done in the present. But how can a manager know what to do in the present? How can he or she be sure his or her actions result in positive consequences for the organization?

Organizations striving to improve performance must develop a systematic measurement system to ensure long-term improvement gains. Without the measurement system, there is no feedback mechanism to indicate the extent of the improvement intervention. Measurement is not an easy task, yet it must be done to ensure long-term improvement. Dixon et al. (1990) conclude that it is not the Japanese culture that makes their country so profound in terms of measurement. But, instead, it is their diligence and persistence at practicing good measurement skills for forty years. With practice, measurement will become easier. It is as with anything worthwhile, it takes hard work to achieve it. However, without measurement, it becomes difficult to determine whether or not the improvement intervention is working in the manner it is intended. As Sink and Tuttle (1989) conclude:

It is difficult to manage what you cannot measure.
You cannot measure what you cannot operationally define.
You can not operationally define what you don't understand.
You will not succeed if you do not manage.

Without measurement, an organization will have difficulty achieving its desired state, because there is no feedback mechanism to reduce uncertainty. Without the feedback mechanism, the organization has no way of knowing the cause and effect

relationships. However, the reduction of uncertainty only takes place when the correct measures are taken to provide the correct information.

Kopeman (1990) quoted Lord Kelvin who wrote in the 19th century, "When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever that may be." Deming is known for saying some of the most important things management must consider are not measurable. This is a valid point, and therefore it is important to measure what we can quantify to gain an understanding of the cause-and-effect relationships. This way we can spend our time contemplating the relationships that are difficult to quantify and not on items that we could easily understand with a strong measurement system. Kurstedt (1990) developed the Management System Model which shows measurement as the mechanism providing management with the necessary information to improve their decision making. This model, shown in Figure 2.18, depicts the management system in a cyclical manner where measurement forms the link between the organization and the manager.

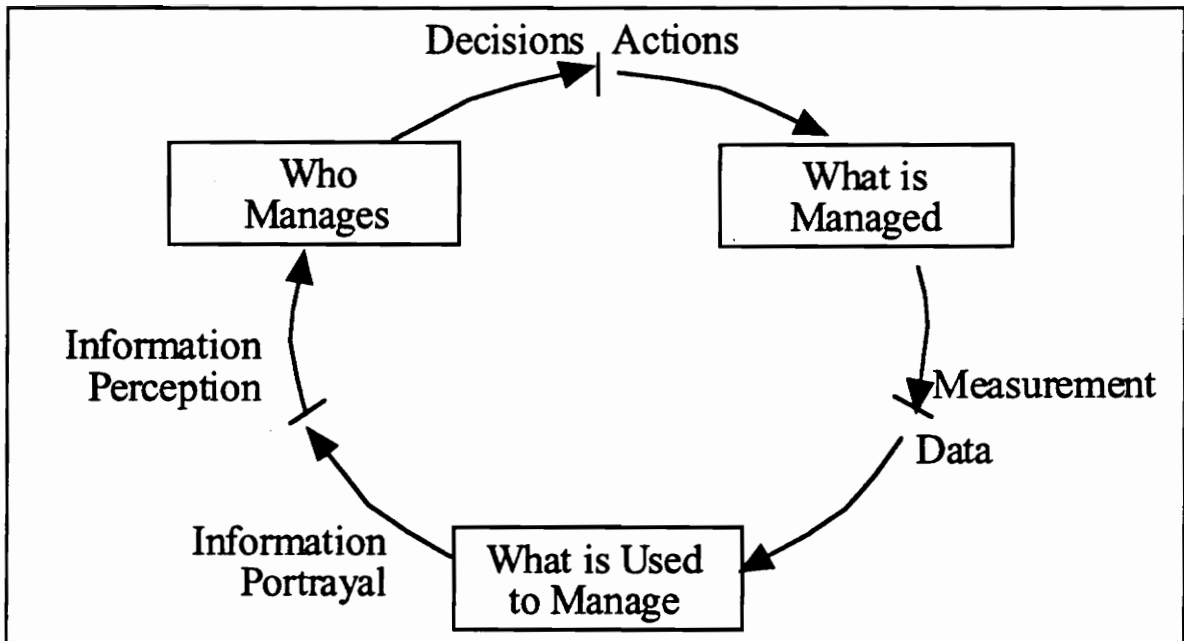


Figure 2.18: The Management System Model (Kurstedt, 1990)

Measurement is used to help the manager improve his decision-making ability. Through measurement, the manager obtains data about the operation (the "what is managed" component). The data are processed using a measurement tool and generated into information by comparing it to a reference point.

For example, a thermostat may read 45 degrees Fahrenheit, but this has little meaning until the manager compares it to a reference point. A person may consider 45 degrees to be okay, until the reference point indicates it needs to be below freezing to keep the food from going bad. The reference point helps to guide the manager to his or her future course of action. As Kurstedt concludes, information is biased data. The bias occurs when comparing the data to the reference points to generate information. Another example could be the amount of rework occurring on a construction project. Until the data are compared to a reference point (such as the amount of rework occurring on previous projects), they have little meaning for the manager. The cyclical process involved with comparing data to a reference point and guiding future actions enables

managers to continually gain a greater understanding of cause-and-effect relationships within their system.

Kanter (1987) describes the kaleidoscope metaphor used to gain a better understanding of measurement in organizations. As with a kaleidoscope, measurement portrays just a portion of reality. And, as with a kaleidoscope, changing measurements change the patterns of how reality is viewed. Measurement is not a view of the complete picture, but instead patterns of the picture. You never see all the components as they truly exist.

A change master sees the need for and leads productive change for the organization. They improve what the organization is doing, but simultaneously build into the organization the ability to improve and change on its own so the organization can then determine new directions for its own productive changes. Successful measurement systems need to be flexible, like playing croquet in Alice's Wonderland, because of the rapidly changing environment. The wickets and croquet mallets are dynamic, as is today's environment, and effective managers must be flexible enough to deal with the changing environment.

2.3.5.1 Problems with the Today's Accounting System

The United States has been plagued with a dependency on strictly financial measurements such as earnings per share, rate of return, and net profit margin. Unfortunately, decisions made solely on these types of measures have caused the United States to lag behind the global competition's understanding of performance improvement. For example, net profit margin tells the user nothing about the quality of the product or how to improve the quality of the product. Therefore, managers making decisions based solely on net profit margin have no understanding of the cause-and-effect relationship to quality. Deming (1986) suggests the dependency on financial measures occurred in the

1950's when the entire world would buy everything and anything made in America. This country was in the leadership position and therefore placed little concern on measuring for performance improvement. The United States' goods were in high demand; however, no one really understood the reasons why they were profitable.

Kaplan (1990) discusses the limitations of traditional cost accounting by stating that the typical accounting systems fail to recognize costs and benefits related to the entire operation. For years, financial measurements emphasized direct labor expense and direct labor efficiencies instead of focusing on matters such as monitoring reductions in inventory levels, rework, scrap, and throughput times. The organization's costs were the results of these activities and Kaplan concluded, "If we want to reduce cost, then we should measure the activities that create costs and attempt to make improvements directly on the underlying activities."

Dixon et. al. (1990) discuss their discontent with traditional cost accounting systems. They place their emphasis on the activities that influence the cost drivers, such as how to keep rework from occurring. They believe that managers who treat cost and short-term financial measures as the decision-divers may be sacrificing the long-term health of the organization.

One example of the downfall of basing decisions strictly on traditional financial measures that current accounting systems do not capture the value of the loyal customer or long-term quality development throughout its processes. Organizations often do not know much it costs to lose a customer. For example, organizations truly interested in long-term profit need to consider the effect of maintaining steady customers year after year as shown by the graph in Figure 2.19 (Reichheld and Sasser, 1990).

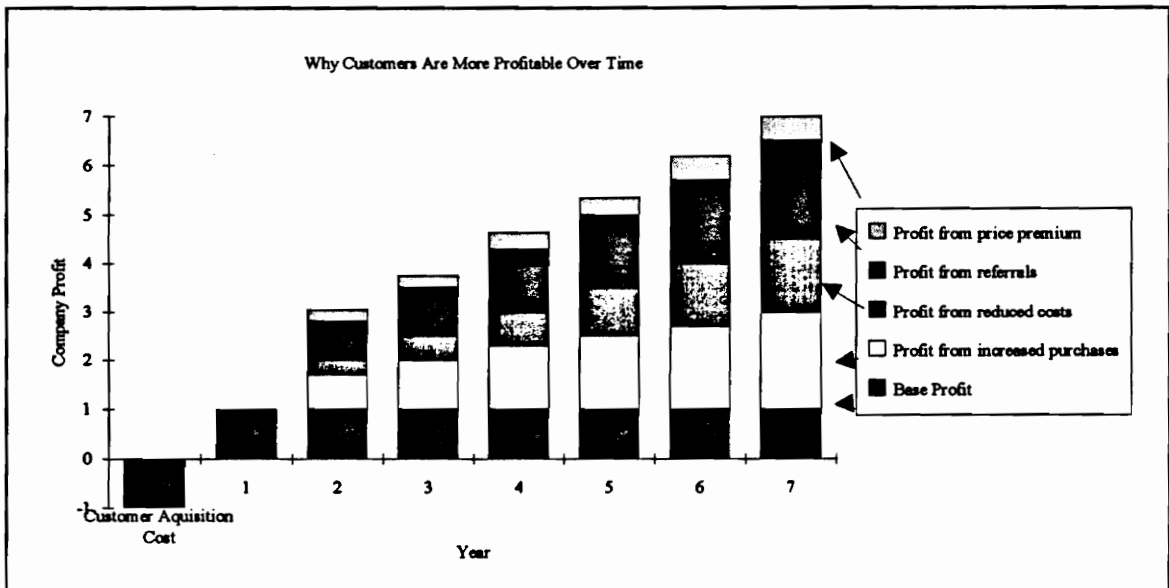


Figure 2.19: Long-Term Profitability of Loyal Customers (Reichheld and Sasser, 1990)

Defecting customers mean profit slumps ahead. Reichheld and Sasser emphasize employees like to work for companies that maintain long-term customers, and this promotes organizational loyalty. Often the service industries fail to understand their cost of poor quality. They conclude the scrap in service industries is the customer that won't come back. Organizations need to understand how to reduce the cost of rework and how to increase the effectiveness of activities designed to prevent rework. But, until the organization begins to measure these cost of quality components, there will be little understanding of how to control them. Good decisions about quality need to be based on facts, not solely on opinions.

Traditional cost systems generally provide little information related to quality cost (Hagan, 1985; Morgan, 1990). Unfortunately, today's quality cost systems are not reaching their full potential. Management often still needs to be convinced of the importance of using cost of quality for improvement efforts to focus on removing problems causing rework. Without tracking the amount of rework and its relative causes, management has little understanding of the rework cause-and-effect of its decisions.

2.3.5.2 Cost of Correcting Rework According to CII Study of Nine Major Projects

Burati and Farrington (1987) studied nine major construction projects to determine the cost associated with correcting deviations to meet requirements in the construction industry. The nine projects were selected from thirteen projects that were initially reviewed from the total of 48 projects offered for use by CII member firms (p. 126).

The results of this study indicated that for all nine projects, the cost of rework accounted for an average of 12.4% of the total installed project cost (p.129). The most common type of rework was due to design changes accounting for 78% of all deviations and 79% of the rework cost and 9.5% of the total installed project cost. Construction changes were the second most common cause of rework resulting in 16% of the total number of deviations. Construction deviations also resulted in 17% of the total deviation cost and 2.5% of the total installed project cost.

2.3.5.3 The Quality of Design Plays a Critical Role in the Amount of Rework

As stated earlier, design deviations accounted for the greatest amount of the rework cost (79% of the total rework cost; 9.5% of the total project cost). The large percentage of problems that occur from design emphasize the critical importance of quality management in this stage of the project life cycle. It is significantly less expensive to correct problems when they are on paper, than to correct them after the concrete has been placed. Because most of the deviations are caused from problems during this stage in the project life-cycle, it also makes practical sense to begin where most of the problems occur (CII, Source Document 29).

2.4 WHY MEASURE COST OF QUALITY

It is a very nebulous task to determine the long-term cost of quality on a construction project. Often problems that occur from poor quality impact the customer long after the construction of the project is finished. This time lag makes it increasingly difficult to fully understand the potential cost of poor quality. The cost of losing customers is practically unmeasurable, since the unhappy customer tells many other potential customers of the bad service or product he or she received. Until management gains a better understanding of the amount of rework occurring on the job and the effectiveness of activities designed to prevent rework, there is little they can do to make long-term improvements to the system.

An initial step to understanding how to reduce rework is to better understand the extent of the problem. Unfortunately, rework in the construction industry has become an accepted part of the construction process. It often appears that the construction industry has become accustomed to paying for the cost of rework and doesn't realize the huge opportunity for improvement to both the customer and the organization, if the cost of rework could be reduced. A big problem with quality in the construction industry is the time lag that takes place with rework. Unfortunately, the time lag only adds to the difficulty of correcting the problem, and often the problem becomes much more difficult to cure (Edmonds et. al., 1989).

Peter Senge describes the dangers associated with the time lag by using the metaphor of the boiled frog. If a frog is placed into a pan of boiling water, it will jump out immediately. However, if you place the frog in a pan of water at room temperature and slowly raise the temperature, the frog will remain in the pan and proceed to be boiled to death. It is often easy to avoid doing the necessary quality management, because the immediate benefits aren't so apparent. The rework occurs further downstream. Therefore, it appears as if the organization is spending money and not seeing any benefits.

In particular, prevention activities solve most problems before they occur, and therefore, it becomes easy to assume all would run smoothly without the prevention techniques.

The construction industry often appears conditioned to ignore the delayed gratification accompanying prevention and focuses on immediate results. It has become part of the job, and the additional cost for rework is regularly built into the construction budget. An insidious, but well-known technique is to underbid a project, with the hope of making up more than the difference in change orders. This technique inherently anticipates rework as part of the construction process (Olgesby et al., 1989). Who knows how the construction industry will be able to endure with such problems? But, following the boiled frog metaphor, the temperature in the kettle continues to rise. Of course, just tracking the rework is like measuring the temperature, it will not solve the problem but at least it highlights how close to boiling the organization is getting. Measuring the cost of quality is the first step in making the fundamental change necessary for the long-term improvement of quality in all operations.

A key criterion is that quality control must be structured explicitly and measurably so as to contribute to business profitability and positive cash flow. The determination of both quality and quality costs takes place throughout the entire project life-cycle. This is why real quality control cannot be accomplished by concentrating on inspection alone, or product design alone, or reject troubleshooting alone, or operator education alone, or supplier control alone, or statistical analysis alone, or reliability studies alone - important as each individual element is. As Feigenbaum (1991) says:

Total quality activities must exist in all the main-line operations: Marketing, Design Engineering, Production, Industrial Relations, Service, and similar key areas. Each quality-improvement and quality maintenance effort-be it a change in equipment and work force, in interrelationship structure, in information flow, or in the management and control of these function-must improve quality both for its own contribution and its contribution toward total quality effectiveness.

Measuring cost of quality throughout the entire project life cycle helps to integrate all of these functions. The cost drivers should be considered in all areas of project development. The cost of quality must be calculated for the amount of rework occurring and for activities designed to prevent rework.

2.4.1 What is Cost of Quality?

There are many types of measurements that need to be processed and applied to help construction organizations improve their quality and productivity. Cost of quality is just one type of measurement that provides the user information about rework and activities designed to prevent rework. It is a measurement that could be considered after-the-fact, because it occurs after the actions have occurred. However, measurement should be used to learn from the past to improve the future (Barnard, 1938). Cost of quality measurements taken throughout the project can be used to help transfer lessons learned to the next project. As Campanella and Corcoran conclude, "Fundamentally, each time work must be redone, we are adding to the cost of quality."

Total Cost of Quality is the sum of prevention, appraisal, and failure cost. It represents the difference between the actual cost of a product, and what the reduced cost would be if there were no possibility of failure of the product nor defects in its manufacture (Campanella and Corcoran, 1983).

Figure 2.20 shows how the cost of quality could be used as information feedback from the organization to help guide management's future actions. Kurstedt (1991) emphasizes that information is gathered by comparing measurements to reference points. Considering this emphasis, management should use the past cost of quality data as reference points to assist

him or her in making improved decisions about future actions.. Juran describes these costs as "gold in the mine" waiting to be extracted.

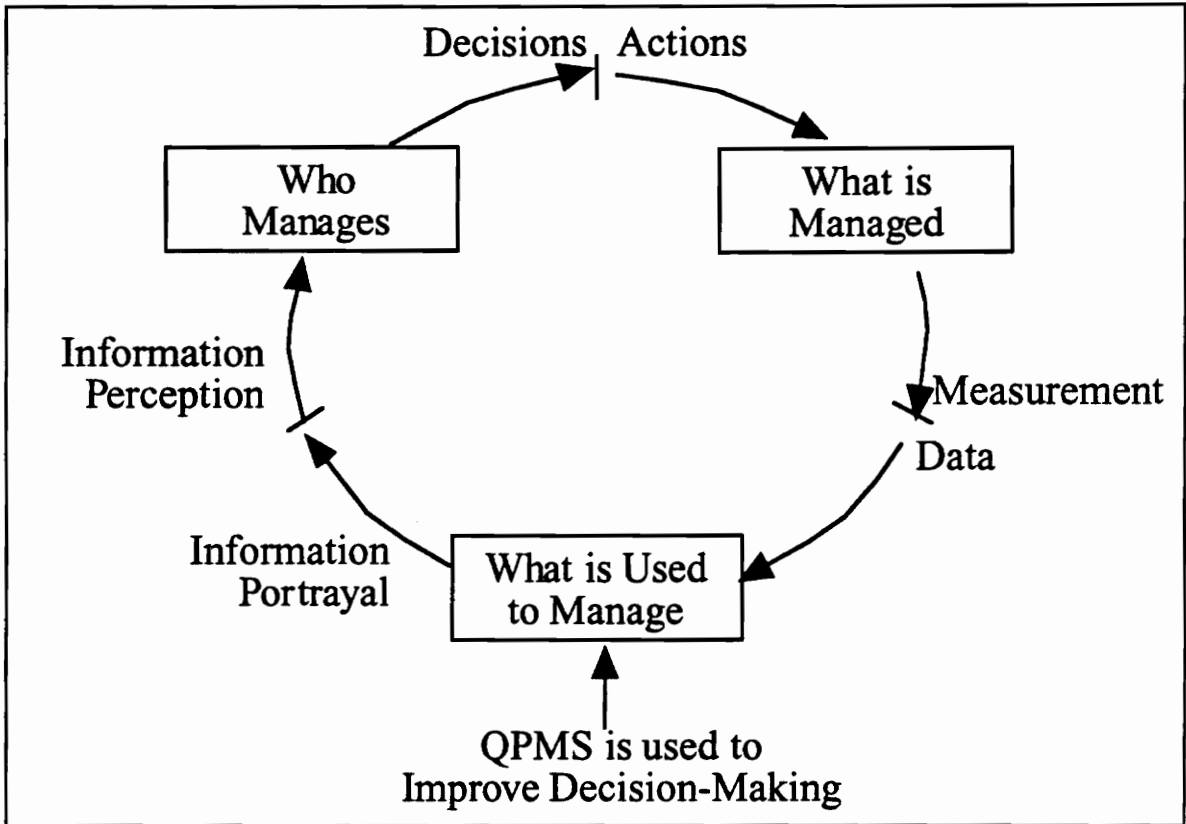


Figure 2.20: Cost of Quality as "What is Used To Manage" (adapted from Kurstedt, 1991)

Campanella and Corcoran (1990): "It should be obvious that increases in expenditures for prevention and appraisal will not show immediate reductions in failure costs because of the time lag between the cause and effect. In the past, management had only a hunch about the amount of money being spent to obtain a quality product. They had no real idea regarding the actual extent of rework." With properly designed cost of quality programs, management can make better decisions about reducing the cost of their rework.

The real challenge is to yield higher quality at lower costs. The movement to lower cost requires a leap in faith. Measurement of the cost of quality provides the diving board for the leap in faith. It is important for long-term success to identify the quality levers: the exact location, cause, and pattern of distribution for each problem. Feigenbaum says quality costs are divided into two categories: cost of control and cost of failure to control as shown in Figure 2.21.

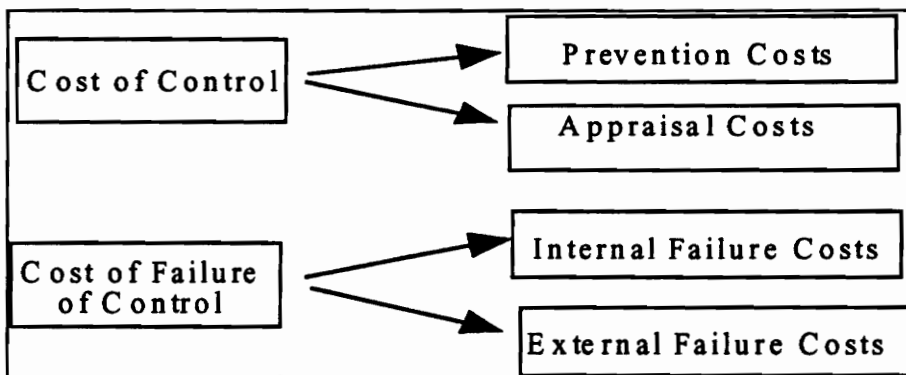


Figure 2.21: Cost of Control and Cost of Failure (Feigenbaum, 1991)

Cost of control includes prevention and appraisal cost. Cost of Failure of Control included internal failure costs and external failure costs.

