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The relationship between quality and quality cost for a manufacturing company

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Abstract *This paper examines the components of quality cost (internal failure, external failure, appraisal cost, and prevention cost) in the context of two key manufacturing inputs, materials and machines; the concept is also explained for the company as a whole. The purpose of this research is to analyze the variables that impact quality in a manufacturing environment. There are three major findings in this research. First, there is an inverse relationship between appraisal cost plus prevention cost and failure cost. Second, the relationship between appraisal cost plus prevention cost and quality is positive. Finally, failure cost is negatively correlated with quality. This analysis also revealed a strong relationship between appraisal cost plus prevention cost and quality for material input, machine input, and the company. The results indicate that as the appraisal cost plus the prevention cost increases, quality improves and failure cost decreases.*

Introduction

In general corporations exist to provide goods and services for the benefit of mankind. The opportunity to make a profit is the incentive for doing so. How much profit is made is a measure of how well the company is doing its job. To achieve the goal of profit maximization, a company must commit to producing its products or services at a continuously lower cost, thereby enchancing the opportunity for increasing market share. The quality cost system concept can be applied to improve productivity. There is a need for an analytical framework that explains the relationship between quality cost components and quality (appraisal cost plus prevention cost and failure cost; appraisal cost plus prevention cost and quality; and failure cost and quality). Once these relationships are defined and clearly understood, the ability of an organization to make decisions related to improving quality, reducing quality costs and increasing productivity will be substantially enhanced.

Over the past two decades, the concept of "quality cost" has been widely studied and discussed in numerous literature including Crosby (1983 quoted in Campanella, 1987a, pp. 95-7), Plunkett and Dale (1986, 1987, 1988), Grimm and

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Fox (1986 quoted in Campanella, 1987a, pp. 409-19), Campanella (1987b), Feigenbaum (1991), Carr (1992), Gray (1995), Diallo *et al.* (1995), Johnson (1995), Willis and Willis (1996), Harrington (1980 quoted in Grimm, 1987, pp. 397-412) Harrington, (1987, 1999), Robinson (1997), Shah and Fitzroy (1998), Gryna (1999), Dale (1999), Dale and Plunkett (1999), Campanella (1999) and Griffith (2003).

The cost of quality is generally classified into four categories: prevention, appraisal, internal failure and external failure. Prevention cost is all of the costs expended to prevent errors from occurring in all functions within a company. They include quality planning cost, new product review cost, process control cost, quality audit cost, supplier quality evaluation cost and training cost. Appraisal cost is the cost incurred to identify poor quality products before shipment to customers. Appraisal costs normally include incoming inspection and testing cost, in-process inspection and testing cost, final inspection and testing cost, accuracy of test equipment cost, inspection and testing of materials and services cost and evaluation of stock cost. Internal failure cost is the cost associated with defects when found before shipment of the product to the customers. Internal failure costs include scrap cost, loss cost, rework cost, failure analysis cost, 100 percent sorting inspection cost, reinspection and retesting cost and downgrading cost. External failure cost is the costs that are associated with defects that are found after shipment of the product to the customers. They may include warranty charges cost, complaint adjustment cost, returned material cost and allowances cost (Gryna, 1999).

Chauvel and Andre (1985) test various hypotheses related to relationships between quality cost components. They find that the prevention activities have a direct and positive influence on the profit margin. They also conclude that quality cost decreases dramatically with the size of the firms and that the investment in both prevention and appraisal reduce quality cost. However, exclusively investing in appraisal may lead to unacceptable costs and may affect a company's reputation.

Harrington (1987) notes that as prevention cost increases, the total number of errors will decrease, thereby reducing the total error cost. Appraisal costs on the other hand, do not reduce the total number of errors. They only detect the output errors before the product is delivered to the customer. According to Harrington, the improvement of quality through quality cost reduction (defect reduction, waste elimination, rework reduction, and machine idle time reduction) leads to productivity improvement.