Prevention Cost: Those costs expended in an effort to prevent discrepancies, such as the cost of quality planning, supplier quality surveys, and training programs.

Appraisal Cost: Those costs expended in the evaluation of product quality and in the detection of discrepancies, such as the costs of inspection, test, and calibration control.

Internal Failure Cost: Those costs resulting from discrepancies found prior to delivery of the product to the customer, such as the costs of rework and scrap.

External Failure Cost: Those costs resulting from discrepancies found after delivery of the product to the customer, such as the costs associated with processing customer complaints, customer returns, and warranties (Campanella and Corcoran, p. 17, 1983).

2.4.1.1 True Cost Actually Greater than the Recorded Cost of Quality

The true cost of quality will inevitably be greater than what the quality cost tracking systems show. No matter how accurate the system, it is impossible to track all of the cost that occurs as the result of bad quality. As Deming concluded, it is impossible to judge the negative impact of an unhappy customer telling ten other people of the poor service received from an organization. There are so many hidden costs occurring throughout the project life-cycle (such as customer good goodwill) that the tracked cost of rework is a very conservative estimate. Minimum quality costs do not necessarily mean maximum profit, because the losses due to failure are not always in failure costs. It is extremely difficult to capture the full cost of a poor design, and therefore it can not be accurately evaluated by the quality cost (Kume, 1985).

This is one aspect that is debatable about the optimal point of traditional cost of quality curves according to Sullivan (1983). The traditional cost of quality curve as shown in Figure 2.22 shows the optimum point where additional cost in prevention and appraisal equal the additional savings in rework.

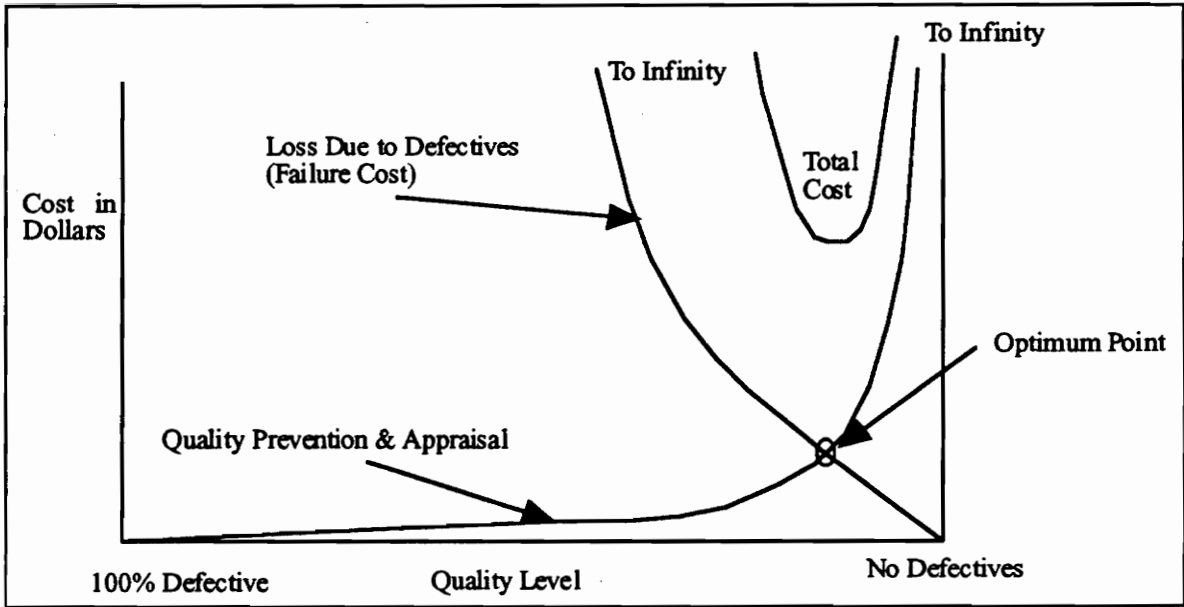


Figure 2.22: Optimal Cost of Quality (Campanella and Corcoran, 1983)

Several quality experts (Sullivan, 1983; Deming, 1986; Taguchi in Roslund, 1989) discuss the concern they have with the cost of quality curve is that you never truly know the true cost of poor quality. Often, it is considerably higher than the recorded dollar amounts lead you to believe. Juran discusses enlightened viewpoint to the curve with his breakthrough management theory. Juran concluded that when a process has achieved steady state any additional costs spent at keeping the process in-control are redundant, because it has reached steady state. At this point, you need to re-focus the efforts to work for a management breakthrough that will improve the process and therefore once again offer a greater reduction in rework.

2.4.1.2 Prevention Cost of Quality

Prevention cost can be considered the cost of all activities specifically designed to prevent poor quality from occurring in the future (Campanella and Corcoran, 1983). For an organization to place time and money into prevention efforts requires a leap of faith about the anticipated benefits. Early implementation of quality management into

prevention efforts help to reduce the long-term failure costs. Failure costs are a consequence of poor quality and occur after-the-fact. Prevention costs are more discretionary, because the organization can determine when and where it wants to place them. Prevention is typically significantly cheaper than rework. (Deming, 1986; Edmonds, 1989; Juran, 1988; Feigenbaum, 1991) It is estimated that the production in the United States typically spends 10-20% of the sales cost for rework, scrap, inspection and testing (Campanella and Corcoran, 1983).

For example, Krishnamoorthi's (1989) study demonstrated a direct correlation with an increase of prevention and the reduction in rework. He concluded it is necessary to know how cost of expenditures relates to quality to justify future budget allocations. Frances Brown's study demonstrated that every dollar spent in reduced failure cost improved profits by \$5.45. One reason for the greatest return for prevention activity is that it helps to reduce both internal and external failure cost, because the mistakes are eliminated (Campanella and Corcoran, 1983; Campanella, 1984; Sullivan, 1983). With inspection, if mistakes are found, there will still be internal failure cost because of the required rework. Inspection doesn't build quality into the process as prevention does (Deming, 1986).

The cost of quality in the US. is typically 10-20% of sales versus 2.5 to 4.0% in Japan (Chauvel and Andre, 1985). Top management has a direct responsibility for quality (Golomski, 1982; Deming, 1986; Juran, 1988; Feigenbaum, 1991; Taguchi in Roslund, 1989; Crosby, 1989). A fundamental change is necessary in how management handles the quality component of its long-term strategy. U.S. organizations have become conditioned to high quality cost, and unfortunately often accept rework as being inevitable. Golomski concluded in today's complex legal environment, increased exposure to product liability has unfortunately placed the emphasis on the detection of defects rather than prevention. However, placing the emphasis on detection of defects to avoid product litigation doesn't heed the fundamental solution necessary to keep the problem from actually occurring.

Today's organizations need to shift the burden of their problems to concentrate on the fundamental changes necessary to make long-term improvements (Senge, 1991).

It is better to prevent a disease from happening in the first place than to work at always curing the disease (Lenane, 1986). Lenane's study of fifty-four firms had a strong correlation indicating that prevention had the greatest impact on reducing rework. Inspection helps to catch the defect, but you will still have to do some rework after catching a bad product. The most important thing about the prevention and appraisal cost is not the total, but the way the money is used. Sometimes, it is crucial to have inspection to protect the customers from receiving a defective product. Over time, however, the organization must continually refine the process to build in quality.

Management often has difficulty finding the time to consider the deep ramifications of poor quality. However, management often makes decisions based on dollar amounts and, therefore, properly tracking the cost of quality is very important. To gain a greater understanding of the cost of quality in construction, the industry needs to adapt its measurement systems to gather this information. As Peter Senge concludes: "Until we alter the structural systems forming the organizational framework, the culture which reinforces decision-making will remain the same." Collecting quality cost data can help reveal the gold mines of opportunity for the organization (Lenane, 1986).

2.4.1.3 Implementing a Cost of Quality System

When implementing a cost of quality tracking system, it is important at first to do a small piece of the puzzle (Rhodes, 1972). It is very important to grasp the extent of failure, but it is important not to place so much emphasis on collecting the data that there is no time left for improvement. Rhodes concludes that it isn't vitally important to draw such distinct fine lines between all prevention and appraisal activity. Especially in the beginning stages, just collecting the data will be a significant task. When comparing

different trends of data, it is important to remember that the cost of quality varies with industry, companies, plants, products, life-cycles.

When collecting the cost of quality data, Plunkett and Dale (1985) give some useful guidelines to accompany the measurement process. They believe the critical factors in cost-of-quality acquisition are: purpose, relevance, ease of collection, size, accuracy, completeness, potential for changes. Plunkett and Dale also caution about believing the numbers are engraved in stone. Figures expressed in dollar amounts give the illusion of being very accurate, because they are numbers. As with any quantitative data, it is the accuracy of the method used to collect it that is relevant. Haggard (1984) lends the advice that the collection of cost of quality information should be free from organization pressure to prove goodness or badness, acceptability or unacceptability. These external pressures could lead to a greater probability of not getting accurate data.

Quality costs are merely a scoreboard reflecting actions that have previously taken place. They do not correct themselves. They tell you where your corrective action dollar affords the greatest return. These are just the beginning stages of organized corrective action. They say it is appropriate to begin by working with the ordinary accounting system for preliminary studies to help convince management of the need to study quality cost. The Construction Industry Institute has developed a measurement tracking system designed to begin capturing the cost of quality in the construction industry.

2.4.2 What is the Quality Performance Management System (QPMS)

According to CII Publication 10-2 (1989) and Davis and Ledbetter (1987), Quality Performance Management System (QPMS)⁸ is the only comprehensive system within the construction industry used to track and understand quality-related cost. CII recognized that tracking quality information has been used in manufacturing for over three decades.

⁸QPMS is referred to as Quality Performance Tracking System (QPTS) in Source Document 30.

But, as noted by Oglesby et. al. (1989), the construction industry varies dramatically from manufacturing. CII also recognizes this difference, and concurs by saying that construction is "anything but steady-state process" (1989).

By developing QPMS, the CII Quality Management Task Force enables some form of quantitative measurement of quality in every segment of the construction industry. QPMS can track quality-related cost incurred in the design, construction, and start-up phases of engineered projects. QPMS relates the disciplines involved and is an effective tool allowing for intelligent benefit/cost decision making. QPMS provides construction industry management with information needed to achieve quality and reduce overall costs (CII Publication 10-2, 1989, p.2).

The QPMS measurement tool was designed to help provide information. As with any management tool, an important characteristic is for the tool to provide rich information. Simply collecting the data is not enough, because it must be compared to a reference point to assist managers in making future decisions. It is critical to the success of measurement as a strategy, to continually define and refine how measurement can better be used to provide managers with more insightful information (Kurstedt, 1991). Ledbetter and Wolter give the following five requirements for QPMS to assist the tool in reaching its full potential in collecting cost-of-quality data (p. 5-5, 1992):

1. QPMS tracks labor cost of normal work, quality management activities and rework. The labor cost of normal work, quality management activities and rework are normalized as percentages of the project's total installed cost (TIC).
2. QPMS captures information by major phase: Design, Construction, Start-Up.

3. QPMS captures information by major disciplines which are project specific.
For Example:

- Civil
- Structural
- Architectural
- Process Engineering
- Mechanical
- Tanks & Vessels
- Piping
- Electrical
- Instrumentation
- Project Management

4. QPMS classifies quality management activities by one of the following eight activity types:

- Quality Systems
- Supplier Qualification
- Personnel Qualification, Testing, and Quality Training,
- Expediting
- Operational/Safety/Value Reviews
- Constructability Review
- Examinations- Internal
- Examinations - External

5. QPMS classifies rework by one of the seven following root causes and the instigating discipline (i.e., the construction discipline from requirement 2 responsible for causing the rework):

- Owner change
- Designer Change
- Vendor Change
- Construction Change
- Design Error
- Vendor Error
- Construction Error⁹

Through QPMS, organizations will be able look for similarities and/or differences associated with the influence of prevention and appraisal activities on the reduction of

⁹ Full operational definitions of all QPMS terms are located in Appendix A.

rework for each discipline. As indicated by Ledbetter and Wolter (1992), if we lived in a perfect world, we would only do normal work to accomplish the task. However, we do not live in a perfect world. Therefore, to understand why rework is happening, we need to study the root cause of rework. To understand how to effectively reduce rework, we must study the influence of prevention and appraisal activity on reducing rework. This research studies rework and activities designed to reduce rework.

2.4.3 Use Cost of Quality Data To Guide Improvement

Juran concluded the reduction of quality cost is not an end in itself, it is the means to an end. For long-term improvement of the organization's profitability, management must focus on the things that lead up to the cost of quality (Israeli and Fisher, 1991; Karabastos, 1991). As managers maneuver the organization toward its vision, they should be leery of the dangers accompanying an over-simplified approach. Improvement efforts must live by the laws of the farm. Successful efforts must plant the seeds in the spring, work the fields through the summer, before they can reap the harvest in the fall (Covey, 1991).

Cost of quality should be used to guide long-term quality improvement efforts. Cost of quality is a decision support system that allows the steering committee to perform detailed analyses on the rework cost drivers. Quality cost reporting alone does not improve quality or reduce cost, and neither does quality cost analysis (Schneiderman, 1986). Organizational management must see the synergistic approach of gathering the cost of quality information and using this information to guide process improvement. The pursuit of quality is a journey with no final destination, quality is not a stable property that once reached, the race is over (Sullivan, 1986). A well-trained organizational staff can increase the organization's profits by using cost of quality information to determine appropriate efforts to reduce scrap, rework and inspection costs (Brown, 1991).

2.4.3.1 Importance of Well-Trained Staff

Companies with stellar reputations for quality, recognize the significance of training for continuous organizational improvement. These firms recognize quality improvement is a long-term process that requires the continued development of employees. Starting engineers in strong quality organizations in Japan spend, on average, 30 days in their first year in training for quality control. They believe if an engineer doesn't know quality control, he or she isn't considered to be an engineer. These engineers spend a lot of time studying theory and formulas for application. These quality control courses require the engineers to solve an assortment of quality problems both in the classroom and on the production floor. Because of the strategic importance of quality, these programs are often run by top management in the organization (Box et. al., 1988).

2.4.3.2 Well-Directed Improvement Efforts Can Lead to Big Benefits.

Future quality improvement efforts can begin with components of cost of quality to find the heavy rework cost drivers that can later lead to Pareto analysis and problem-solving of the problems (Edmonds et. al., 1989). Denton and Kowalski (1988) emphasized an old management axiom the "What gets measured gets done" as an additional benefit to just gathering the cost-of-quality data. Their firm used cost-of-quality data to guide prevention activities and, within one year, reduced their cost-of-quality costs from 37% to 17%. As Deming specified, you continually improve the process and reduce variation by gaining greater control of the process. Cost of quality data help to show the need for future improvements in up-stream data as shown in figure 2.23.

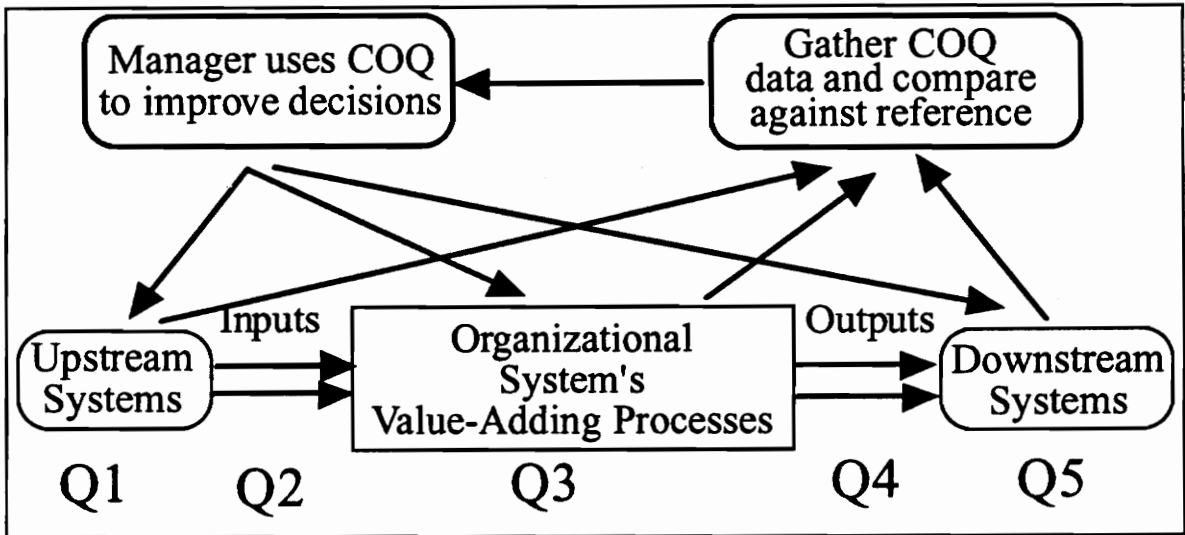


Figure 2.23: Use Cost of Quality to Guide Improvement

These efforts are particularly important for future work in design to make significant improvements. As Schrader (1986) concluded, an error in engineering can cost thousands to fix later in production. It is extremely important to produce a proper design for construction. This firm used inspections in the design phase to help prevent rework from occurring later in the production stage. The engineering firm in Schrader's study used a Pareto analysis of cost-of-quality data to a guide brainstorming for improvement actions in design.

2.4.3.3 The Importance of Understanding Variation

One of the reasons optimum quality cost is very difficult to ascertain is the critical role variation plays in quality improvement. The quality of a product that barely makes it within the specified requirement is considerably different than one that hits the target perfectly. A good example is a passenger door that closes snugly and helps reduce outside noise in the car. When this door is compared to one that fits loosely, the variation in the product plays a critical role in the eyes of the customer (Jamieson, 1989).

There are two types of variation occurring within the process: variation due to a special cause and variation due to the system. Deming estimates that 85% of the problems of the organization are due to variation due to the system with only 15% attributable to special cause (Nolan and Provost, 1990). Nolan and Provost shows a flow chart describing the aspects of system and special cause variation in figure 2.24.

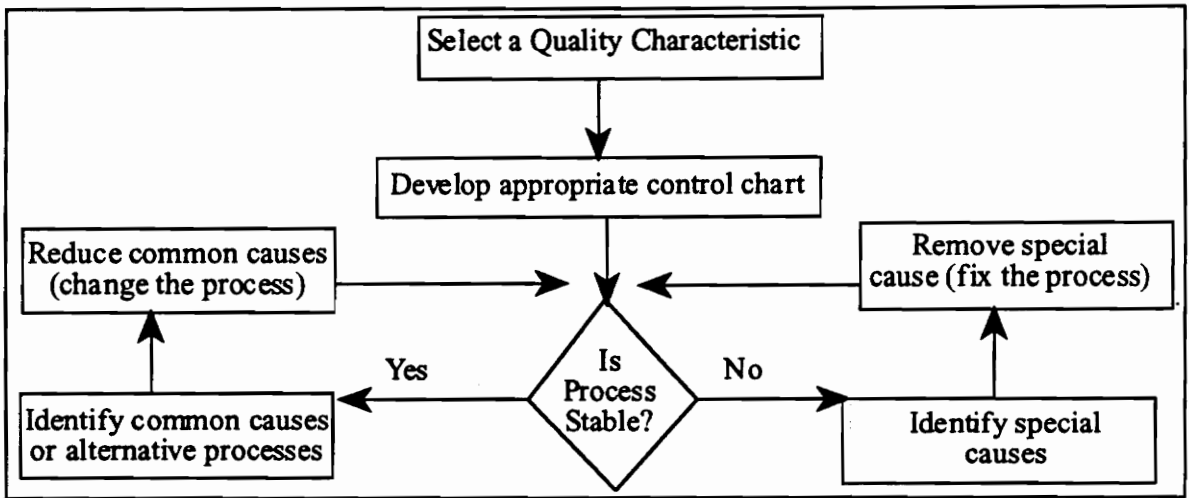


Figure 2.24: Variation in the System (Nolan and Provost, 1990)

One of the easiest ways to understand normal variation is through the use of control charts. When a product's attribute falls out of the control limits, its variation is considered to be a special cause. When a product's attribute is within the control limits, its variation is due to the system. The process would have to be changed to make any conclusive improvements to the process. An important element to consider when determining quality improvement efforts is whether or not the process is in control (Gitlow and Hertz, 1983).

2.4.3.4 The Importance of Process Improvement

Before any improvements can be made to a process, there must be a thorough understanding of how it works. Too often, improvement efforts jump directly into the

solution mode without gaining an accurate understanding of the process. Once the value-adding processes are viewed objectively from a systems standpoint, improvement efforts become less ambiguous. The use of operational definitions are critical, because everyone involved in the improvement effort must communicate in the same terms (Burr, 1990; Propts, 1989; Deming, 1986).

When improving a process, management must consider two dimensions important to process improvement. These dimensions are whether the processes are in control and whether the processes are capable of meeting specified requirements (Ridgon, 1990). The definition of a process that is "in-control" is that there is no special sources of problems. In this state of control, the study of defective items yields no useful information for improvement (Mann, 1989). The definition of a capable processes is that the process is producing output within the specification range of the customer's requirements. Figure 2.25 demonstrates the relationships of in-control and being capable.

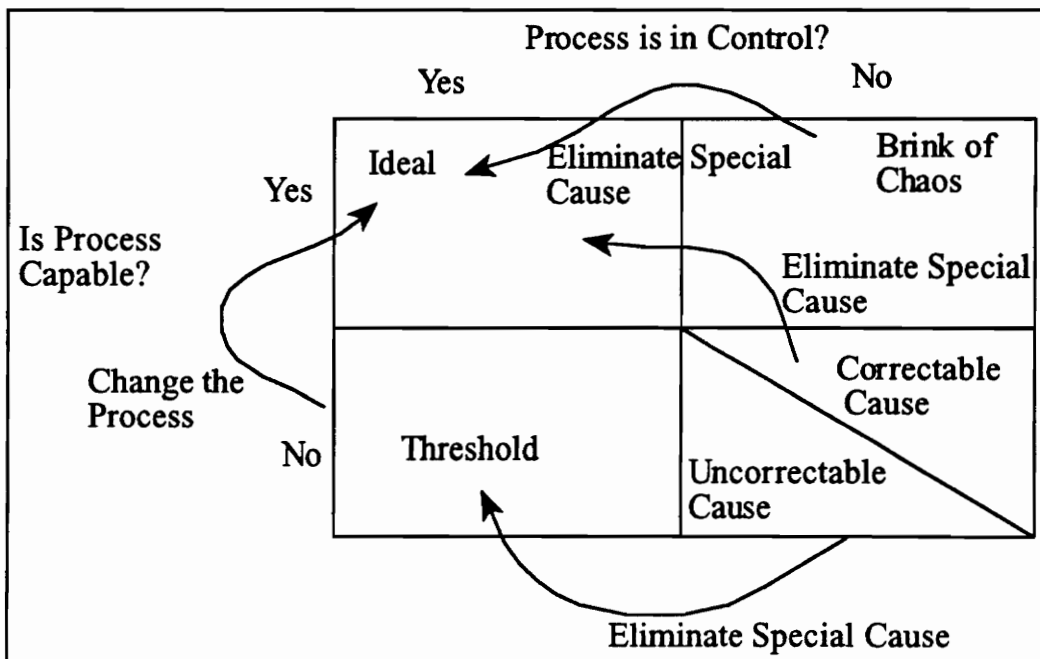


Figure 2.25: The Difference Between Process Being Capable and In-Control (Ridgon, 1990)

A process can be in-control and not capable of meeting requirements or out-of-control, but still within requirements. These two dimensions give four possible stages of a process.

- Ideal processes are in-control and capable.
- Threshold processes are in-control, but are not capable.
- Brink of chaos are processes that are capable, but not in-control.
- Chaos process are both out-of-control and incapable.

The intent is to continually move toward the ideal process. Juran strongly emphasizes Shewhart's conclusion as it relates to the importance of process improvement in quality control, "No inspector is half as effective as a well-controlled process."

The traditional inspection, sorting, techniques are ineffective toward process improvement, because they do nothing to prevent the defect from ever occurring. Organizations must remember that customers don't want products just to meet the requirement, they want it clustered around the targeted value. The intent is to continually improve the process to provide the customer with a product that exactly meets his or her requirements. The following steps represent a typical pattern used for process improvement (Bhote, 1988; Skrabec, 1986).

- Step 1)** State problems in terms of deviation from acceptable performance (what, where, when, how often)
- Step 2)** Identify control elements affecting performance
- Step 3)** Identify all possible causes of problems
- Step 4)** Analyze each possible causes based on historical data
- Step 5)** Draw conclusions and verify data
- Step 6)** Recommend improvement of standard
- Step 7)** Implement action
- Step 8)** Define new problems requiring attention

Peter Senge concludes that we must continually improve our ability to make process improvements until it becomes a routine of our daily work. We can pay a smaller price for the efforts to reduce rework, or pay a significantly higher price in the long term for poor quality.

Until we can eliminate rework, we have to give it conscious attention to preventing rework from happening. Organizations should create the necessary energies to improve the processes affecting rework. As with any learning, this type of improvement will be difficult, but as we get better at it, the course of reducing rework will become more habit forming. Just as we have learned to be in the habit of allowing rework, we can learn to be in the habit of reducing rework (Peter Senge, 1991).

SECTION 3: DATA AND TREATMENT OF THE DATA

This chapter discusses how the Quality Performance Management System (QPMS) Data were used to study the relationship between quality management and rework. QPMS was described in section 2.4.2 of the literature review.

3.1 THE QPMS DATA

QPMS is a measurement tracking system developed by the CII Quality Management Task Force to identify and understand the cost of quality. QPMS has been implemented on one completed project and is currently being implemented on three projects in progress. QPMS tracks the labor cost in both quality management and rework activity within each discipline and by construction phase. On projects where QPMS is implemented, employees record their time on a time card designed to capture the necessary QPMS information. Table 3.1 portrays the matrix displaying the summary of QPMS classification (Ledbetter and Wolter, 1992).

Table 3.1: Summary of QPMS Data Classification (Ledbetter & Wolter, 1992)

Work Class	What/why	When	Who
Normal Work	N/A	Design Construction Start-up	Discipline doing the work
Prevention & Appraisal	Activity Type (from list in Appendix A)	Design Construction Start-up	Discipline doing the work
Rework	Root Cause (from list in Appendix A)	When defect was detected	Instigating Discipline

3.1.1 The Frequency of Data Collection

The data are compiled by one-month periods. The monthly reports aggregate the data as percentages of budgets for each work classification in each discipline. Therefore for each discipline, I have the percentage of the total budget spent on each classification of prevention and appraisal activities and rework for each month. All four projects of this study use the same classification of prevention appraisal activities and rework (Taken from Ledbetter and Wolter, 1992).

3.1.2 Confidentiality of Proprietary Data

Due to the proprietary nature of the QPMS data, insofar as the data represent actual dollars spent by the customer, I abided by three guidelines to disguise certain project specifics from identification. I was given permission to use the CII QPMS data on the condition that I honored three requirements: 1) I did not publish any company name involved in the study; 2) I did not use the total dollar amount, instead I will use percentages of total dollar expenditures; 3) I did not publish the location of each project.

3.2 THE WORK-BREAKDOWN STRUCTURE OF DATA ACROSS PROJECTS

Although all four projects classify their times according to the same types of quality management activities and rework activities, there are some differences between the number of companies on a project and the disciplines doing the work.¹ The work-breakdown structure by project and discipline is shown in Table 3.2.

¹ This variance among the disciplines doing the work is typical of the unique nature of each construction project. The required disciplines vary depending on the type of work necessary to complete the project.

**Table 3.2: Work-Breakdown Structure by Project and Disciplines
(CII QPMS Data, 1992)**

Project Number	1	1	2	2	3	3	4	4
Company ID: D=Design C=Construction	D	C	D	C	D	C	D	C
Mechanical	x	x	x	x	x	x	x	x
Electrical	x	x	x	x	x	x	x	x
Piping	x	x	x	x	x	x	x	x
Instrumentation	x	x	x	x	x	x	x	x
Project Services	x	x	x	x			x	x
Project Eng.	x	x	x	x			x	x
Management					x	x		
Process Eng.					x	x		
Tanks, Vessels,	x	x	x	x	x	x	x	x
Structural	x	x	x	x			x	x
Civil	x	x						
Architectural	x	x						
Civil/Architectural			x	x			x	x
Civil/Architectural/Structural					x	x		
Fire Proofing/ Insulation/ Painting			x	x			x	x
x = project using this discipline category								

3.3 MODIFICATIONS TO THE WORK-BREAKDOWN STRUCTURE

I adapted the above work breakdown structure slightly by combining the three disciplines of civil, architectural, and structural. Because some projects combined the three disciplines as one category and others classified each discipline individually, I need to make a modification of the breakdown structure to provide a common denominator of the three disciplines. By combining these disciplines, I will have the same work-breakdown structure in each project. In essence, on projects where the three disciplines were classified individually, I will sum the three together to form one-inclusive discipline

civil/architectural/structure across all four projects. Table 3.3 shows this modification in how the civil, structural, and architectural data are aggregated.

Table 3.3: Combine Civil, Structural, and Architectural to Form One Discipline.

Project Number	1	1	2	2	3	3	4	4
Company ID	D	C	D	C	D	C	D	C
Civil/Structural/ Architectural	x	x	x	x	x	x	x	x

This research will use the aggregated data of six disciplines to test the specified hypotheses. The six disciplines studied by this research were²:

- Mechanical
- Electrical
- Piping
- Instrumentation
- Tanks and Vessels
- Civil/Structural/Architectural

3.4 METHODOLOGY FOR TESTING EACH HYPOTHESIS

The following sections describe the methodology used to test each hypothesis. The sections describe how the data were aggregated, analyzed, and interpreted.

3.4.1: Hypothesis 1: Prevention/Appraisal Activity has a negative correlation with rework (i.e., the more prevention/appraisal activity, the less rework).

3.4.1.1: How the data were aggregated for Hypothesis 1: For each of the six disciplines, I determined the cumulative quality management expenditures and cumulative

² This research did not study the relationships of Fire Proofing/Insulation; Project Engineering, Process Engineering, Management and Project Services because of difficulty in drawing cause-and-effect relationships with QPMS.

rework expenditures for all of the root causes excluding owner change³ for each company using QPMS. I ran this study combining all disciplines to do an overall project comparison between quality management and rework. Because some projects are not complete to the same level (i.e., some disciplines are 100 % complete and others only 90% complete), I needed to have a common unit of analysis to compare the four projects. To obtain this common denominator among projects, I interpolated the data of the four projects at 10%, 20%, 30%.....90%, and 100% of their budgeted total installed cost (TIC). The projects were compared at the highest percentage increment where all four projects were complete. For example, if there were five projects: A, B, C, D, and E; and D and E of the projects were only 90% complete, whereas the other projects were 100% complete; I compared the four projects at 90% complete. The results section of this research displays the analysis comparing the highest percentage where all projects were complete. The hypothetical aggregation of the five projects is shown in Table 3.4:

Table 3.4: Hypothetical Aggregation of Cumulative Quality Management (QM) and Rework (RW) at 10%, 20%, and 30% complete.

Projects	A	B	C	D	E
Cum QM at 90% complete	19%	9%	5%	12%	8%
Cum RW at 90% complete	2.5%	7%	13%	3%	6%
Cum QM at 100% complete	26%	13%	7%	N/A	N/A
Cum RW at 100% complete	3.2%	12%	20%	N/A	N/A

³ In the construction industry an owner change should not be considered "bad". The owner is the customer, and his/her desired changes should be considered meeting the customer's needs. Owner changes should not be evaluated in the same manner as design, vendor, or contractor changes (Ledbetter & Wolter, 1992).

3.4.1.2: How the data were analyzed and interpreted for Hypothesis 1.

3.4.1.2.1 Kendall Rank-Order Correlation Coefficient

To analyze the correlation between the percentage of quality management and the percentage of rework, I used the Kendall Rank-Order Correlation Coefficient T. This test measured the association between two variables and required at least ordinal data so that variables under study may be ranked in two ordered series (Siegel and Castellan, 1988). The purpose of using a correlation test was to determine whether or not there was a direct relationship between quality management and rework. The steps in using the Kendall rank-order correlation coefficient T according to Siegel and Castellan were:

1. Rank the percentages of the QM variable from one to five in increasing order, and rank the percentages on the RW variable from one to five as shown in Table 3.5. This is still the hypothetical example.⁴

Table 3.5: Ranking of QM and RW variable.

Company	A	B	C	D	E
Cum QM at 90% complete	15%	6%	3%	8%	5%
	(5)	(3)	(1)	(4)	(2)
Cum RW at 90% complete	2%	4%	5%	2.5%	3%
	(1)	(4)	(5)	(2)	(3)

2. Arrange the list of five companies so that the ranks of the variable QM were in their natural order, that is, 1,2,...5.
3. Observe the RW ranks in the order in which they occurred when the QM ranks were in natural order. Determine S, which was the number of agreements in order minus the number of disagreements in order, for the observed order of the RW ranks. The re-

⁴ I will continue to use the hypothetical aggregation to explain the procedures of the Kendall rank-order correlation coefficient T.

arrangement of QM in chronological order using the hypothetical example is shown in Table 3.6.

Table 3.6: Re-Arranging Data FOR QM To Be In Chronological Order.

Company	C	E	B	D	A
Cum QM at 90% complete	3%	5%	6%	8%	15%
	(1)	(2)	(3)	(4)	(5)
Cum RW at 90% complete	5%	3%	4%	2.5%	2%
	(5)	(3)	(4)	(2)	(1)

$$S = (0-4) + (1-2) + (0-2) + (0-1) = -8$$

Since Projects E,B,D, and A all have less rework than Project C, the first component of the "S" calculation is (0-4). For the second component, Project B is greater than Project E while Project D and A are less than Project E, therefore the component is (1-2).

4. Compute T (the degree of correlation) = $(2S)/N(N-1) = -12/20 = -.8$

3.4.1.2.2 Distribution-Free Test for the Slope Coefficient (Theil)

The Theil Distribution-Free Test for the Slope coefficient is a non-parametric regression test of the hypothesis that there is a change in one variable *Y* caused by a change in another variable *x*. The reason for using a regression test was to predict the probability of a change in the rework variable based on the change in the quality management variable. For this test, regression slope parameter β represents the unit change in *rework "Y"* per unit change in *quality management "x"*. The purpose should be viewed as a test of the hypothesis that the amount of rework occurring on the construction project does not change due to the amount of quality management occurring on the project against the alternative that there is a decrease in rework caused by the amount of quality management occurring in the project (Hollander and Wolfe, 1973, p. 201).

3.4.1.2.3 Example of Testing Methodology

The test of $\beta_0 = 0$ can be interpreted as a correlation test between the sequencing of the rework (Y) and quality management (x) variables (Hollander and Wolfe, 1973). However, the regression test provides the alpha probability for a type one error, and therefore offers more information about the hypothesis than just Kendall's correlation test. The two test use the same process of placing the quality management variable in increasing order, and then evaluating the ranks of the rework variable.

The steps in using the slope coefficient are:

1. Rank the percentages of the quality management variable in their natural order of increasing percentages of quality management
2. Observe the rework in the order in which they occur when the quality management percentages are in natural order. For example, Table 3.7 displays the increasing quality management variable with the corresponding rework variable.

Table 3.7: Quality Management and Rework Data as a Percent of Total Project Budgeted Cost.

Projects at 90% Complete	% Quality Mgt. of Budget	% Rework of Budget
Project 1	3%	5%
Project 2	5%	3%
Project 3	6%	4%
Project 4	8%	2%
Project 5	15%	1%

3. Form the differences of rework $D_i = Y - \beta_0 x_i$, where $i=1, \dots, n$. The rework difference are simply found from subtracting the second rework variable from the first rework variable, then the third rework variable

from the first rework variable, and so on until finally subtracting the fifth rework variable from the fourth rework variable as shown in Table 3.8

Table 3.8 The Rework Differences Based on the Corresponding Order of Quality Management

(i,j)	D _j -D _i
(1,2)	-2%
(1,3)	-1%
(1,4)	-2.5%
(1,5)	-3%
(2,3)	1%
(2,4)	-0.5%
(2,5)	-1%
(3,4)	-1.5%
(3,5)	-2%
(4,5)	-0.5%

4. Let $C = \sum_{i < j}^n c(D_j - D_i)$, where

$$c(a) = \{1 \text{ if } a > 0, 0 \text{ if } a = 0, -1 \text{ if } a < 0\}$$

That is, for each pair of subscripts (i,j) with $i < j$, score one if $D_j - D_i$ is positive, and score minus one if $D_j - D_i$ is negative. Take the sum of the positive ones and the negative ones and call this sum C . The regression analysis using Theil's Distribution-Free Test for the Slope Coefficient, ranks the differences in rework based on the natural ordering of quality management. The results of the rework differences are shown below in Table 3.9.

Table 3.9: Testing for regression slope of the project rework based on the natural order of quality management.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-2%	-1
(1,3)	-1%	-1
(1,4)	-2.5%	-1
(1,5)	-3%	-1
(2,3)	1%	1
(2,4)	-0.5%	-1
(2,5)	-1%	-1
(3,4)	-1.5%	-1
(3,5)	-2%	-1
(4,5)	-0.5%	-1

$$C = \sum_{i < j}^5 c(D_j - D_i) = -8$$

5. For a one-sided test of H_0 versus the alternative $\beta < \beta_0$, at the α level of significance. The chosen α is .05.

reject H_0 if $C \leq -k(\alpha, n)$

accept H_0 if $C > -k(\alpha, n)$

The slope parameter β_0 represents the rate of change in rework per unit change in quality management. A one-sided test is applied and is viewed as a test of the hypothesis that the rework does not change with an increase of quality management against the alternative that there is a decrease in rework, because of an increase in quality management (Hollander and Wolfe, 1973). The lowest level at which H_0 is rejected (according to Table A.21 in Hollander and Wolfe, p. 384, 1973) with the data $C = -8$ is:

$$P_0\{c \leq -8\} = .042$$

Because .05 is greater than .042, the null hypothesis is rejected for the hypothetical example.

3.4.2: Hypothesis 2: Prevention activity occurring in the design phase of a project life-cycle has a negative correlation with rework due to design error in the construction phase (i.e., the more prevention activity that happens in the design phase, the less design errors occur in construction).

3.4.2.1: How the data were aggregated for Hypothesis 2:

Prevention costs are those costs associated with preventing a problem from recurring (Harrington, 1987). For the purpose of this research, I depicted activities tracked by QPMS that serve the purpose of preventing rework occurring later in the project life-cycle. Some of these costs are inspection costs of the design phase serving the purpose of preventing rework in the construction phase. This research used those activities specifically designed for preventing rework occurring in the construction phase due to design errors. The three type of activities are operability reviews, constructability reviews, and internal examinations. This research will sum the rework due to design errors for each of the four projects and sum the prevention costs.

This portion of the methodology determined if there was an inverse relationship between the amount of prevention activity occurring in the design phase with the amount of rework occurring in the construction phase due to design error. This analysis began exploring the impact of quality management depending on when it occurred in the project life-cycle and the relative impact on rework. The results section displays the analysis at the highest percentage where all four projects are at the same level. The highest percentage were evaluated at both the design phase and the overall construction phase.

3.4.2.2: How the data were analyzed for Hypothesis 2:

Kendall Rank-order Correlation Coefficient

To analyze the correlation between doing prevention activities in the design phase and reducing the rework in the construction phase due to design errors, I used the Kendall Rank-Order Correlation Coefficient T. I ranked each company based on how much they spent on prevention activity in the design phase and rank the amount of rework performed in the construction phase due to design errors. I then used the Kendall Correlation Coefficient to determine whether companies that put more prevention effort in the design phase had less rework. The analysis will occur for both the project level and the discipline level.

I also used the Theil Distribution-Free Test for the Slope Coefficient to evaluate the slope of the regression line. The purpose should be viewed as a test of the hypothesis that the amount of rework due to design errors occurring in the construction project does not change due to the amount of prevention activity occurring in the design phase against the alternative that there is a decrease in rework caused by the amount of prevention activity occurring in the design phase.

CHAPTER FOUR RESULTS

The data were analyzed for both Hypothesis One and Hypothesis Two at the project level and the discipline level. A detailed explanation of the methodology is located in chapter three, section 3.4. The following section contains the results of the data analysis for the two hypotheses.

4.1 RESULTS FOR HYPOTHESIS 1:

4.1.1 Project Level Analysis

At the project level, the four projects were analyzed at 90% complete of the budgeted cost. Ninety percent was chosen as the cutoff point, because that was the highest percentage of the total budgeted cost where all four projects were complete. The quality management and rework data as a percentage of the total project budgeted cost are shown below in Table 4-1.

Table 4.1: Quality Management and Rework Data as a Percent of Total Project Budgeted Cost.

Projects at 90% Complete	% Quality Mgt. of Budget	% Rework of Budget
Project 1	6.334177	8.613826
Project 2	7.439508	2.304809
Project 4	10.61594	3.040975
Project 3	17.9846	0.994265

Figure 4.1 below displays a graphical comparison between quality management and rework for the four projects.

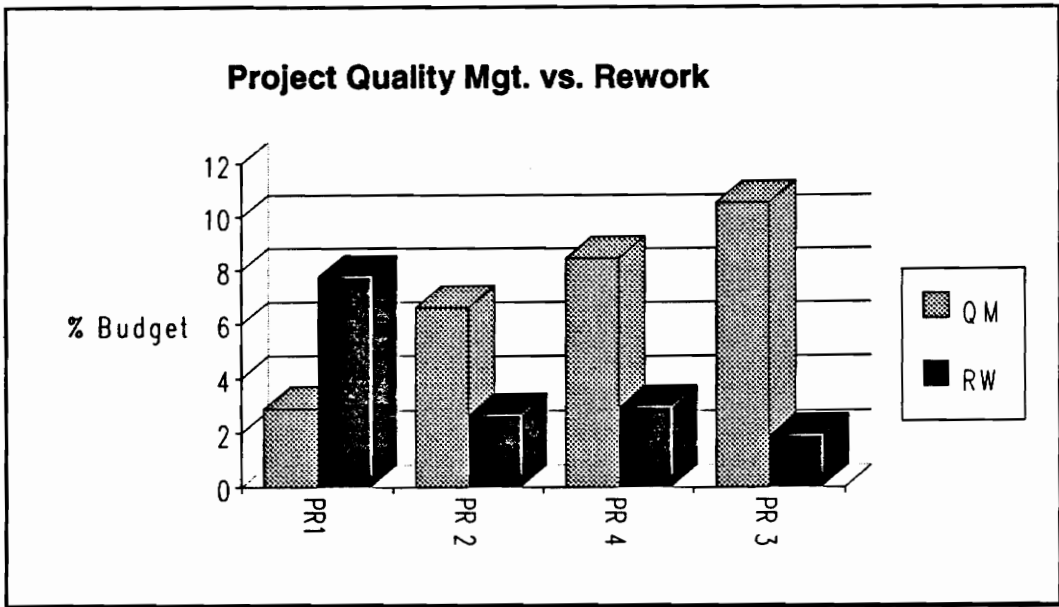


Figure 4.1: Project Quality Management versus Rework for Hypothesis 1.