Carr and Ponoemon (1994) study the relationships among quality cost components by using 46 paper and pulp manufacturing mills for a period of 48 months. They observe the following relationships: internal failure is the most expensive and prevention is the least expensive quality cost component, the combination of internal and external failure costs is always higher than prevention and appraisal costs, and the quality reject rate decreases with increased volume output. Moreover, this study suggests that only internal failure and external failure costs have a statistically significant correlation with the level of quality.

Bell *et al.* (1994) estimate that quality cost in the manufacturing industry is between 5 percent and 25 percent of sales. Service industries however, expend an estimated 30-40 percent of operating costs in their quality cost. In addition, up to 95 percent of this cost may be expended on failure and appraisal. In some service organizations, it has been estimated that up to 60 percent of employee time is spent in checking and rectifying errors and also apologizing for errors.

McCrachen and Kaynak (1996) study the relationship between quality and productivity by analyzing 12 fictional competitive undergraduate student companies participating in an in-class simulation of the production function of a manufacturing company. They point out that as quality increases (fewer defects, less scrap, and less rework), productivity increases. This study also find that there are strong relationships between total productivity and partial productivity indexes, material productivity, labor productivity, and capital productivity, in descending order.

There are many uses of quality costs. According to Dale and Plunkett (1999), the uses of quality costs can be grouped into four categories. First, for promoting quality as a business parameter; second, they give rise to performance measures and facilitating improvement activities; third, they provide a means for planning and controlling future quality costs; and fourth, they act as motivation. Dale and Plunkett note that in order to evaluate the business aspects of quality, businesses must pay attention to the following four aspects of quality. Quality cost performance indicators, investment criteria, quality efficiency indices, and other specific quality costing problems (i.e. costs of equipment downtime, extra costs incurred due to order-splitting).

Gryna *et al.* (1999), state that quality cost is a measure of appraisal, prevention and failure costs associated with the achievement of product quality. Quality in this case means conformance to requirements. More specifically, quality costs are:

- the costs of appraising a product for conformance to design requirements and to market specifications (e.g. product inspection and design qualification);
- the cost due to failure to meet requirements (e.g. redesign, rework, scrap and warranty costs); and
- the cost of preventing failures (e.g. design reviews, vendor qualification and process capability studies).

Furthermore, many authors including Feigenbaum (1991), Gryna (1999), Harrington (1987) and Zhao (2000) note that an increase in appraisal and prevention costs results in a reduction in failure cost; consequently, the level of quality increases and productivity improves.

Gryna (1999) analyzes quality costs and presents a model for optimum quality costs as shown in Figure 1.

This model shows three curves: failure costs, costs of appraisal plus prevention, and the sum of curves. Failure costs are zero when the product is 100 percent good. As nonconformance increases, the failure costs rise rapidly at 100 percent nonconformance (the left-hand boundary of the chart), the product is 100 percent defective. At this point, none of the units are good, and the failure cost per good unit becomes infinite. When the product is 100 percent defective, the cost of appraisal plus prevention is zero (left-hand boundary of Figure 1). To improve conformance, costs of appraisal and prevention are increased until perfection is approached. The costs of appraisal and prevention rise asymptotically, becoming infinite at 100 percent conformance. The total quality cost curve (summation of failure, appraisal and prevention costs) represents the total quality cost per good unit.

Very few studies establish an effective empirical relationship among quality cost components and quality. This is because it is very difficult to observe the quality data for a particular industrial segment unless firms agree to provide the data. In this research the data are obtained from a wire and cable company in Thailand over a period of 24 months. The quality cost system has been established in the company in an attempt to increase the value of the product and process output and to enhance customer satisfaction. The company employs about 250 people and produces wires and cables for telephone, electric power, and electric building wire applications. It has annual sales of about US$150 million per year. The data collection process was managed by one of the authors of this research, who is also an ex-employee of the company.