The regression analysis using Theil's Distribution-Free Test for the Slope Coefficient, as described in chapter three, ranks the differences in rework based on the natural ordering of quality management. The results of the rework differences are shown below in Table 4.2.

Table 4.2: Testing for regression slope of the Project rework based on the natural order of quality management.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-6.30902	-1
(1,3)	-5.57285	-1
(1,4)	-7.61956	-1
(2,3)	0.736166	1
(2,4)	-1.31054	-1
(3,4)	-2.04671	-1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -4$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -4}{4 \times 3} = -.6667$$

The slope parameter β_0 represents the rate of change in rework per unit change in quality management. A one-sided test is applied and should be viewed as a test of the hypothesis that the rework does not change with an increase of quality management against the alternative that there is a decrease in rework, because of an increase in quality management (Hollander and Wolfe, 1973). The lowest level at which H_0 is rejected (according to Table A.21 in Hollander and Wolfe, p. 384, 1973) with the data $C = -4$ is:

$$P_0\{C \leq k\} = .167$$

The $P_0 = .167$ is the probability that the null hypothesis is true or that there is no relationship between the amount of quality management and the amount of rework. Because $P_0 = .167$ is greater than $\alpha = .05$, the statistical test is not significant, and it is not possible to reject the null hypothesis. In a practical sense, there is a probability that 83.3% of the time there is a relationship between the amount of quality management occurring and the amount of rework. The results were influenced by Project 4 having a slightly higher amount of rework than Project 2, although Project 4 spent a higher percentage of quality management as shown in Table 4.1 above.

4.1.2 Discipline Level Analysis

This section displays the analysis for each discipline studied by this research for hypothesis 1. The disciplines are: electrical, instrumentation, mechanical, piping, tanks and vessels, and civil/architectural/structural.

4.1.2.1 Electrical Analysis

Table 4.3 below display the matrix of the percent of the total project budget spent on quality management and rework for the electrical disciplines in the four projects.

Table 4.3: Electrical Quality Management and Rework Data as a Percent of Total Discipline Budgeted Cost..

90% Complete	% Quality Management	% Rework
Project 3	2.326527	0.673493
Project 2	2.665331	7.51572
Project 1	4.733079	3.663158
Project 4	7.849049	1.189445

Figure 4.2 below displays a graphical comparison between quality management and rework for the electrical discipline on the four projects.

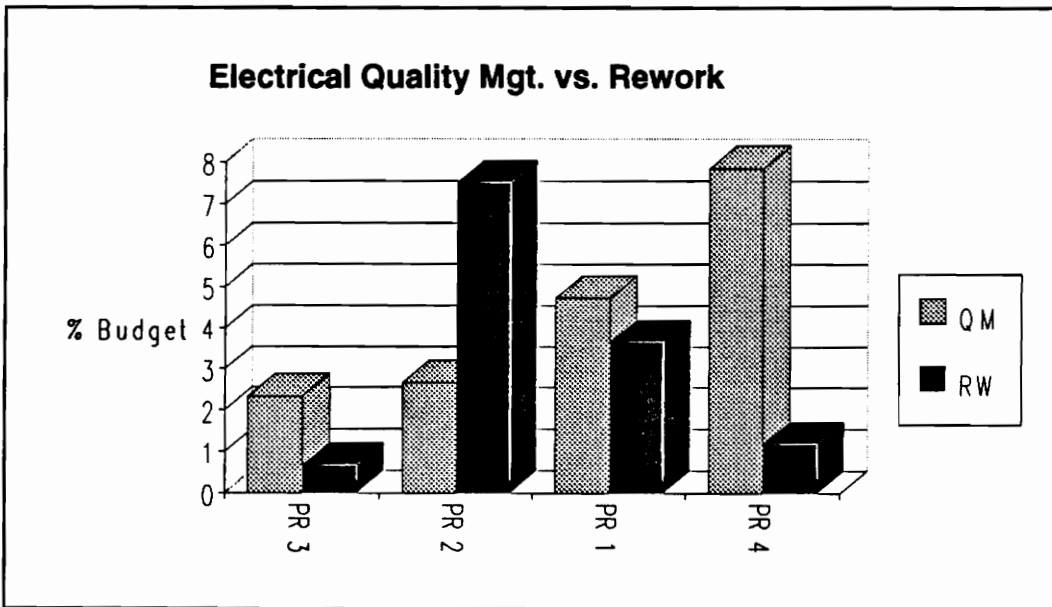


Figure 4.2: Electrical Quality Management versus Rework for Hypothesis 1.

Table 4.4 below displays the matrix showing the differences between projects and the relative rating using the non-parametric constant for the electrical discipline.

Table 4.4: Testing for Regression Slope of the Electrical Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 1.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	6.842227	1
(1,3)	2.989666	1
(1,4)	0.515952	1
(2,3)	-3.85256	-1
(2,4)	-6.32627	-1
(3,4)	-2.47371	-1

$$C = \sum_{i < j}^4 c(D_j - D_i) = 0$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times 0}{4 \times 3} = 0$$

$$P_0\{C \leq k\} = .625$$

Because $P_0 = .625$ is greater than $\alpha = .05$, the results of the statistical test is not significant, and it is not possible to reject the null hypothesis. The results were influenced by Project 3 having the least amount of quality management and the least amount of rework as shown in Table 4.3 above. Project 3 is an anomaly compared to the other projects, because the others followed the hypothesized order.

4.1.2.3 Instrumentation Analysis

Table 4.5 below display the matrix of the percent of the total project budget spent on quality management and rework for the instrumental disciplines in the four projects.

Table 4.5: Instrumentation Quality Management and Rework Data as a Percent of Total Discipline Budgeted Cost..

100% Complete	% Quality Management	% Rework
Project 2	5.465	2.545
Project 1	10.76092	0.655739
Project 4	14.90845	1.175107
Project 3	16.01888	0.533514

Figure 4.3 below displays a graphical comparison between quality management and rework for the instrumental discipline on the four projects.

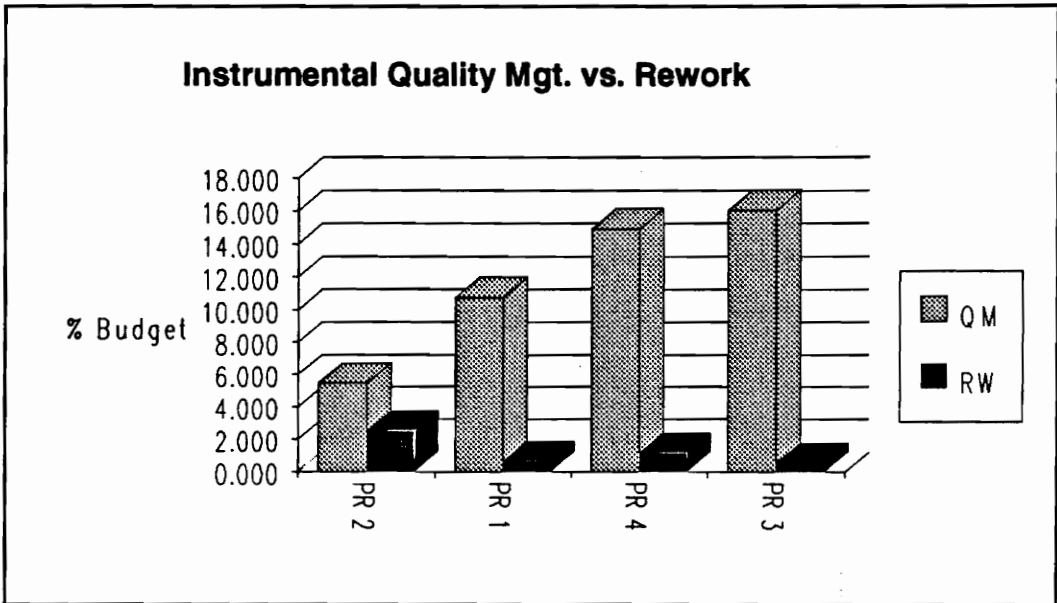


Figure 4.3: Instrumentation Quality Management versus Rework for Hypothesis 1.

Table 4.6 below displays the matrix showing the differences between projects and the relative rating using the non-parametric constant for the instrumental discipline.

Table 4.6: Testing for Regression Slope of the Instrumentation Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 1.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-1.88926	-1
(1,3)	-1.36989	-1
(1,4)	-2.01148	-1
(2,3)	0.519368	1
(2,4)	-0.12223	-1
(3,4)	-0.64159	-1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -4$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -4}{4 \times 3} = -.6667$$

$$P_0\{C \leq k\} = .167$$

Because $P_0 = .167$ is greater than $\alpha = .05$, the result of the statistical test is not significant, and it is not possible to reject the null hypothesis. Project 3 influenced the outcome of the results, because it had less rework than both Project 1 and Project 4, even though Project 3 had a higher percentage of quality management as shown in Table 4.5.

4.1.2.4 Mechanical Analysis

Table 4.7 below display the matrix of the percent of the total project budget spent on quality management and rework for the mechanical disciplines in the four projects.

Table 4.7: Mechanical Quality Management and Rework Data as a Percent of Total Mechanical Discipline Budgeted Cost.

90% Complete	% Quality Management	% Rework
Project 1	1.812191	4.609269
Project 2	11.46155	1.322965
Project 3	28.5918	1.720401
Project 4	37.44761	5.863911

Figure 4.4 below displays a graphical comparison between quality management and rework for the mechanical discipline on the four projects.

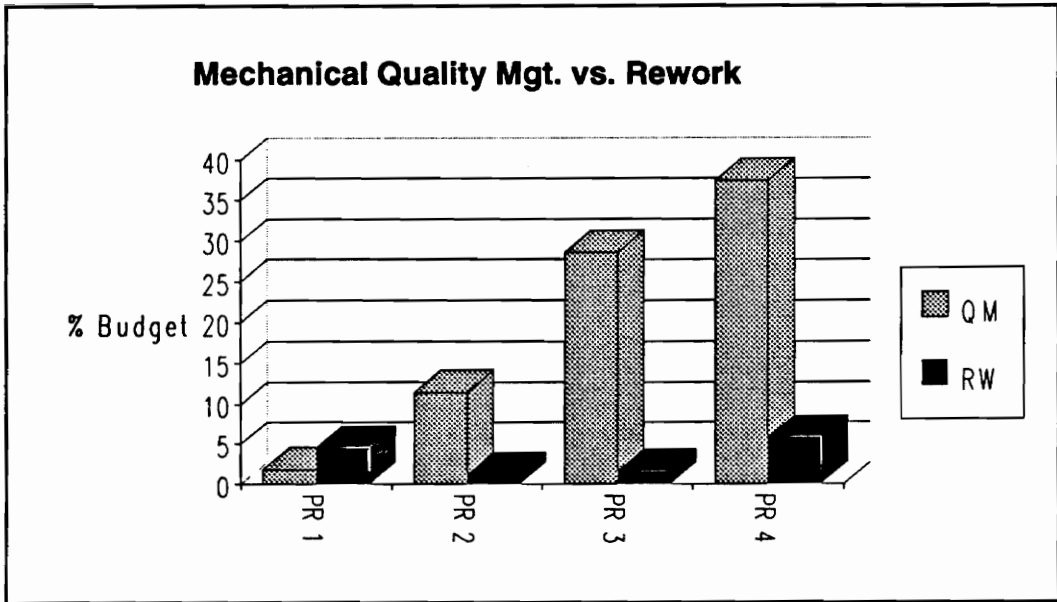


Figure 4.4: Mechanical Quality Management versus Rework for Hypothesis 1.

Table 4.8 below displays the matrix showing the differences between projects and the relative rating using the non-parametric constant for the mechanical discipline.

Table 4.8: Testing for Regression Slope of the Mechanical Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 1.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-3.2863	-1
(1,3)	-2.88887	-1
(1,4)	1.254642	1
(2,3)	0.397436	1
(2,4)	4.540947	1
(3,4)	4.14351	1

$$C = \sum_{i < j}^4 c(D_j - D_i) = 2$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times 2}{4 \times 3} = .3333$$

$$P_0\{C \leq k\} = .625$$

Because $P_0 = .625$ is greater than $\alpha = .05$, the statistical test is not significant, and it is not possible to reject the null hypothesis. The result was influenced by Projects 3 and 4 which both had increasing percentages of rework, even though they had higher levels of quality management as shown in Table 4.7 above.

4.1.2.5 Piping Analysis

Table 4.9 below displays the matrix of the percent of the total project budget spent on quality management and rework for the piping disciplines in the four projects.

Table 4.9: Piping Quality Management and Rework Data as a Percent of Total Piping Discipline Budgeted Cost..

90% Complete	% Quality Management	% Rework
Project 2	7.655017	3.002238
Project 1	7.853694	14.91668
Project 4	10.32059	4.669412
Project 3	19.20054	0.230476

Figure 4.5 below displays a graphical comparison between quality management and rework for the piping discipline on the four projects.

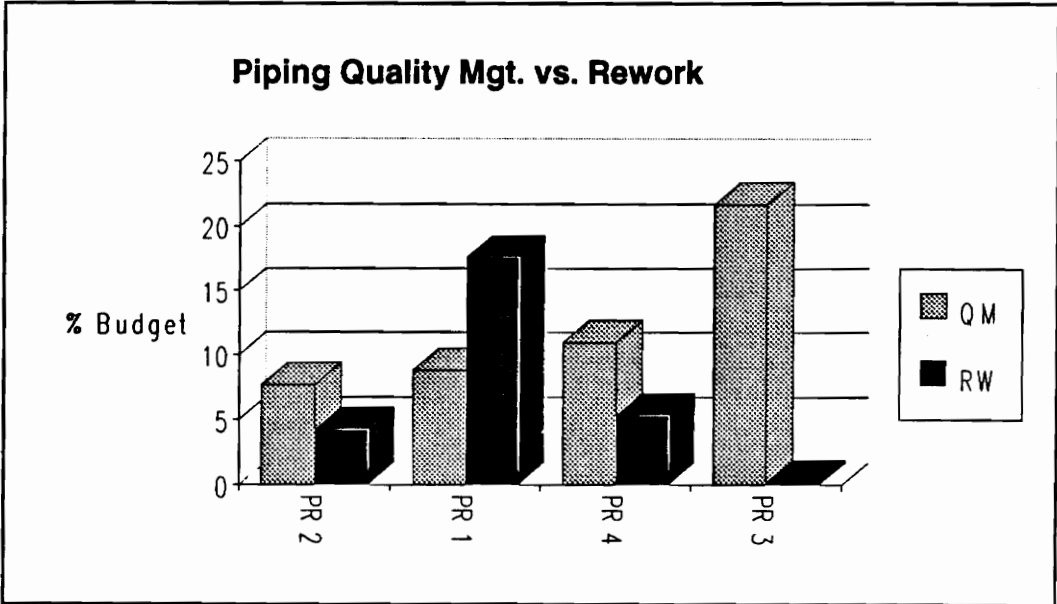


Figure 4.5: Piping Quality Management versus Rework for Hypothesis 1.

Table 4.10 below displays the matrix showing the differences between projects and the relative rating using the non-parametric constant for the piping discipline.

Table 4.10: Testing for Regression Slope of the Piping Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 1.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	11.91445	1
(1,3)	1.667173	1
(1,4)	-2.77176	-1
(2,3)	-10.2473	-1
(2,4)	-14.6862	-1
(3,4)	-4.43894	-1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -2$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -2}{4 \times 3} = -.3333$$

$$P_0\{C \leq k\} = .375$$

Because $P_0 = .375$ is greater than $\alpha = .05$, the result of the statistical test is not significant, and it is not possible to reject the null hypothesis. Projects 1 and 4 influence the lack of statistical significance, because they experience higher percentages of rework as shown in Table 4.9.

4.1.2.7 Tanks and Vessels Analysis

Table 4.11 below displays the matrix of the percent of the total project budget spent on quality management and rework for the tanks and vessels disciplines in the four projects.

Table 4.11: Tanks and Vessels Quality Management and Rework Data as a Percent of Total Tanks and Vessels Discipline Budgeted Cost.

90% Complete	% Quality Management	% Rework
Project 1	3.795858	7.962559
Project 2	16.6907	2.575271
Project 4	17.47173	3.541516
Project 3	37.57322	1.982016

Figure 4.6 below displays a graphical comparison between quality management and rework for the electrical discipline on the four projects.

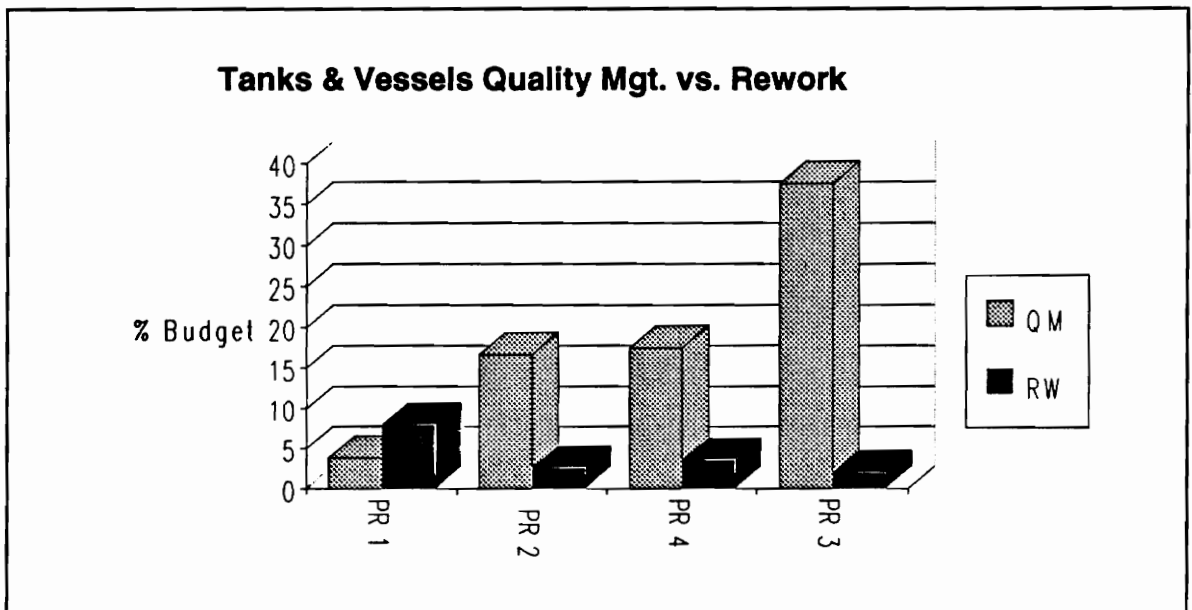


Figure 4.6: Tanks & Vessels Quality Management versus Rework for Hypothesis 1.

Table 4.12 below displays the matrix showing the differences between projects and the relative rating using the non-parametric constant for the tanks and vessels discipline.

Table 4.12: Testing for Regression Slope of the Tanks and Vessels Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 1.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-5.38729	-1
(1,3)	-4.42104	-1
(1,4)	-5.98054	-1
(2,3)	0.966245	1
(2,4)	-0.59325	-1
(3,4)	-1.5595	-1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -4$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -4}{4 \times 3} = -.6667$$

$$P_0\{C \leq k\} = .167$$

Because $P_0 = .167$ is greater than $\alpha = .05$, the result of the statistical test is not significant, and it is not possible to reject the null hypothesis. Project 4 influenced the lack of significance, because it experience a higher percentage of rework than Project 2 which had a lower percentage of quality management as shown in Table 4.11 above.

4.1.2.8 Civil/Architectural/Structural Analysis

Table 4.13 below display the matrix of the percent of the total project budget spent on quality management and rework for the civil/structural/architecture disciplines in the four projects.

Table 4.13: Civil/Architectural/Structural Quality Management and Rework Data as a Percent of Total Discipline Budgeted Cost..

100% Complete	% Quality Management	% Rework
Project 1	2.892672	7.758451
Project 2	6.616534	2.67137
Project 4	8.465747	2.974963
Project 3	10.53629	1.907476

Figure 4.7 below displays a graphical comparison between quality management and rework for the civil/structural/architectural discipline on the four projects.

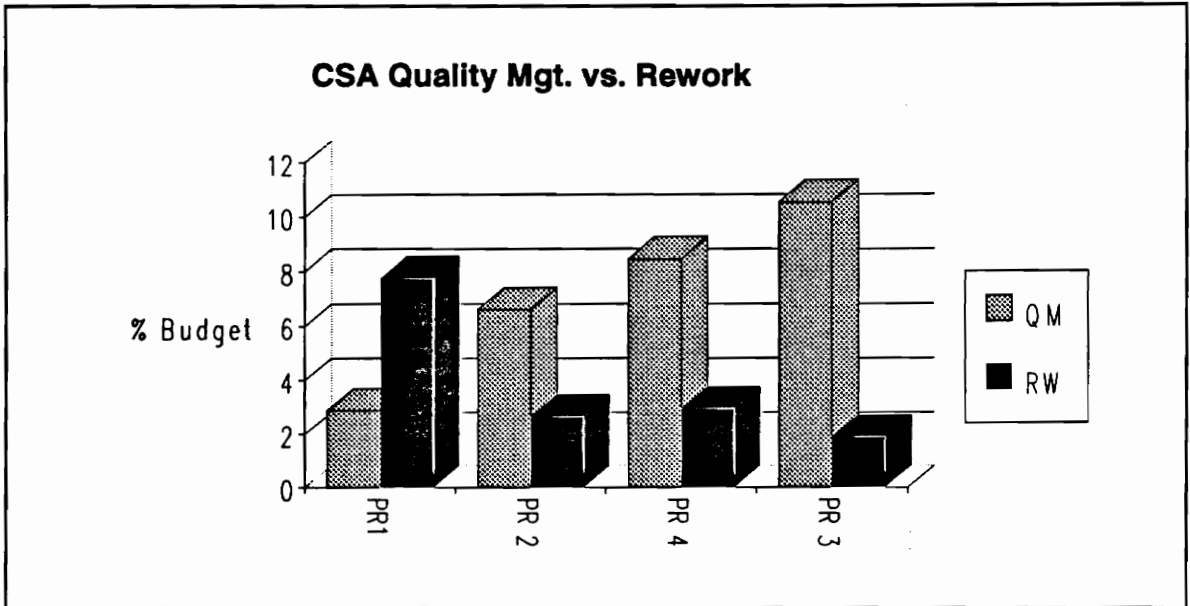


Figure 4.7: Civil/Structural/Architectural Quality Management versus Rework for Hypothesis 1.