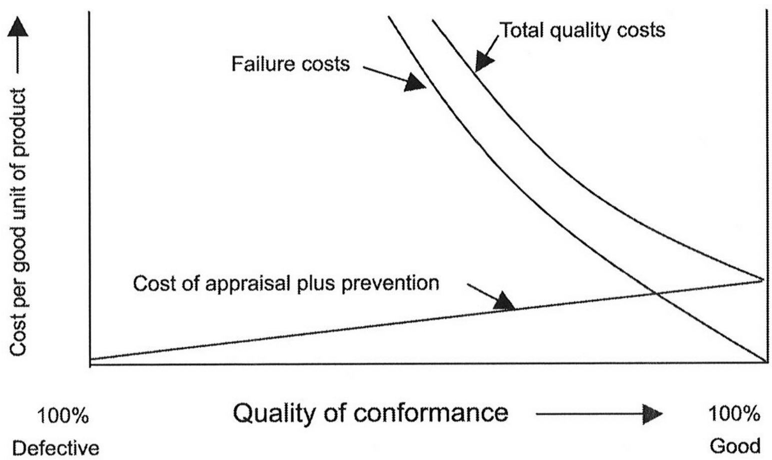


Figure 1.
Model for optimum quality costs

Source: Gryna (1999, p. 8.22)

Research objectives

This research is concerned with the integration of the concepts of quality cost (appraisal cost, prevention cost, internal failure cost, and external failure cost) and the level of quality for three major input elements: material input, machine input and the company as a whole. Specifically, this research defines and quantifies the relationship between changes in the quality cost components and the level of quality for each element (material, machine and company). The primary objectives of this research are to answer the following questions:

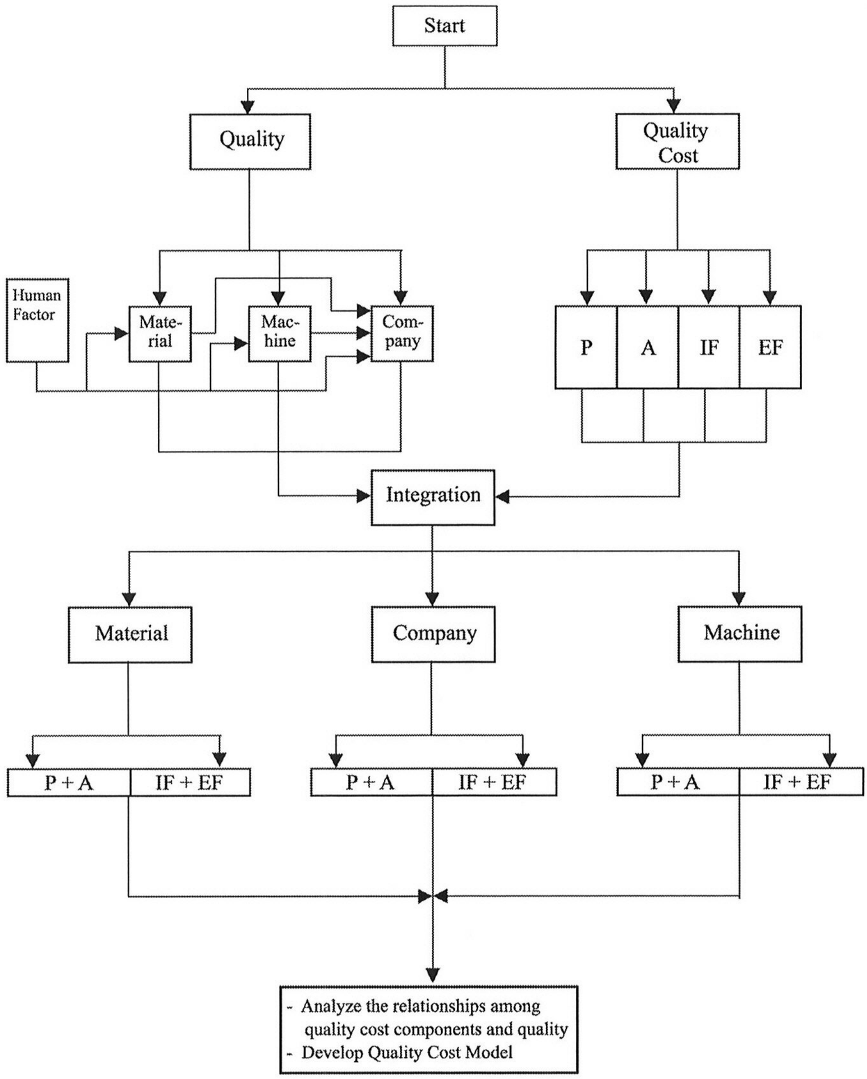
- Is there an inverse relationship between appraisal cost plus prevention cost and failure cost for material input, machine input and the company as a whole?
- Is there a direct relationship between appraisal cost plus prevention cost and the level of quality for material input, machine input, and the company as a whole?
- Is there an inverse relationship between failure cost and level of quality for material input, machine input, and the company as a whole?