Table 4.14 below displays the matrix showing the differences between projects and the relative rating using the non-parametric constant for the civil/structural/architectural discipline.

Table 4.14: Testing for regression slope of the Civil/Architectural/Structural discipline rework based on the natural order of quality management for Hypothesis 1.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-5.08708	-1
(1,3)	-4.78349	-1
(1,4)	-5.85097	-1
(2,3)	0.303593	1
(2,4)	-0.76389	-1
(3,4)	-1.06749	-1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -4$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -4}{4 \times 3} = -.6667$$

$$P_0\{C \leq k\} = .167$$

Because $P_0 = .167$ is greater than $\alpha = .05$, the statistical test is not significant, and it is not possible to reject the null hypothesis. Project 4 influenced the lack of significance, because it experienced a higher percentage of rework than Project 2 even though Project 4 spent a higher percentage of rework as shown in Table 4-13 above.

4.1.2.9 Summary Of Discipline Results For Hypothesis 1.

A summary of the results for all discipline regarding Hypothesis 1 is shown below in Table 4.15.

Table 4.15: Summary of Discipline Results for Hypothesis 1.

DISCIPLINE	$C = \sum_{i < j}^4 c(D_j - D_i) =$	Kendall's Tau T	$P_0\{C \leq k\} =$
Electrical	0	0	.625
Instrumentation	-4	.6667	.167
Mechanical	2	.3333	.625
Piping	-2	-.3333	.375
Tanks & Vessels	-4	-.6667	.167
Civil/Arch/Structural	-4	-.6667	.167

Because all the discipline P_0 's are greater than $\alpha = .05$, the results of the statistical tests for all of the disciplines were not significant, and it was not possible to reject any of the null hypotheses for the disciplines.

4.2 RESULTS FOR HYPOTHESIS 2:

Hypothesis 2 states that the amount of prevention occurring earlier in the project life-cycle is more effective on reducing rework. This hypothesis was analyzed by comparing the sum of three types of prevention activities occurring in the design phases to the rework caused by design errors in the construction phase.

4.2.1 Project Level Analysis

The four projects are analyzed at 90%, because project 4 is not complete to 100%. The prevention cost occurring in the design phase and the rework cost occurring in the construction phase due to design errors are shown below in Table 4.16.

Table 4.16: Quality Management as a Percent of Total Design Budgeted Cost and Rework as a Percent of Total Project Budgeted Cost.

Projects Number	% Prevention Cost in Design Phase	% Rework due to Design Error in Construction
Project 1	3.070268	2.424019
Project 2	11.03602	1.642695
Project 3	13.4684	1.230414
Project 4	16.8977	1.078025

Figure 4.8 below displays the relationship between the amount of prevention occurring in the design phase of a project and the amount of rework occurring in the construction phase due to design errors for the overall project.

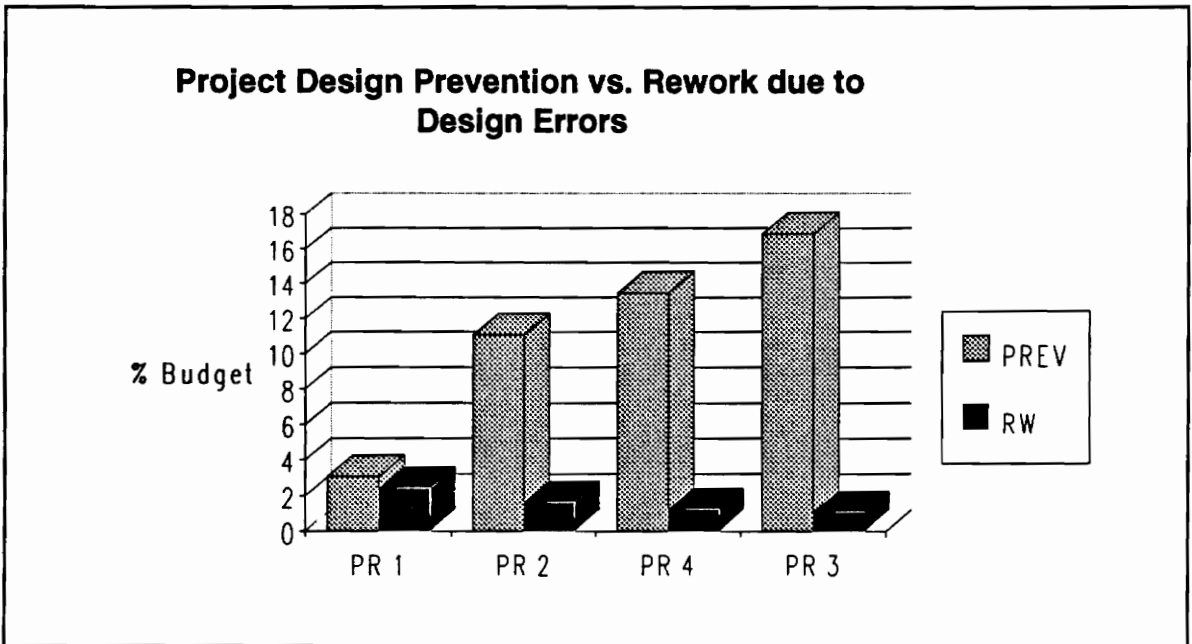


Figure 4.8: Project Design Prevention versus Design Error Rework Occurring in the Construction Phase.

The regression analysis using Theil's Distribution Test for the Slope Coefficient, as described in Chapter 3, ranks the differences based on the natural order of quality management in the design phase. The results of the rework differences are shown below in Table 4.17.

Table 4.17: Testing for regression slope of the overall Project rework based on the natural order of quality management occurring in the design phase Hypothesis 2.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-0.78132	-1
(1,3)	-1.19361	-1
(1,4)	-1.34599	-1
(2,3)	-0.41228	-1
(2,4)	-0.56467	-1
(3,4)	-0.15239	-1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -6$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -6}{4 \times 3} = -1$$

The slope parameter β_0 represents the rate of change in rework per unit change in quality management of the design phases. A one-sided test is applied and is viewed as a test of the hypothesis that the rework does not change with an increase of quality management in the design phases against the alternative that there is a decrease in rework, because of an increase in prevention activity in the design phase (Hollander and Wolfe, 1973). The lowest level at which H_0 is rejected (according to Table A.21 in Hollander and Wolfe, p. 384, 1973) with the data $C = -6$ is:

$$P_0\{C \leq k\} = .042$$

The P-Value $P_0 = .167$ is the probability that the null hypothesis is true or that there is no relationship between the amount of quality management and the amount of rework. Because $P_0 = .167$ is greater than $\alpha = .05$, the statistical test is not significant, and it is not possible to reject the null hypothesis. In a practical sense, there is a probability that 83.3% of the time there is a relationship between the amount of quality management occurring and the amount of rework occurring. The P-Value $P_0 = .042$ is the probability that the null hypothesis is true or that there is no relationship between the amount of quality management and the amount of rework. Because $P_0 = .042$ is less than $\alpha = .05$, the result of the statistical test was significant, and it is possible to reject the null hypothesis based on this methodology. In a practical sense, there is a 95.9% probability at the project level that there is a relationship between the amount of design occurring in the design phase with the amount of rework occurring due to design errors. All four projects experienced a reduction in the percentage of rework in the construction phase due design errors as the percentage of prevention in the design phase increased.

4.2.2 Discipline Level Analysis For Hypothesis 2.

This section displays the analyses of each of the disciplines studies by hypothesis 2.

4.2.2.1 Electrical Analysis for Hypothesis 2

The analysis was conducted at a completion interval of 90% of the overall budgeted discipline cost for the total project for the electrical discipline. The prevention cost occurring in the design phase and the rework cost occurring in the construction phase due to design errors are shown below in Table 4.18.

Table 4.18: Electrical Quality Management and Rework Data

Project Number	% Prevention Cost in Design Phase	% Rework due to Design Error in Construction
Project 1	0.496023	1.171361
Project 2	0.578179	6.245234
Project 3	5.329918	0.393814
Project 4	8.734012	1.056871

Figure 4.9 below displays the relationship between the amount of prevention occurring in the design phase of a project and the amount of rework occurring in the construction phase due to design errors for the electrical discipline.

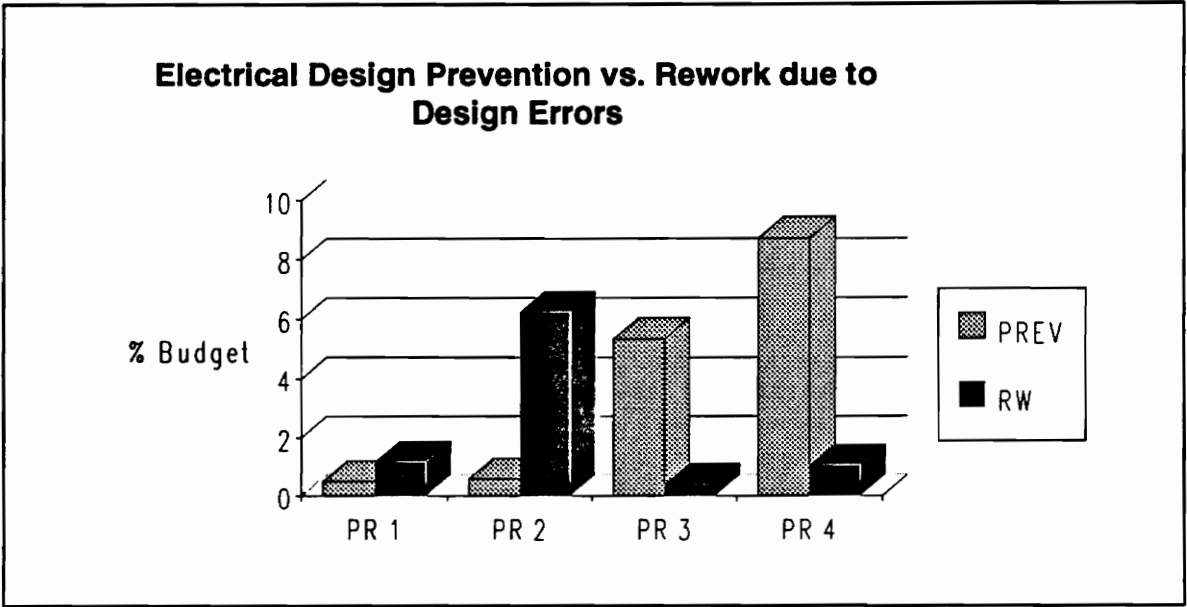


Figure 4.9: Electrical Design Prevention versus Design Error Rework Occurring in the Construction Phase.

The results of the rework differences are shown below in Table 4.19.

Table 4.19: Testing for Regression Slope of the Electrical Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 2.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	5.073873	1
(1,3)	-0.77755	-1
(1,4)	-0.11449	-1
(2,3)	-5.85142	-1
(2,4)	-5.18836	-1
(3,4)	0.663058	1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -2$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -2}{4 \times 3} = -.3333$$

$$P_0\{C \leq k\} = .375$$

Because $P_0 = .375$ is greater than $\alpha = .05$, the statistical test is not significant, and it is not possible to reject the null hypothesis. Projects 2 and 4 influenced the lack of significance, because they experienced a higher percentage of rework even though they had increased percentages of design prevention.

4.2.2.3 Instrumentation Analysis For Hypothesis 2.

The analysis was conducted at completion interval of 100% of the overall budgeted discipline cost for the total project for the instrumentation discipline. The prevention cost occurring in the design phase and the rework cost occurring in the construction phase due to design errors are shown below in Table 4.20.

Table 4.20: Instrumentation Quality Management and Rework Data

Project Number	% Prevention Cost in Design Phase	% Rework due to Design Error in Construction
Project 2	4.891876	1.144023
Project 1	6.263311	0.157884
Project 3	9.043941	2.544652
Project 4	15.22156	0.715843

Figure 4.10 below displays the relationship between the amount of prevention occurring in the design phase of a project and the amount of rework occurring in the construction phase due to design errors for the instrumental discipline.

Instrumental Design Prevention vs. Rework due to Design Errors

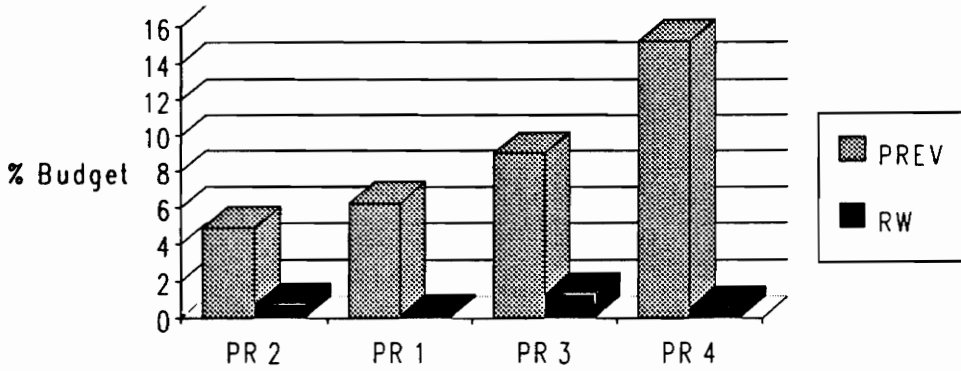


Figure 4.10: Instrumental Design Prevention versus Design Error Rework Occurring in the Construction Phase.

The results of the rework differences are shown below in Table 4.21.

Table 4.21: Testing for Regression Slope of the Instrumentation Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 2.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-0.98614	-1
(1,3)	1.40063	1
(1,4)	-0.42818	-1
(2,3)	2.386768	1
(2,4)	0.557959	1
(3,4)	-1.82881	-1

$$C = \sum_{i < j}^4 c(D_j - D_i) = 0$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times 0}{4 \times 3} = 0$$

$$P_0\{C \leq k\} = .625$$

Because $P_0 = .625$ is greater than $\alpha = .05$, the statistical test is not significant, and it is not possible to reject the null hypothesis. Projects 3 and 4 each experienced higher levels of rework than projects with less percentages in design prevention.

4.2.2.4 Mechanical Analysis For Hypothesis 2.

The analysis was conducted at completion interval of 90% of the overall budgeted discipline cost for the total project for the electrical discipline. The prevention cost occurring in the design phase and the rework cost occurring in the construction phase due to design errors are shown below in Table 4.22.

Table 4.22: Mechanical Quality Management and Rework Data

Project Number	% Prevention Cost in Design Phase	% Rework due to Design Error in Construction
Project 1	0.868272	0.842436
Project 4	3.971073	0
Project 2	4.486045	0.551787
Project 3	7.783552	0.138376

Figure 4.11 below displays the relationship between the amount of prevention occurring in the design phase of a project and the amount of rework occurring in the construction phase due to design errors for the mechanical discipline.

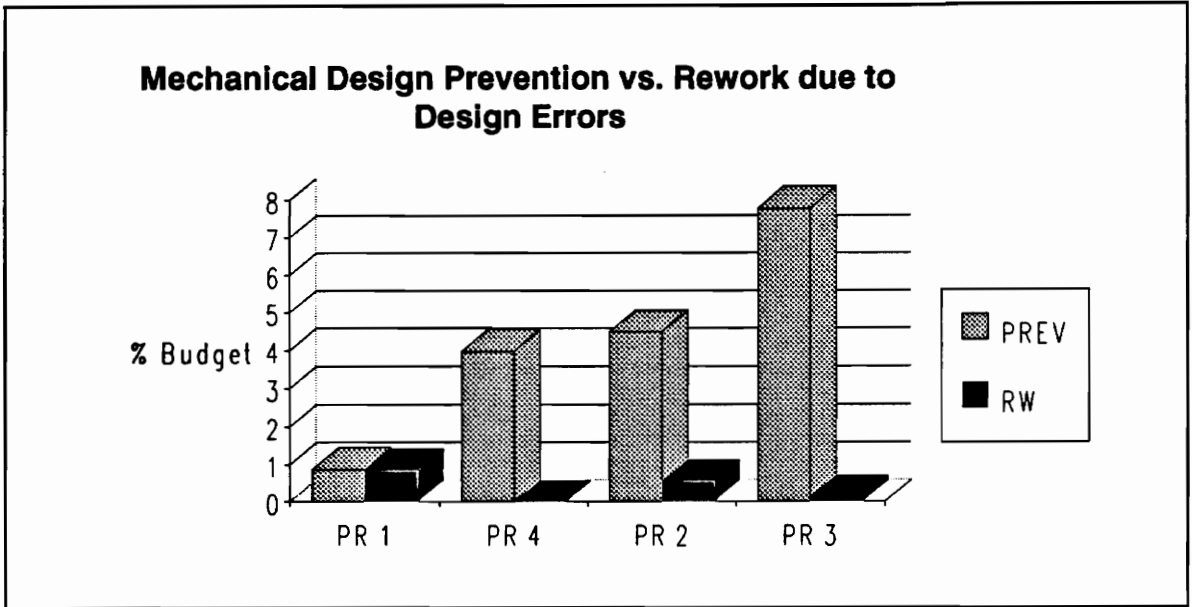


Figure 4.11: Mechanical Design Prevention versus Design Error Rework Occurring in the Construction Phase.

The results of the rework differences are shown below in Table 4.23.

Table 4.23: Testing for Regression Slope of the Mechanical Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 2.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-0.84244	-1
(1,3)	-0.29065	-1
(1,4)	-0.70406	-1
(2,3)	0.551787	1
(2,4)	0.138376	1
(3,4)	-0.41341	-1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -2$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -2}{4 \times 3} = -.3333$$

$$P_0\{C \leq k\} = .375$$

Because $P_0 = .375$ is greater than $\alpha = .05$, the statistical test is not significant, and it is not possible to reject the null hypothesis. Because Project 4 experienced no rework even though it had a lower percentage of design prevention than Projects 2 and 3, it influenced the lack of significance as shown in Table 4.22.

4.2.2.5 Piping Analysis For Hypothesis 2.

The analysis was conducted at completion interval of 90% of the overall budgeted discipline cost for the total project for the piping discipline. The prevention cost occurring in the design phase and the rework cost occurring in the construction phase due to design errors are shown below in Table 4.24.

Table 4.24: Piping Quality Management and Rework Data

Project Number	% Prevention Cost in Design Phase	% Rework due to Design Error in Construction
Project 1	4.733612	3.373375
Project 3	17.57869	2.293073
Project 2	20.10277	1.51575
Project 4	30.20727	1.993985

Figure 4.12 below displays the relationship between the amount of prevention occurring in the design phase of a project and the amount of rework occurring in the construction phase due to design errors for the piping discipline.

Piping Design Prevention vs. Rework due to Design Errors

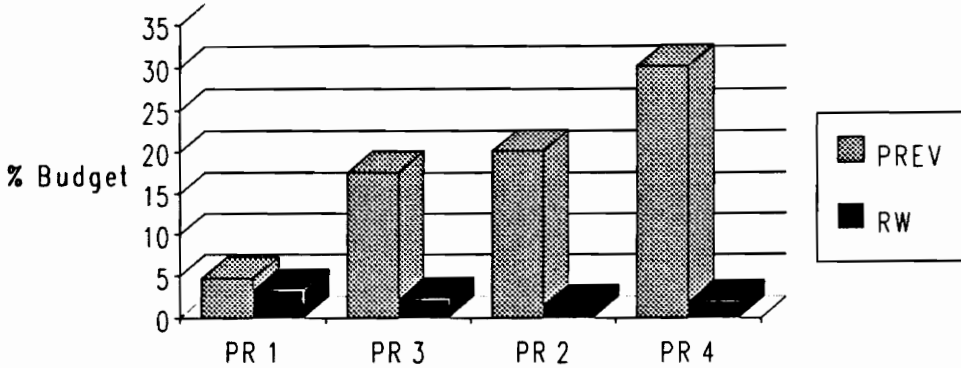


Figure 4.12: Piping Design Prevention versus Design Error Rework Occurring in the Construction Phase.

The results of the rework differences are shown below in Table 4.25.

Table 4.25: Testing for Regression Slope of the Piping Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 1.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-1.0803	-1
(1,3)	-1.85763	-1
(1,4)	-1.37939	-1
(2,3)	-0.77732	-1
(2,4)	-0.29909	-1
(3,4)	0.478235	1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -4$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -4}{4 \times 3} = -.6667$$

$$P_0\{C \leq k\} = .167$$

Because $P_0 = .167$ is greater than $\alpha = .05$, the statistical test is not significant, and it is not possible to reject the null hypothesis. Because Project 4 experienced a higher percentage of rework than Project 2, it influenced the lack of significance in the test as shown in Table 24 above.

4.2.2.7 Tanks and Vessels Analysis For Hypothesis 2.

The analysis was conducted at completion interval of 90% of the overall budgeted discipline cost for the total Project for the tanks and vessels discipline. The prevention cost occurring in the design phase and the rework cost occurring in the construction phase due to design errors are shown below in Table 4.26.