This research seeks to verify the ideals of the quality cost model presented by Gryna illustrated in Figure 1 using data from a leading wire and cable manufacturing company. Once the model is validated, it will be confidently applied to the context of a company. In other words, it provides a useful guideline for production, which would allow a company to operate at optimal levels (within product specification limits at the lowest quality cost).

Methodology and conceptual framework

In this research, 24 months (January 1996 to November, 1997) of quality cost and production data were collected from a leading wire and cable manufacturing company. The company developed the method for estimating quality cost data for the purpose of a cost of quality program. The method takes into account the number of people, machine and material involved in any given manufacturing activities. Expenditures are subsequently assigned to the virous quality cost componenets. The data consist of quality cost componenets (appraisal cost, prevention cost, internal failure cost, and external failure cost), production output, and quality performance data for machine, material and company. Other factors that may affect the production process such as new technology, new investment, and new processes have been controlled for the purpose of this research. SAS software is used to determine the relationship (Pearson Correlation Coefficient Analysis) among the quality cost components and quality.

A conceptual framework is developed by integrating three major elements: material input and machine input, and the company as a whole with the quality cost components (appraisal cost plus prevention cost, internal failure cost plus external failure cost). For the purpose of simplify, the human input is allocated to both material and machine, is not treated as a separate input factor in this research. This conceptual framework is presented in Figure 2.



Note: A = Appraisal cost, P = Prevention cost, IF = Internal Failure cost, EF = External Failure cost

Figure 2.
Conceptual framework for the study of the relationship between quality and quality cost

The following notations are used in the analysis:

(1) *Quality cost factors*

- P = prevention costs;
- A = appraisal costs;

- IF = internal failure costs; and
- EF = external failure costs.

(2) *Input factors*:
- M = material input;
- C = machine input; and
- H = human input.

Thus:

$$\text{Prevention cost} = M_P + H_P + C_P$$

$$\text{Appraisal cost} = M_A + H_A + C_A$$

$$\text{Internal failure cost} = M_{\text{IF}} + H_{\text{IF}} + C_{\text{IF}}$$

$$\text{External failure cost} = M_{\text{EF}} + H_{\text{EF}} + C_{\text{EF}}$$

and

$$\text{Quality cost for material} = M_P + M_A + M_{\text{IF}} + M_{\text{EF}}$$

$$\text{Quality cost for machine} = C_P + C_A + C_{\text{IF}} + C_{\text{EF}}$$

$$\begin{aligned}\text{Quality cost for company} &= M_P + M_A + M_{\text{IF}} + M_{\text{EF}} + C_P + C_A + C_{\text{IF}} \\ &\quad + C_{\text{EF}} + H_P + H_A + H_{\text{IF}} + H_{\text{EF}}.\end{aligned}$$

The term "quality" in this research is based on the following definitions:

(1) *Material*. The quality of material measured in term of the degree to which the material conforms to company specifications (percentage raw material conformance).

(2) *Machines*. The quality of machinery and equipment measured in terms of machine up time and the degree to which it produces products to specifications (percentage machine utilization).

$$\begin{aligned}\text{Machine utilization} &= \frac{\text{Actual operating time}}{\text{Schedule time}} \\ &= \frac{\text{Schedule time} - \text{breakdown time}}{\text{Schedule time}}.\end{aligned}$$

(3) *Company*. Company quality is measured by the percent of units that conform to specifications (percentage product conformance).

Quality costs for these three elements are defined as follows:

(1) *Material*. The quality cost for material consists of the combination of appraisal and prevention costs (e.g. raw material inspection, supplier quality evaluation, and process control) and failure cost (e.g. scrap, loss, and rework) associated with material and the cost due to personnel assigned to material input.

(2) *Machines*. The quality cost for machine consists of the combination of appraisal and prevention costs (e.g. calibration of machine, preventive maintenance, inspection and test set-up, and activities to ensure that the most efficient design and planned construction methods for machines) and failure cost (e.g. repair and operating cost for rework) associated with the machine and the cost due to personnel assigned to machine input. In addition, the investment cost of the machines is not considered as quality cost for this research.

(3) *Company*. The quality cost for the company consists of the combination of appraisal and prevention costs (e.g. inspection, quality planning, and training) and failure cost (e.g. scrap, loss, and rework) associated with both machine and material and the cost due to personnel assigned to both material and machine components.

Results and discussions

Table I illustrates Pearson Correlation Coefficient for the relationship between appraisal cost plus prevent cost and failure cost, appraisal plus prevent costs and quality, and failure cost and quality for material input, machine input and company. This correlation value will help in understanding the strength of the relationship between the two sets of variables.

The relationship between appraisal cost plus prevention cost and failure cost

The results in Table I indicate that there is an inverse relationship between appraisal cost plus prevention cost and failure cost for all elements. The degree of the relationship that is measured by the Pearson Correlation Coefficient is

The relationship	Material	Machine	Company
Appraisal cost + prevention cost vs failure cost	−0.69 ($p = 0.005$)	−0.67 ($p = 0.007$)	−0.69 ($p = 0.009$)
Appraisal cost + prevention cost vs quality	0.79 ($p = 0.006$)	0.78 ($p = 0.009$)	0.82 ($p = 0.003$)
Failure cost vs quality	−0.83 ($p = 0.007$)	−0.87 ($p = 0.003$)	−0.84 ($p = 0.008$)

Table I. The correlation coefficient (Pearson) for a wire and cable company found to be −0.69 ($p = 0.005$) for materials, −0.67 ($p = 0.007$) for machines and −0.69 ($p = 0.009$) for the company. In other words, the failure cost decreases when the appraisal cost and prevention cost increase for all elements. This means that as an organization expends more of its budget on appraisal and prevention activities, the failure cost will decrease.

The relationship between appraisal cost plus prevention cost and quality
In contrast with the study of Carr and Ponoemon in 1994, this research indicates the statistically significant relationship between quality and the combination of appraisal and prevention costs. The correlation coefficient is found to be 0.79 ($p = 0.006$) for materials, 0.78 ($p = 0.009$) for machines and 0.82 ($p = 0.003$) for the company (Table I). This indicates that as appraisal cost and prevention cost increase, quality increases. For this reason, if a company spends more of its budget on appraisal cost and prevention cost for materials, the result will be an improved quality of material (percentage raw material conformance). In the same way, the level of the quality of machines (percentage machine utilization) increases as a result of increasing appraisal and prevention activities for machines. Thus, increasing appraisal cost and prevention cost for both materials and machines would lead to an improvement in the level of quality for the company as a whole (percentage product conformance). In addition, the findings show that the relationship between the combination of appraisal and prevention costs and quality are stronger than the relationship between the combination of appraisal and prevention costs and failure costs.

The relationship between quality and failure cost
Similar to the study conducted by Carr and Ponoemon in 1994, this research shows that the failure cost has a statistically significant correlation with quality. The correlation coefficient for the relationship is found to be −0.83 ($p = 0.007$) for materials, −0.87 ($p = 0.003$) for machines and −0.84 ($p = 0.008$) for the company (Table I). It can be seen that the level of quality and failure cost bears an inverse relationship. This implies that as the level of quality increases, failure cost decreases. When a company gets a high percentage of conformance of raw materials and a high percent of machine utilization for its processes, it will experience a reduction in scrap, rework, returns, and customer complaints. The research also indicates that the relationship between failure cost and quality is strongest compared to others.