Table 4.26: Tanks and Vessels Quality Management and Rework Data

Project Number	% Prevention Cost in Design Phase	% Rework due to Design Error in Construction
Project 1	0.558378	1.25667
Project 3	2.769614	0.515673
Project 2	3.066882	1.197322
Project 4	5.433984	0

Figure 4.13 below displays the relationship between the amount of prevention occurring in the design phase of a project and the amount of rework occurring in the construction phase due to design errors for the tanks and vessels discipline.

Tanks & Vessels Design Prevention vs. Rework due to Design Errors

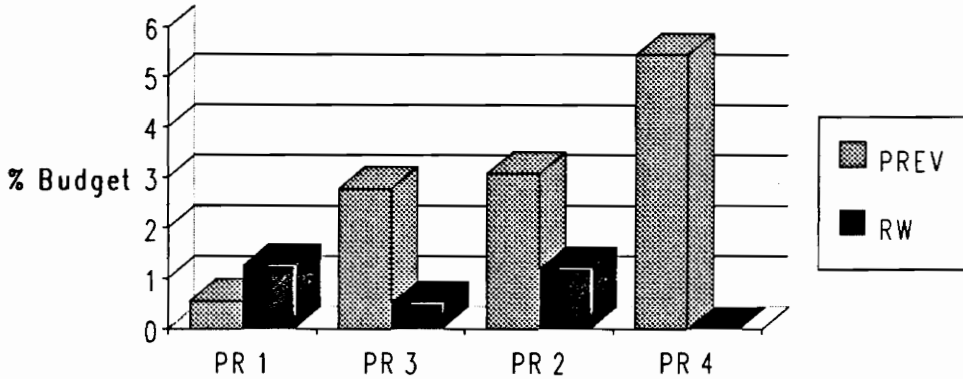


Figure 4.13: Tanks & Vessels Design Prevention versus Design Error Rework Occurring in the Construction Phase.

The results of the rework differences are shown below in Table 4.27.

Table 4.27: Testing for Regression Slope of the Tanks and Vessels Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 2.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	-0.741	-1
(1,3)	-0.05935	-1
(1,4)	-1.25667	-1
(2,3)	0.681649	1
(2,4)	-0.51567	-1
(3,4)	-1.19732	-1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -4$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -4}{4 \times 3} = -.6667$$

$$P_0\{C \leq k\} = .167$$

Because $P_0 = .167$ is greater than $\alpha = .05$, the statistical test is not significant, and it is not possible to reject the null hypothesis. Because Project 2 experienced a higher percentage of rework than Project 3 as shown in Table 4.26 above, it influenced the lack of significance in the test.

4.2.2.8 Civil/Architectural/Structural Analysis For Hypothesis 2.

The analysis was conducted at completion interval of 100% of the overall budgeted discipline cost for the total project for the civil/architectural/structural discipline. The prevention cost occurring in the design phase and the rework cost occurring in the construction phase due to design errors are shown below in Table 4.28.

Table 4.28: Civil/Architectural/Structural Quality Management and Rework Data

Project Number	% Prevention Cost in Design Phase	% Rework due to Design Error in Construction
Project 1	1.282006	4.779562
Project 2	12.39832	6.391084
Project 4	18.61828	1.720659
Project 3	26.82553	2.380274

Figure 4.14 below displays the relationship between the amount of prevention occurring in the design phase of a project and the amount of rework occurring in the construction phase due to design errors for the civil/architectural/structural discipline.

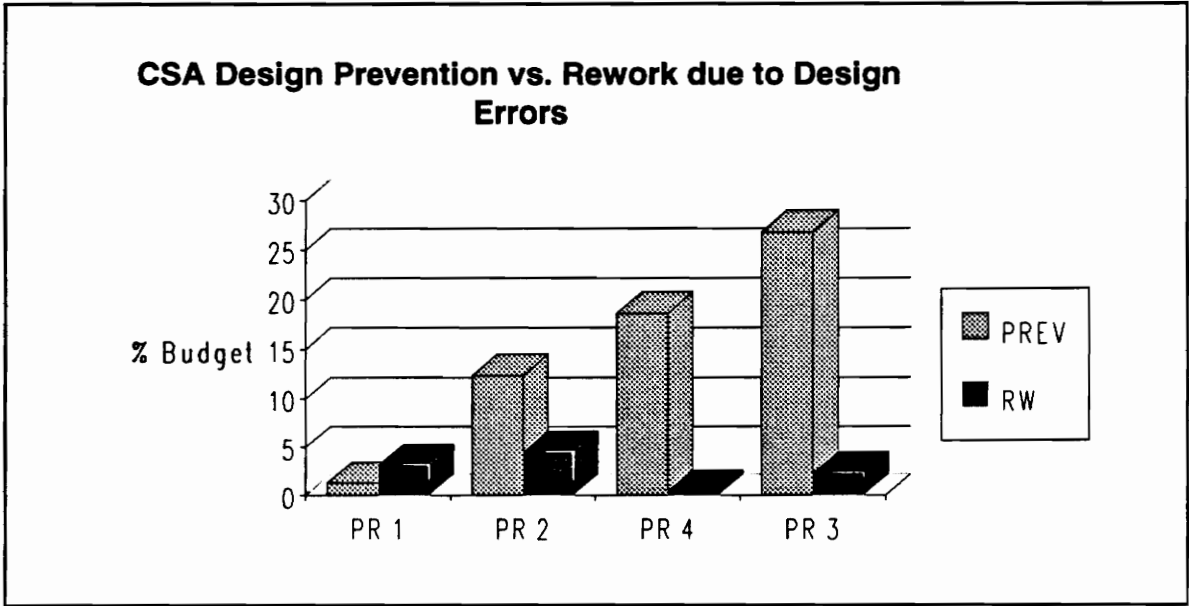


Figure 4.14: Civil/Structural/Architectural Design Prevention versus Design Error Rework Occurring in the Construction Phase.

The results of the rework differences are shown below in Table 4.29.

Table 4.29: Testing for Regression Slope of the Civil/Architectural/Structural Discipline Rework Based on the Natural Order of Quality Management for Hypothesis 2.

(i,j)	$D_j - D_i$	$c(D_j - D_i)$
(1,2)	1.611523	1
(1,3)	-3.0589	-1
(1,4)	-2.39929	-1
(2,3)	-4.67043	-1
(2,4)	-4.01081	-1
(3,4)	0.659615	1

$$C = \sum_{i < j}^4 c(D_j - D_i) = -2$$

$$T = \frac{2 \times C}{N(N-1)} = \frac{2 \times -2}{4 \times 3} = -.3333$$

$$P_0\{C \leq k\} = .375$$

Because $P_0 = .375$ is greater than $\alpha = .05$, the statistical test is not significant, and it is not possible to reject the null hypothesis. Because Project 3 experienced a higher percentage of rework than Project 4, it influenced the lack of significance in the test.

2.2.9 Hypothesis 2 Discipline Summary

A summary of all the discipline results for the second hypothesis are shown below in Table 4-30.

Table 4.30: Discipline Summary for Hypothesis 2.

DISCIPLINE	$C = \sum_{i < j}^4 c(D_j - D_i) =$	Kendall's Tau T	$P_0\{C \leq k\} =$
Electrical	-2	-.3333	.375
Instrumentation	0	0	.625
Mechanical	-2	-.3333	.375
Piping	-4	-.6667	.167
Tanks & Vessels	-4	-.6667	.167
Civil/Arch/Structural	-2	-.3333	.375

Because the P_0 's are greater than $\alpha = .05$, the results of the statistical tests were not significant, and it was not possible to reject any of the null hypotheses based on this methodology.

DISCUSSION OF RESULTS

CHAPTER FIVE

As this research cycled through the scientific method, it began with describing the insidious problem of rework in construction that has been a plague throughout the industry. The research continued through the scientific method by aggregating data gathered by the Construction Industry Institute, so that the problem could be studied. The hypotheses were determined and analyzed, and for the scientific method to go through its recursive method, this section of the research will discuss the conclusions of this research and chapter six will describe how the scientific method could be applied in the future. This process of scientific investigation is crucial for learning, because through science, knowledge is gained by systematic observation, experiment, and reasoning (Frederick Taylor, 1912).

5.1 Discussion of Hypothesis 1: Prevention/Appraisal Activity has a negative correlation with rework.

The project-level analysis for hypothesis had a correlation equal to -0.6667 , as determined in section 4.1.1. The graph displayed in Figure 5.1 shows that Project 4 had a slight increase in rework over Project 2, even though it had a higher percentage of quality management. Although the correlation can't be described as statistically significant, in practical terms, three out of the four projects experienced a decline in rework, indicating that the prevention/appraisal activity are having some effect on rework.

With only four data sets, the statistical test isn't very powerful. In section 5.3, there is a detailed explanation of how increasing the number of data sets directly influences the power of the test. Project 4 had a slight increase in the percentage of rework as compared to Project 2. Unfortunately, the way the statistical test works with only four data sets, having one project out of sequence significantly impacts the results of the statistical test. With only four data sets, it is necessary to have a perfect sequencing of the

projects for the test to be significant. Therefore, it is fairly difficult to reject the null hypothesis and a strong potential for committing a Type II error¹ due to the lack of power in the test.

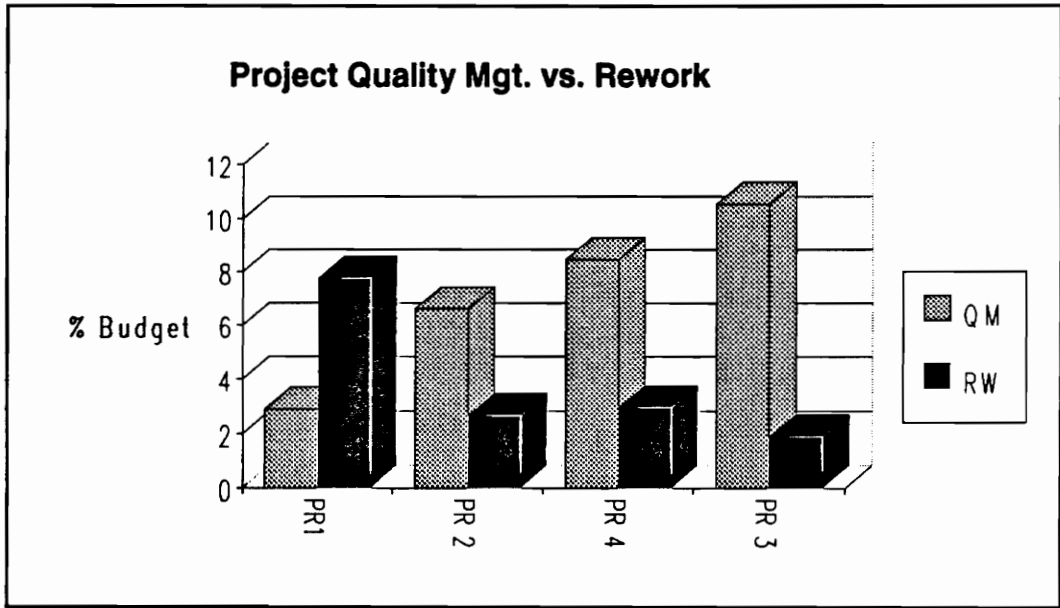


Figure 5.1 Project Quality Management versus Rework

With more data sets, the correlational study could have projects out of sequence, but the increased number would allow the total to average out. For example, Chauvel and Andre's (1985) study, as discussed in chapter four, had a data set of $n = 54$ giving their test more power. They were able to conclude a much stronger correlation, even though many of their data fell out of sequence. It was the overall combination of all the data forming the regression line that allowed them to determine the relationship.

As for the discipline analysis, instrumentation, tanks and vessels, and civil/architectural/structural each had the same correlation equal to -0.6667 as the overall project. The other disciplines had weaker correlations or no relationship at all. An interesting comparison was that Project 4 was out of sequence for each of the disciplines. Project 4 experienced a slightly greater percentage of rework for each of these disciplines,

¹ A Type II error involves failing to reject the null hypothesis, when it is in fact false.

influencing the lack of significance for the statistical test. It would be erroneous to draw any definitive cause-and-effect relationship why Project 4 fell out of sequence; however, one could speculate that there was evidently some difficulty that occurred and influenced the amount of rework. However, this is only speculation. The variation between the disciplines due to uniqueness of each project seemed to have a greater influence on the results at the discipline level. Section 5.3.3 further discusses this situation.

5.2 Discussion of Hypothesis 2: Prevention activity occurring in the design phase of a project life-cycle has a negative correlation with rework due to design error in the construction phase.

The project-level analysis for hypothesis had a correlation equal to -1.0, as determined in section 4.2.1. The graph displayed in Figure 5.2 shows that all four projects experienced a reduction in rework due to design errors as the prevention activity in the design phase increased. The correlational test is statistically significant, although with only four data sets being used it is difficult to make generalizations. However, the practical application can be interpreted that four out of the four projects experienced a decline in rework as the prevention activity in the design phase increased.

With only four data sets, there is limited power to the test. With only four data sets, it is necessary to have a perfect sequencing of the projects for the test to be significant. If only one project fell out of sequence, the test would no longer be significant. In section 5.3, there is a detailed explanation of how increasing the number of data sets directly influences the power of the test.

The study of the relationship between prevention in design and rework in construction due to design errors successfully demonstrated that prevention activity is effective in reducing rework. This research is the first to use the QPMS data to demonstrate that spending time during design on prevention activity will help eliminate rework from occurring. The significant correlation indicates that using resources to check

operability and constructability of the design, will lead to a reduction in the rework occurring in the construction project.

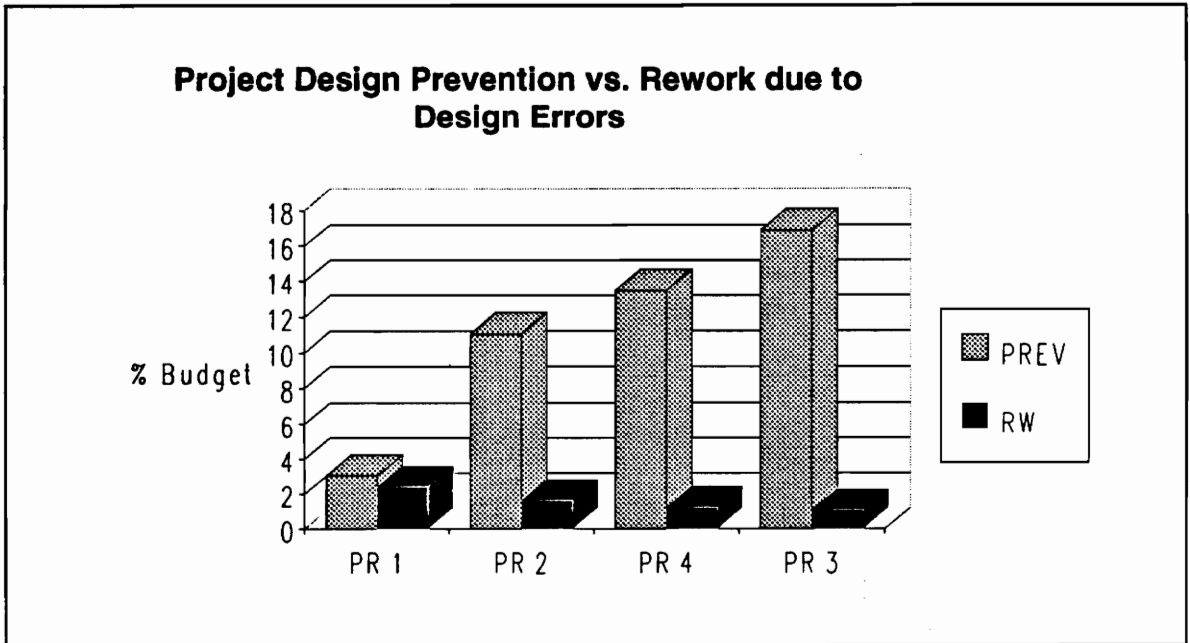


Figure 5.2 Project Design Prevention versus Design Error in Construction

With more data sets, the correlational study could have projects out of sequence, and it would be more appropriate to generalize to other projects. The p-value of the test was .042 which was less than the level of significance $\alpha = .05$; however, as noted earlier, this changes significantly by altering just one project. If there were more data sets, the conclusive evidence would be more substantial. It is still promising that four out-of-the four followed sequence.

As for the discipline analysis, tanks and vessels, and piping each had the same correlation equal to -0.6667. The other disciplines had weaker correlations or no relationship at all. Each of the disciplines had at least one project fall out of sequence, and, thereby, influenced the lack of significance in the statistical test.

5.3 Other Variables Affecting the Results of the Statistical Test

There are several variables that could have influenced the results of the statistical test. As with many issues of quality improvement, the external parameters can have a significant effect on how the components of the study work together.

5.3.1 All Projects Had Less Rework Than The Industry Average

According to the Construction Industry Institute study (Source Document 29), the average rework on a construction project is 12.4%. Each of the projects studied by this research had a significantly smaller percentage of their budget spent on rework than the industry average. Compared to this industry average, there was a reduction in rework with the increased use of quality management. Even though there is no guarantee that spending a higher percentage on quality management will continually lower the rework percentage, these projects were successful in bringing their average below the industry's percentage.

5.3.2 The Impact of Increasing the "n" on Statistical Power

The power of a test is defined as the probability of rejecting the null hypothesis when it is false (Siegel, 1988).

There are two practical ways of increasing the power of a statistical test: 1) decreasing the variance, and 2) increasing the number of data sets "n". The potential of reducing the variance isn't possible with this research, because of the use of previously collected data from the Construction Industry Institute. This is a dilemma of "real world" research. It is nearly impossible to run a tightly-controlled experiment (which thereby helps to reduce extraneous sources of variability and, therefore, increases the chance of reaching a correct decision) when collecting data from the real-world environment (Schulman, 1991).

Increasing "n" provides more power for the statistical test. As Schulman concluded, common sense indicates that to gather more data increases the chances of reaching the correct decision. The curves in figure 5.3 shows that for a particular test, that probability of committing a Type II error decreases as the sample size increases. Therefore, because the probability of a Type II error decreases, the power of the test increases².

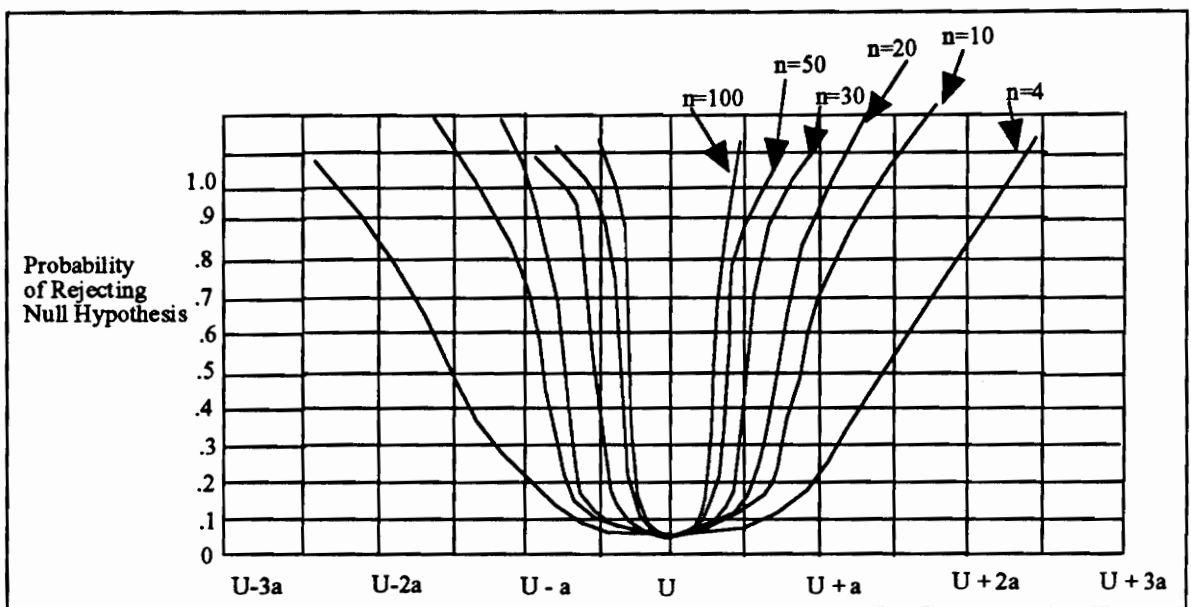


Figure 5.3: The Sample Size Influences the Power of the Test

5.3.3 Result Difficulty Due to Unique Projects

As described in the delimitation's section of this research, the probability of committing a Type II error was influenced by extraneous variables, such as unique project designs, locations, and firms doing the work. Rhodes (1972) concluded that when implementing a quality cost system, the user must recognize that the cost of quality varies with industries, companies, plants, products, and life-cycles. Based upon Rhodes'

²Note: The samples from Figure 5.3 are drawn from populations with normal distributions. However, the theory of power applies similarly for non-parametric test. The normal distribution figure was used strictly for explanatory reasons.

conclusions, it is not unusual to have some fluctuations in the expected trends, because of these different variables. As Campanella and Corcoran describe cost of quality:

Total Cost of Quality is the sum of prevention, appraisal, and failure costs. It represents the difference between the actual cost of a product, and what the reduced cost would be if there were no possibility of failure of product nor defects in its manufacture (Campanella and Corcoran, 1983).

Due to the uniqueness of each project and a greater uniqueness among the disciplines, there is variance in the probability for rework. Table 5.1 displays the discipline percentages of their project's total budget. This table shows the differing percentages among the disciplines that increases the internal variability of a project. The overall projects' trends appear to negate the biases created within the specific disciplines.

Table 5.1: Different Discipline Percentages Of The Total Budget.

	Project 1	Project 2	Project 3	Project 4
Piping	.44	.31	.32	.25
CSA	.16	.23	.13	.21
Electrical	.13	.05	.12	.08
Instrumentation	.07	.09	.06	.105
Mechanical	.015	.04	.06	.04
Tanks & Vessel	.03	.08	.06	.045

They also concluded that increases in expenditures for prevention and appraisal will not show immediate reductions in failure costs because of the time lag between cause and effect. Different projects will have different relationships between the cause-and-effect relationships. For example, if the design of one project was significantly more complex than another, this may influence the amount of rework occurring. Taguchi claims that a significant parameter to consider in design is the constructability of the design.

Complexity of the project was not studied by this research, but it could have played a major role in influencing the project's cost of quality.

5.3.4 True Cost of Rework Actually Greater than the Numbers Show

The true cost of quality is greater than what QPMS tracks. No matter how accurate QPMS becomes, it is impossible to track all of the costs that occur as the result of bad quality in design and construction. Deming states that it is impossible to judge the negative impact of an unhappy customer spreading the word of poor service received from an organization. There are too many hidden costs that the measurement system can't pick up such as schedule delays, litigation fees, the full cost of a poor design. These parameters must be considered when management is making decisions to allocate resources for the reduction of rework (Forker, 1991). Management's understanding that the actual cost of quality is greater than what has been determined should be used to guide future efforts to reduce rework.

5.3.5 Cost of Quality Just a Scoreboard.

By developing QPMS, the CII Management Task Force has provided managers the ability to track some form of quantitative measurement of quality in every segment of the construction industry (CII Source Document, 30). The objective is to provide a reference point for management to improve their decision-making information (Kurstedt, 1990). In the past, management had only a hunch about the amount of money being spent to obtain a quality product. They had no real idea regarding the actual extent of rework. With properly designed cost of quality programs, management can make better decisions about reducing the cost of their rework (Campanella and Corcoran, 1983).

An important rationale when considering the results of this analysis is that quality costs are merely a scoreboard reflecting actions that have previously taken place. The cost of quality does not correct itself, but, instead, should be used to direct future improvement efforts. The amount of time the organization has been using cost of quality will impact the cost of quality levels in that organization.

5.3.6 Organizational Learning Life Cycle

If an organization had progressed down the learning curve of performance improvement, this would influence its cost of quality. The percentage of their budget spent on both quality management and rework would be less than an organization just beginning a continuous improvement program. The significance of this conclusion is based on the fact that each organization's appropriate cost of quality is unique to itself. The percentage an organization needs to spend on inspection depends on the capability of its processes and whether or not they (processes) are in-control (Ridgon, 1990). The element of process control of course has direct implications to the amount of rework.

As Campanella and Corcoran conclude: "It should be obvious that increases in expenditures for prevention and appraisal will not show immediate reductions in failure costs because of the time lag between the cause and effect." The movement to use prevention to lower cost requires a leap in faith, and measuring the cost of quality helps to provide the diving board (Sullivan , 1986).

As indicated in section 2.4.1.2, the amount of prevention, that has progressed throughout the organization significantly impacts the cost of quality. Chauver and Andre (1985) concluded that the cost of quality typically is 10-20% of sales in the United States versus 2.5 to 4.0% in Japan. If an organization has systematically removed many of the causes of variation, this organization does not need to spend as many resources to prevent rework as an organization on the brink of chaos. Unfortunately, the methodology used by this research did not consider this learning curve variable. Essentially, an organization could have taken great strides on previous projects to study the impact of parameter variation in design, and, therefore, would not need to spend much energy now. This organization would be producing a high quality output without having to spend large percentages of their budget. Hypothetically, if the organization were able to transfer the learning from previous projects to this project, the cost of quality should be lower.

5.4 The Most Important Issue is How Cost of Quality is Used for the Future

The most important thing about the prevention and appraisal cost is not the total cost, but the way the money is used (Campanella and Corcoran, 1983). As concluded by Juran (1991), the reduction of quality cost is not an end in itself, it is the means to an end. For long-term improvement of profitability, management must focus on the things that lead to the cost of quality (Israeli and Fisher, 1991; Karabastos, 1989). Continued use of cost of quality data help to reveal the gold mines of opportunity for the organization (Lenane, 1986).

As discussed in section 2.4.3.4, cost of quality information should be used to provide management with a reference point to help them improve their decision-making ability for use on future quality efforts. Although this research focused on studying the relationship between increased quality management expenditures with reduced rework, the most important issue is how those quality management efforts are used in preventing rework from occurring.

5.5 The Future Significance of Prevention

As indicated in section 5.3, the amount of prevention learning that can be transferred from former projects to strengthen the design of current projects is a critical task for success. It is better to prevent a disease from happening in the first place than it is to work at always curing the disease (Chauvel and Andre, 1985).

The organizations must see the synergistic approach of gathering the cost-of-quality information and using this information to guide prevention improvements for future design efforts. Management's continued use of this information should help it progress through the Shewart Plan-Do-Check-Act cycle. Over the long-term, this will enable the construction industry to continue providing its customers with higher quality outputs at more affordable cost. The cost over the long-term will be reduced, because the consumer will no longer have to pay for rework that has become built into the system.

5.6 Using Quality Improvement to Better Society

The philosophical approach to company-wide quality control takes quality control technology into the humanistic stage and deploys the "voice of the customer" throughout the company and mobilizes all employees to focus on continued quality improvement at lower cost (Sullivan, 1986). When using Taguchi's interpretation that the cost of quality should be measured as the loss to society, the purpose of quality improvement has a new responsibility.

The ideal future goals for an organization would be to begin working for its own improvement through the use of cost of quality data and problem-solving methods. As the organization begins to optimize its own system over time, it then progresses to continually improve its surrounding environment through the use of its quality-improvement technology. The organization's improvement efforts begin acting as a catalyst for the improvement of society as a whole.

Over the long-term, an organization's improvement efforts will be measured by its contribution to society. As Sullivan concluded, working for continued improvement of quality involves the ever-present subliminal reference to the quality of society, the quality of industries, the quality of the national economy, and the quality of world trade. We should recognize our failure to reach this potential as an opportunity for future improvement and growth. Peter Senge describes how failure should be used for continued learning:

Failure is, simply, a shortfall, evidence of the gap between vision and current reality.

Failure is an opportunity for learning about inaccurate pictures of current reality, about strategies that didn't work as expected, about the clarity of the vision. A mistake is an event, the full benefit of which has not yet been turned to your advantage (Peter Senge, 1991, p.154)

FUTURE RESEARCH AREAS

CHAPTER SIX:

Leedy (1989) emphasized the academic axiom that research begets research, because complete research should generate more questions than it answers. The iterative nature of this process causes the researcher to reflect how the study should be continued in the future. This reflection includes what could have been done differently to change the outcome of results and what are new areas that were not considered for their significance previously.

6.1 The Established Level of Significance

One thing that could have been done differently with this research would be to change the practical level of significance. According to Siegel, the common values of the level of significance are $\alpha = .05$ or $.01$. However, since the probability of α enters into determining whether H_0 is or is not rejected, the level at which the researcher sets α should be determined by the importance or possible practical significance of the result.

For example, in conducting testing for potential brain surgery patients, the efficacy of a stringent level of significance is very apparent. However, for the purposes of this research, it may have been practical and correct to recognize a relationship when three out of four projects were in the proper sequence. I could have discussed this situation with my faculty committee prior to my proposal defense to seek their opinion on the subject. For present practical purposes, I did include the actual probability level associated with the obtained results, therefore, allowing the readers the opportunity to use their judgment in deciding whether or not the null hypothesis should be rejected (Siegel, 1988).

6.2 Analyze the Hypotheses with an Increased Sample Size

As indicated in section 5.3.2., the sample size of this research had an impact on the statistical power of the testing methodology. Chauvel and Andre's study in 1985 obtained significant results on determining a relationship between quality management and the reduction of rework. I strongly believe that if there were a larger sample size, the p-value determined by the statistical test would have consistently been more significant.

Future research efforts should conduct this study again using a larger data size. This is a feasible endeavor, because companies continue to pursue future efforts using the Quality Performance Management System (QPMS).

6.3 Case Studying Using Cost of Quality to Guide Improvement

There needs to be continued research on how cost of quality can be used to guide improvement in the construction industry. A probable area for future research efforts would be to conduct case study research analyzing organizations that have tracked their cost of quality through several projects. This research would describe how organizations use the cost of quality information as a reference point to improve the quality of their design.

The purpose of this descriptive study would be to determine how an organization could transfer the learning from one organization to another. Once this information was captured, the process of transferring learning from one project to another could be improved to ease the transition. Other organizations could then begin using this approach to help guide their improvement efforts.

6.4 Continue to Study the Impact of Prevention Techniques

Prevention activity, as demonstrated by the results of the second hypothesis, has the greatest impact on reducing rework. However, there is a time lag between when the prevention activities occur and when their benefits are received. More empirical evidence

is needed to demonstrate the importance of prevention. Prevention activities require an up-front investment. Future research that continues to demonstrate the positive impact of prevention activities will help to encourage the project stakeholders to make that up-front investment in prevention. The construction industry could benefit from the empirical evidence that supports the "Pay to prevent it now or pay a lot more later."

Unfortunately, there has not been a lot of research in the construction industry giving empirical evidence supporting the importance of prevention activity in real-world projects. The collection of the QPMS data by Bill Ledbetter is one of the first attempts to gather real-world information about the cost of quality in the construction industry. Studies on prevention activities need to be continued, because the results are often hidden. For example, if you prevent the rework from happening, it could be easy to forget about something that never occurred. However, if prevention doesn't occur, the construction project could get into serious problems. One only has to remember incidents such as the Hyatt Regency disaster or Three Mile Island to consider the seriousness of the problem. The unfortunate thing about most rework is that it is preventable.

6.5 Determine How Team Building Between All Project Stakeholders Influences Cost of Quality

Because there are so many stakeholders involved in a construction project, it gives reason to believe that the quality of the project is influenced by how well these groups work together. Often due to the amount of litigation in today's society, there can be an increased amount of tension between all of the parties involved in the construction project. This tension obviously has an adverse effect on how well people work together.

The intent of all the stakeholders should be to optimize the performance of the project and consider the long-term benefits to all parties involved. Research should be conducted to determine how the goals of all the parties involved can be oriented toward a successful project.

6.6 Determine the Impact of Organizational Learning and the Relative Impact on Cost of Quality

As discussed in section 5.3.6, the stage of a company in terms of its organizational learning, could influence the cost of quality. Research should be conducted in the future to determine how the level of the organization's progress in its continuous improvement efforts influences the cost of quality. This research would help provide management with a reference point to encourage continued emphasis in quality improvement efforts. If a relationship could be determined between the extent of an organization's learning development and its overall success, it could help promote future endeavors.

6.7 Polynomial Regression

This research studied the amount of prevention occurring in design and its relative influence on the reduction of rework due to design errors in the construction phase. Future research studying the life-cycle variable of quality management could attempt to define the quality management throughout the project life-cycle by using polynomial regression.

Polynomial regression attempts to model the curve using polynomial equations. Each project has a unique spending pattern throughout the project's life-cycle. This modeling technique involves determining a polynomial model that fits the budgeting curve. Research using this method would be fairly complex, because it would involve using multiple order variables capturing model the curve. This method would apply a polynomial equation giving a good fit for each of the project's unique data sets. The polynomial equation could then be compared using regression analysis (Neter, Wasserman, Kutner, 1989).

6.8 Analysis of Variance of Rework

Future research efforts should be used to study the impact of prevention and appraisal activity on reducing the variation of performance of a construction project. The reduction in variation would help construction manager make better decisions based on predictable results. If it could be shown that quality management reduces the overall variation of problem areas on the project, the construction manager could make intelligent decisions about where to focus his or her resources.

WHAT IS RESEARCH?

CHAPTER SEVEN

Yet, truth, which only doth judge itself, teacheth that the inquiry of truth, which is the love-making or wooing of it, the knowledge of truth, which is the presence of it, and the belief of truth, which is the enjoying of it, is the sovereign good of human nature. The first creature of God, in the works of the days, was the light of the sense; the last was the light of reason. Francis Bacon, 1597

7.1 Research and the Search for Truth

Through time, human man has been continually challenged in the search for truth. Philosophers, historians, religious leaders, and scientist have long debated among themselves in their pursuit of truth. Leedy (1989) states,

Research seeks, through data, to discover what is true absolutely. In a sense, research is a constant pursuit after the complete meaning of the data. Experienced researchers are constantly aware what they most ardently seek as the ultimate goal of research (Truth) is forever just beyond what is represented by the data and, hence, just beyond human grasp.

Through research lies the path to a greater expansion of humankind's knowledge. Thus lies the foundation of the scientific method for the systematic acquisition of knowledge.

Leedy interprets the scientific method as the 1) identification of the problem that defines the purpose of the research, 2) gathering of data relating to the problem, 3) positioning the hypothesis as a logical means to locate data and as an aid to resolve the problem, 4) empirically testing the hypothesis by processing and interpreting the data. Kurstedt (1991) operationally defines research as the systematic approach to the interpretation of data. However, the researcher must realize that even though new

knowledge is discovered about certain relationships, the research will never uncover the complete truth. There will always be aspects of truth that remain unknown and unknowable. Figure 7.1 shows how the systematic interpretation of data can lead to new knowledge, but the ultimate truth lies beyond the impenetrable barrier (Leedy, 1989).

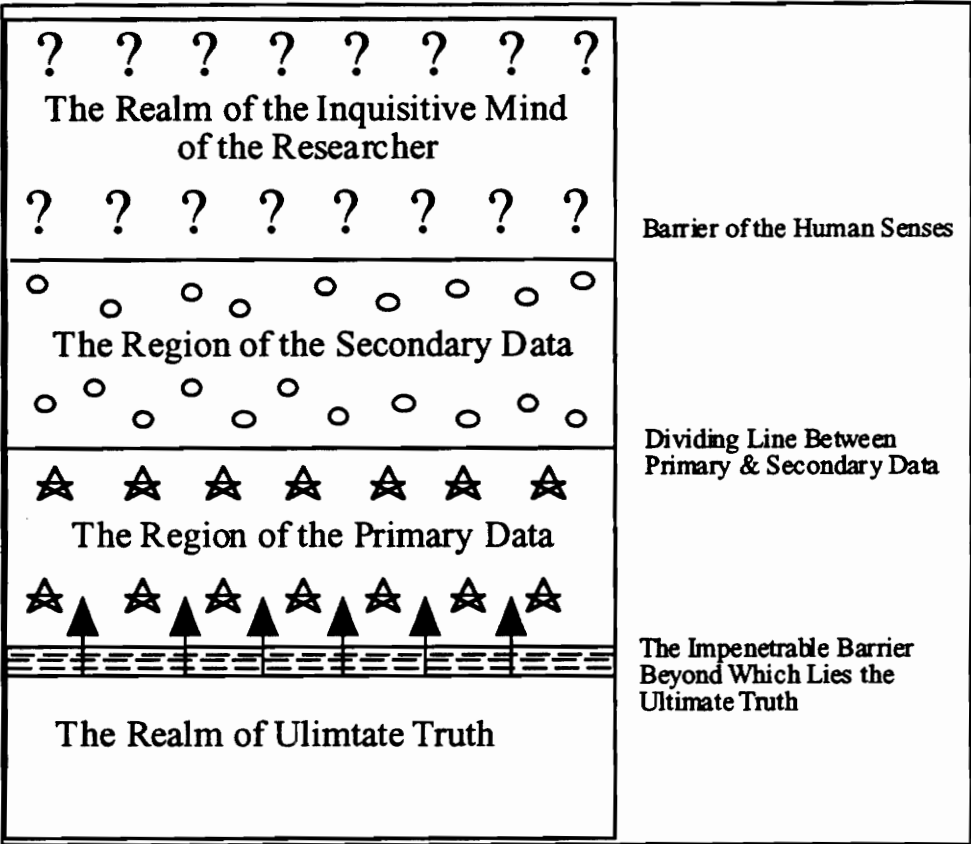


Figure 7.1: Data and the Ultimate Truth (Leedy, 1989)

Early in this century, Frederick Taylor (1915) stressed the dependency of success on science, because in science knowledge is gained by systematic observation, experiment, and reasoning. By systematic application of the scientific method, you continue to access new knowledge as you learn more about the research problem. Leedy (1989) concludes, "Every great researcher learns that genuine research creates more problems than it resolves. Such is the nature of the discovery of truth."

Leedy models the scientific method by representing the cyclical nature of research as shown below in Figure 7.2. However, Leedy believes research is more like a helix than a circle, because the research is never conclusive. Following the metaphor of the helix spiraling upward, research studies and resolves one problem and then develops additional problems needing resolving. The helix exemplifies the fundamental principle that research begets research.

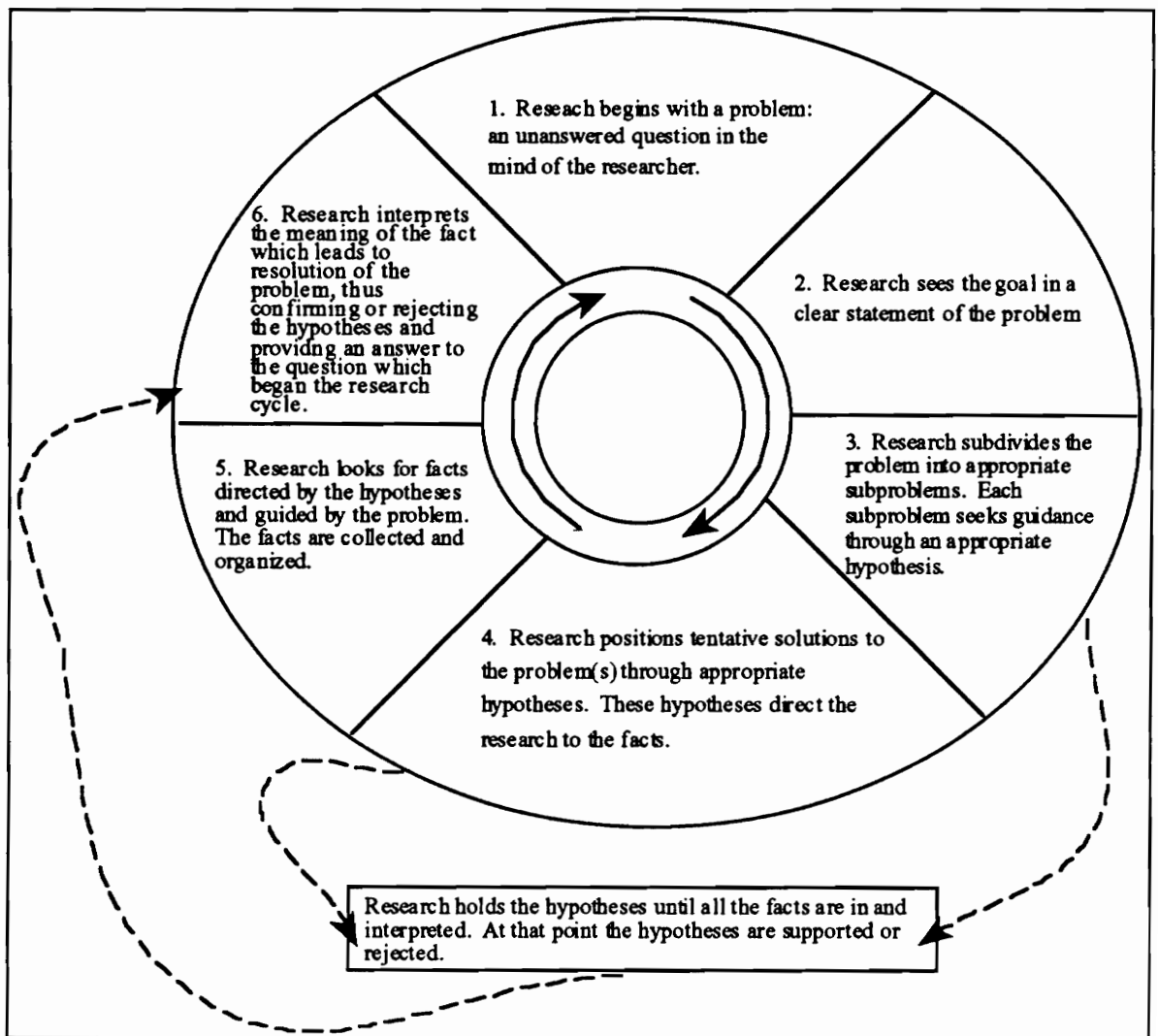


Figure 7.2: The cyclical nature of research (Leedy, 1989)

7.1.1 Deductive and Inductive Reasoning

Research begets research by complementing deductive reasoning with inductive reasoning. In essence, as deductive reasoning uses analytical techniques to test the hypothesis, inductive reasoning uses synthetic techniques to form generalizations into theories. Wallace (1971) interprets deductive reasoning as transforming theories into new hypotheses. The deductive reasoning continues as the hypotheses are transformed into new observations of the proposed theory. Inductive reasoning synthesizes the observation as an empirical generalization. The empirical generalizations are then synthesized into a theory and thus again commences the application of deductive reasoning. This ongoing relationship between deductive and inductive research is modeled below in Figure 7.3.

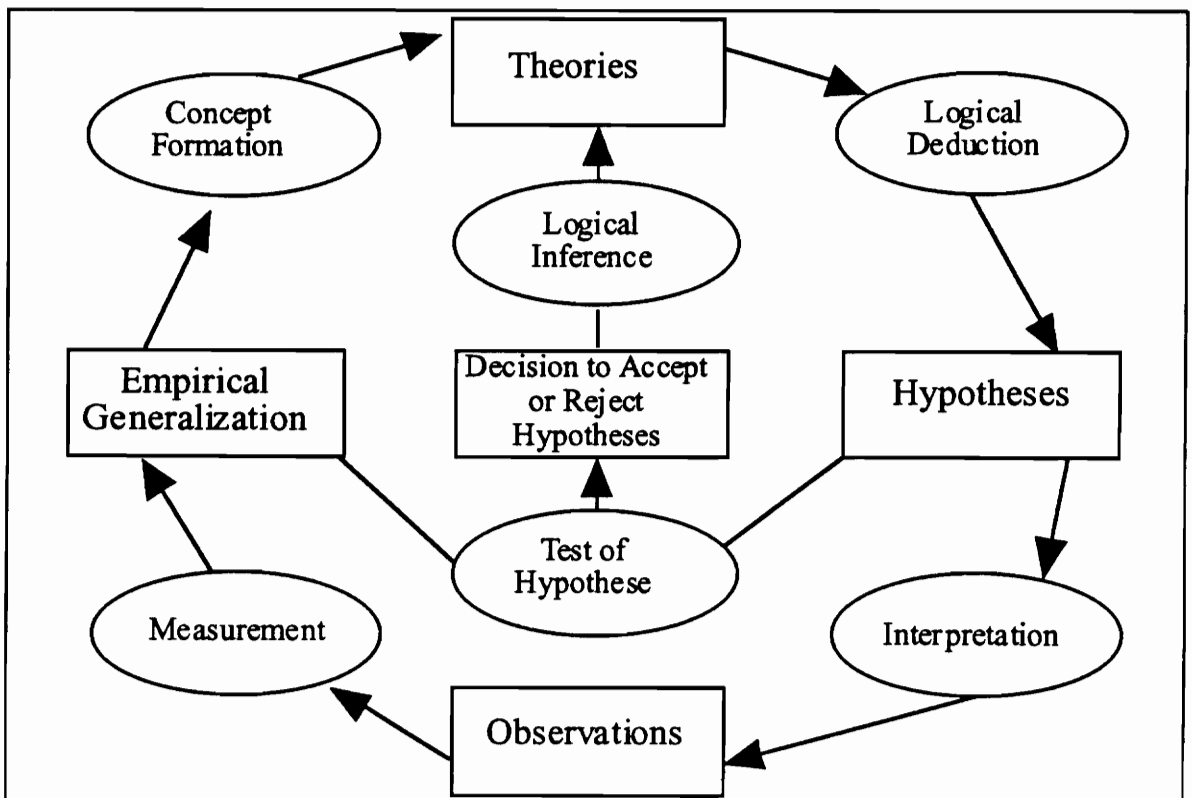


Figure 7.3: The Wallace Wheel Complementing Inductive and Deductive Reasoning

Wallace describes the cyclical nature of research as the never-ending manifestation of exploring a given phenomena followed by the testing of the hypothesis resulting in new areas of exploration. The continuous cycle of expanding research on the previous research questions generates a greater refinement of the research purpose.

7.1.2 The Significance of the Research Purpose

The Research Purpose can be interpreted as "Why" the researcher is conducting the study. The purpose is viewed as the global, over-riding reason behind the research (Management System Laboratories, 1991). The researcher must understand the research purpose to narrow the scope and focus the research question. Patton (1990) believes the research purpose to be the controlling force, because decisions about design, measurement, analysis, and reporting evolve from the purpose. Patton's typology of research purposes shown below in Table 7.1 demonstrate the centrality of the purpose in guiding research.

Table 7.1: A Typology of Research Purposes (Patton, 1990)

Types of Research	Purpose	Focus of Research	Desired Results	Desired Level of Generalization
Basic research	Knowledge as an end in itself; discover truth	Questions deemed important by one's discipline or personal intellectual interest	Contribution to theory	Across time and space (ideal)
Applied research	Understand the nature and sources of human and societal problems	Questions deemed important by society	Contribution to theories that can be used to formulate problem-solving programs and interventions	Within as general a time and space as possible, but clearly limited application context
Summative evaluation	Determine effectiveness of human interventions and actions	Goals of the intervention	Judgments and generalizations about effective types of interventions and the conditions under which those efforts are effective	All interventions with similar goals
Formative evaluations	Improving an intervention: a program, policy, organization, or product	Strengths and weaknesses of the specific program, policy, product, or personnel being studied	Recommendations for improvements	Limited to specific setting studied
Action research	Solve problems in a program, organization, or community	Organization and community problems	Immediate action; solving problems as quickly as possible	Here and now

These classifications are not hard-and-fast lines of demarcation between these types of research. The continuum ranges from highly action-oriented research aimed at solving immediate problems in a short time-frame to very basic research aimed at theory development and knowledge for the sake of knowledge over a long-term time span. It is significant to understand variations in the purpose of research along this continuum because different purposes will lead to different approaches in the conceptualization of problems, the design of research, the types of data gathering, and the publication of results (Patton, 1990).

There are no clear lines dividing the boundaries of the continuum. How the researcher chooses to describe what is being studied and how it is to be done, in part, determines where a certain type of research fits in the continuum. It is not uncommon in the field of research for different reviewers of the same piece of research to use different labels to describe it. The critical concern is that the researcher understands the implications of the distinctions, what choices must be made, and the implications those choices have of the kind of research to be conducted and the status as a professional within the academic environment (Patton, 1990).

According to Thompson (1967), we are continually faced with a limited capacity to gather and process information. It is necessary to recognize the limited capacity to develop the most efficient and effective means to develop process of searching, learning, and deciding what to do next. Therefore, we must set limits of our rationality based on how we wish to bound the research question by the purpose we are trying to serve. Once the researcher has designated the boundaries of the rational study, he or she must select an appropriate method to secure the most information from the scope of the study.

7.1.3 Research Objective and Selection of an Appropriate Research Method

A clear and unambiguous understanding of the research objective is necessary to guide the selection of an appropriate research method. The application of an appropriate

method develops the opportunity for the research to contribute more thoroughly to the body of knowledge (Jenkins, 1985). The Research Objective can be viewed as "what" is desired as an outcome of this research. The objective is what can be learned or used from conducting the study (Management System Laboratories, 1991). Jenkins concludes the selection of an appropriate method is crucial to ensure the research contributes to the body of knowledge. He believes you must determine your research objective and orient your research methodology to meet that objective. The focus of the methods matrix is to demonstrate what particular methods can achieve when developed rigorously (Leedy, 1989). The better the selection of the appropriate method, the greater likelihood of accomplishing the research objective. These methods are displayed in Table 7.2.

Table 7.2: Matrix of Research Methods and Their Appropriate Use (Leedy, 1989)

Method	Characteristics of the Method and the Research Goals the Method Attempts to Achieve
Action Research	The approach in action research is to see if it works.
Case and Field Study Research	A type of descriptive research in which data are gathered directly from individuals (individual cases) or social or community groups in their natural environment for the purpose of studying interactions, attitudes, or characteristics of individuals or groups.
Correlational Research	A statistical investigation of the relationship between one factor and one or more other factors. Correlational research looks at surface relationships but does not necessarily probe for causal reasons underlying them.
Descriptive Survey or Normative Survey	This research method is attempts to document everything happening in a situation.
Developmental	This is an observational-descriptive type of research that usually stretches over a period of time and is frequently called the longitudinal study.
Ex Post Facto or Causal-Comparative	This research method observes existing condition and searches back through the data for plausible causal factors.
Historical	The historical research method attempt to solve certain problems arising out of a historical context through gathering and examining relevant data.
Quasi-Experimental	Quasi-experimental research is used when it is not possible to make random assignments.
True Experimental Method	This research method uses random selection and assignments for conducting the research to help improve internal and external validity.

The selected research method provides certain information, but the researcher must remember the context in which the method was chosen, used, and interpreted. These elements are part of the contextual rationality surrounding the research decision and therefore only display a piece of the entire picture. The researcher must recognize that it is only a piece of the puzzle. Peter Senge (1990) describes the need for seeing both the forest and the trees simultaneously with a parable of the three blind men and the

elephant. Each man was touching a different piece of the elephant: one was holding the trunk; the next, a leg; and the third, an ear. Each man accurately described what they were touching, but failed to see the whole elephant.

Thus lies the dilemma of research methods: each method provides us with pieces of information, but we will always be missing some of the whole picture. The researcher must recognize that the method itself biases the information generated by the study. To better understand the "whole elephant," it is necessary to both analyze and synthesize the information. The research must look closely at pieces of the whole and gather quantitative data to provide a measurable component in the research. However, the researcher must also synthesize the pieces together to understand the whole picture that is different than just the sum of the parts.

7.1.4 Qualitative Versus Quantitative Research Methods.

Clarence Lewis concluded, "The only knowledge a priori is purely analytic; all empirical knowledge is probable only." Using a qualitative method will allow the evaluator to study an area in great depth and detail. For example, to be able to approach fieldwork without being constrained by predetermined categories of analysis lends the researcher the opportunity to develop the depth, openness, and detail of qualitative inquiry. On the other hand, quantitative methods facilitates the comparison and statistical aggregation of the data. By using objective quantitative data, the research is able to give a broad, generalizable set of findings presented in a succinct and parsimonious fashion (Patton, 1990).

The quantitative method contributes to the generalizability of the data, because of the objective analysis of the numbers. Quantitative methods develop and analyze specific linear-relationships between the cause-and-effect of the research question.

However, qualitative data can provide new insights to the extraneous variables regarding the uniqueness of cause-and-effect relationships. Both forms of data are valuable, with one complementing the other. Qualitative data may help explain what the numbers do not express, and quantitative data evaluates the statistical validity of the cause and effect relationships. Regardless of how objective the method is in analyzing the data, it is impossible to remove all forms of bias from the research.

7.1.5 All Research Is Biased

O'Reilly (1983) indicates that all information is biased by the process used to acquire the information. The contextual rationality in which the information acquisition takes place is embedded in a complex environment being biased by both social structures and cognitive styles. It is impossible to remove all bias from the research, because merely doing the research affects the domain. O'Reilly concludes that even the process used to establish the required testing methodology is biased by our own beliefs in cause and effect relationships. Based on the assumption that all research is biased, it is necessary to scrutinize the chosen methodology to remove as much bias as possible. The methodology should objectively analyze the data to help form conclusive evidence of cause-and-effect relationships.

The Hawthone studies (Homans, 1941) perhaps have had the greatest impact on management theory over any single research substantiation. The impact was not from the actual research question addressed, but instead from what was learned about research in general. The researchers from this study discovered that the actual process of conducting the research influenced the results instead of being influenced from the alternative hypothesis. This study helped to demonstrate the conclusion that it is virtually impossible to completely remove the researcher from the actual research being studied. It is through the methodology that we help to establish validity, but as Brinberg

and McGrath (1985) state: "Validity is not a commodity that can be purchased with techniques." Brinberg and McGrath believe validity to be much like the ideal state ... one that is pursued, but never attained. Abraham Kaplan draws the following conclusion about the scientific method (Miller, 1991, p. 23):

"In the conduct of inquiry, we are continuously subjected to pulls in opposite directions: to search for data or to formulate hypotheses, to construct theories or to perform experiments, to focus on general laws or on individual cases, to conduct molar studies or molecular ones, to engage in synthesis or in analysis. It is seldom much help, in the concrete, to be told that we must do both. In the constraints of specific problematic situations these are genuine dilemmas. But, they are a species that have come to be known as existential dilemmas: not characteristic of some special historical situation but intrinsic to the pursuit of truth. We do not make a choice of the lesser of two evils and abide by the unhappy outcome. The problems which the existential dilemmas pose cannot be solved at all, but only coped with; which is to say, we learn to live with them. We need hard workers and empiricism, not inspiration, it is urged with good reason. But equally good reason can also be given for the converse. The fact is we need all we can get. This state of affairs is in no way peculiar to behavioral science. Its methodology, as I see it, is not different from that of any other science whatever. If this identity is contemplated in speaking of the scientific method, I warmly approve of the usage."

7.2 How I Used This Information to Conduct My Research

This research has been conducted to gain a better understanding of the rework problem occurring in the construction industry. As discussed in section 2.1.2, rework in construction is something that society pays for, not just the immediate project team. As

indicated in chapter one, this research studies the interrelationship between the cost of rework and the cost of prevention and appraisal activities.

7.2.1 This Research is a Correlational Study

The purpose of this research is to give a visibility tool to help demonstrate the relationship between prevention/appraisal activity and rework. Since this research is concerned with the relationship between two variables, quality management and rework, it is considered to be a correlational study. According to Leedy (1989), correlational research is a statistical investigation of the relationship between one factor and one or more other factors. The aim is to gain a better understanding of the relationship between the two factors of prevention/appraisal activity and rework.

7.2.2 Why I Chose To Do This Type of Research

I chose to study the relationship between prevention/appraisal activity and rework, because I believe there is a significant need to reduce the amount of rework occurring in the construction industry. I also was interested in conducting this research, because it gave me exposure to the quality management trends occurring in the construction industry. Quality management is being rigorously explored in the manufacturing industry, but this research allowed me to transfer some of the general theory to the construction industry. Therefore, I needed to be skilled at learning the specialties to quality management to the general construction industry. As with any research project, it works to answer a few questions, but also to generate many more.

LESSONS LEARNED

CHAPTER EIGHT

As a researcher cycles through the scientific method, lessons are learned about surviving the research process. The skills and discipline necessary to complete a research project are evolutionary in nature. The researcher must continually practice and refine these skills, recognizing that they will not occur overnight. This chapter highlights some of the more important lessons to assist future researchers come down the learning curve more quickly.

There is no quick-fix to conducting research. It is a very long and lonely process to define the problem, gather the data, state the hypothesis, and evaluate the hypothesis. Research is conducted to gain knowledge. If the researcher cuts corners, the knowledge acquisition process will be flawed. It is necessary to allow a significant amount of time for incubation of the material. I think too often, people try to rush through the process, and then at the end of the project their knowledge is jumbled-up instead of clear and precise.

Another important lesson about research is that nobody else will do it for you. You have to set your own deadlines and stick to them. It is very tempting to ignore your to-do list, but the consequences are severe. The work will not get done if the researcher doesn't do it, and it will be waiting to be done the next day. This is not to say that it isn't important to take a break now and then. At times, it seems impossible to write anything coherent. You might be suffering from a little burnout. It is important to give yourself a little time to enjoy life. One of the tricks I used was to set up a list of things that needed to be done each week on my research. When I had completed those items, I would give myself a reward such as going to a movie or out to dinner with friends. I would use the to-do list and the rewards to motivate myself to continue my research, but also to prevent burnout on the research.

It is important to be disciplined about doing the research. It is important to set aside time each day to work on your thesis. It is like exercise: The first day you run a mile, it is difficult. But, each day it becomes a little easier, and before long, it becomes a natural process in your day. However, if you skip too many days, you will have to backtrack, and it will be painful to get back into the swing of things. As with exercise, it is important to pace yourself, and carefully determine how much you can do each day. Recognize that you can't write a thesis in a day, but that it takes a long, disciplined approach to accomplish the task.

As you begin the research process, it is very important to narrow the scope of your research project. You must recognize that you will not be able to solve all of the problems in the world with your research. Instead, concentrate on the problem you have chosen and concentrate on defining it in specific terms that you can use to conduct your study. You must also recognize that delimitations of your research, or those factors that it is not going to study. This will assist you in getting a firm grasp of the phenomenon you are attempting to study.

It helps to break your research into pieces and focus on one at a time. As with any large project, the thesis is too big to tackle all at once. It needs to be broken into sections that are manageable, and then at the end, you concentrate in pulling together all of the pieces. If you try to do too many pieces at one time, you will be overwhelmed and not be able to accomplish anything well. I found it valuable to take each piece and determine what I was trying to accomplish by writing that section. Once this was accomplished, it seemed much easier to pull it all together.

It is valuable to conduct a pilot study of the data. I found that after I manipulated the data the first time, I needed to change how I aggregated the data to get the information I needed. Cycling through the data manipulation in the pilot study enables you to see what your results are going to look like, and enables you to make any necessary

changes. By doing this step, I was able to further refine my approach and gain better results.

Finally, the last piece of advice regarding the research process is to use the talents of each of your committee members in guiding your research. I found that when I was struggling with a certain concept it often helped to go talk to different members of my committee for advice. You choose your committee to use their talents to assist you in conducting your research, and letting them help you work through problems is a valuable aspect to ensuring a successful project.

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APPENDIX A
Operational Definitions

Tables 1, 2, and 3 are QPMS operational definitions taken from Ledbetter and Wolter (1992, pp. 18-22).

Table 1: Prevention/Appraisal Activities:

Quality Systems	<p>The activities of managing and performing the Quality Performance Management system on the Project</p> <ul style="list-style-type: none"> - Quality System/Program/Manual Development - Quality Orientation Studies/Seminars/Training - Team Building Exercises/Seminars - Client quality Planning Meetings - Quality Performance Reporting
Supplier Qualification-	<p>Activities to investigate and evaluate suppliers, vendors, contractors, subcontractors to assure that they will be able to perform if awarded a contract.</p> <ul style="list-style-type: none"> - Vendor Pre-qualification - Supplier Reviews/Ratings
Personnel Qualification/ Training	<p>Testing personnel to perform work to specified quality standards. Training to perform quality activities.</p> <ul style="list-style-type: none"> - Craft Certification - Personnel Training for Quality Assurance and Quality Control Activities
Expediting	<p>Activities with suppliers and vendors before they have delivered their product or service to assure they will on schedule and as specified</p> <ul style="list-style-type: none"> - Long Lead Equipment Planning - Expediting 3rd Party Engineering Information - Expediting Client Purchased Material/Equipment/Services
Operability/ Safety/Value Reviews	<p>Activities performed to evaluate the operability, safety, or value of the design to determine if it complies with client industry and government requirements</p> <ul style="list-style-type: none"> - Process Hazards Analyses - Operability Reviews - Maintainability Reviews - Safety Analyses - Value Engineering Studies - Start-up Sequencing

Constructability Reviews	<p>Activities to appraise that the design enables the most efficient construction methods to be used and to appraise that planned construction methods are most efficient</p> <ul style="list-style-type: none"> - Dewatering Studies - Prefabrication/Pre-assembly Studies - Rigging Studies - Standardization Studies - Construction Site Layout Studies
Examination-Internal	<p>Inspecting, testing, observing, checking and reviewing products/services already produced internally for the purpose of determining whether or not they meet the requirements</p> <ul style="list-style-type: none"> - Interdiscipline Check/Review - Formal Design/Drafting/Document Review - Quality Control Testing of Internal Work (Concrete testing, Soil Testing, Weld S-Ray, Hydrotesting Pipe, Site Loop Testing, Equipment Alignment Checks)
Examination-External	<p>Inspecting, testing, observing, checking and reviewing products/ services produced externally to determine if they meet requirements.</p> <ul style="list-style-type: none"> - Shop inspection - Field QC Inspections by External Groups - Third Party Design/Construction Reviews - Vendor Document Reviews - Receiving Inspection of Materials and Equipment

Table 2: Rework Causes

Owner Change	Client change to a requirement after some work has been performed (may occur during design, construction, or start-up)
Design Change	A change made by the designer in the design of a product or process. This change may occur during design, construction or start-up. Often, the change results in improved value and operability of the product or process, or is the result of "out-of-sequence" work. But, if rework results, the costs of the rework need to be measured.
Vendor Change	A change made by the vendor to a purchased product or to its interface with the project. This change may occur during design, construction or start-up. Often, the change results in improved value and operability of the product or process. But, if rework results, the costs of the rework need to be measured.
Construction Change	A change made by the constructor on a product or process. this change may occur during design, construction or start-up of a project. Often the change results in improved constructability, value or operability of the product or process. But, if rework results, the cost of the rework need to be measured.
Design Error	A error or omission made by the designer of a product or process. This rework may occur during the design, construction or start-up of a project.
Vendor Error	An error or omission made by the vendor furnishing a product for the project. This rework may occur during the design, construction or start-up of a project.
Construction Error	An error or omission made by the constructor on a product or process involved on the project. This rework may occur during the construction or start-up of a project.

Table 3. Discipline Breakdown

Project Services	Purchasing, expediting, project management, project controls, materials management, general staff, site construction management, services, procurement activities
Project Engineering Management	P&ID's, Line Designation Tables, PFD's, General Specs., etc. Project management, home office management, cost/scheduling/project services, materials management, document control, purchasing, clerical
Process Engineering	P&IDs, PFD's, process data sheets
Tanks, Vessels, Exchangers	Boilers, pressurized vessels, tanks, columns, silos, exchangers, condensers, reactors
Instrumentation	Automation and control, control systems, control components
Piping	Piping materials, manholes, catchbasins, valve boxes models
Structural	Structural steel and wood, walkways, bridges, handrails, stairs, decking
Electrical	Conductors, support devices, power generation and transmission, lighting, conduits, special systems
Civil	Stabilization, paving, concrete (including reinforcement and formwork), foundations, site activities, demolition
Architectural	Ornamental metal, masonry, rough and finished carpentry, doors windows, painting, flooring, woodwork, finishes, furnishing, protection systems
Mechanical	Mechanical systems such as cranes, pumps, machinery, conveyors, filters

Exogenous Variables: Those variables considered to be outside the scope of this research.

Total Installed Project Cost: The overall cost of a completed construction project.

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Industrial Engineer, IBM. Poughkeepsie, NY 1989

- Implemented analytical techniques to determine competitiveness of IBM suppliers. Evaluated suppliers based on efficiency, reliability, quality, timeliness, service, and growth potential.
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