The quality cost model
This section compares the quality cost model as shown in Figure 1 with the quality cost model for material (Figure 3), machine (Figure 4) and the company (Figure 5). These models show three curves: failure costs, costs of appraisal plus prevention, and total quality cost (the algebraic sum of the appraisal cost, the prevention cost and failure cost at each point along the axis). Although the research finds that the shapes of the quality cost curves are slightly different

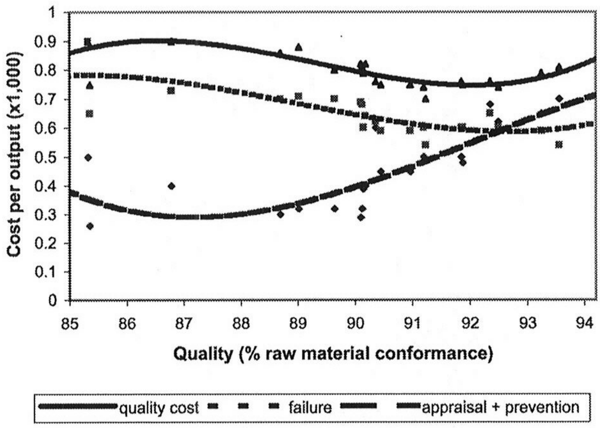


Figure 3. Quality, appraisal cost plus prevention cost and failure cost for material

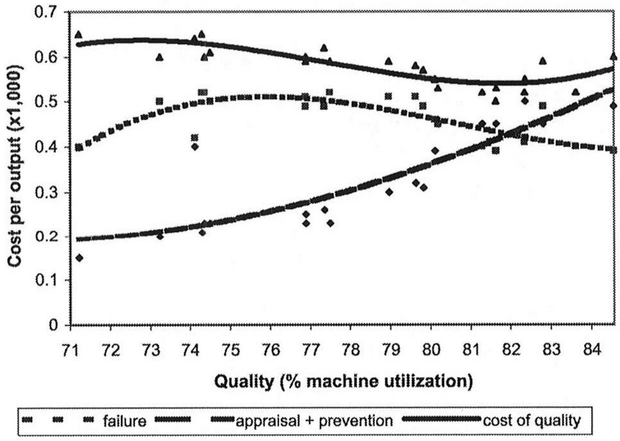


Figure 4. Quality, appraisal cost plus prevention cost and failure cost for machine

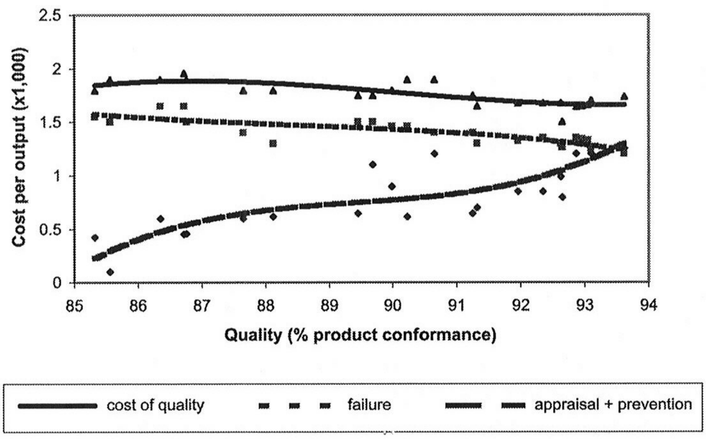


Figure 5. Quality, appraisal cost plus prevention cost and failure cost for the company

from Gryna's model (Figure 1), the curves behave in the same manner. In other words, as prevention and appraisal costs increase, quality increases and failure costs decrease slightly for all elements (material, machine and company).

For instance, with respect to material input (Figure 4), if the company invests US$0.30 in appraisal and prevention activities, failure costs are approximately US$0.75, the total quality cost is US$0.90 (based on a per US$1,000 product value) and the quality of material is at 85 percent raw material conformance. If the expenditures for appraisal and prevention activities increase to US$0.50, failure costs decrease to approximately US$0.60, the total quality cost reduce to US$0.75 (based on a per US$1,000 product value) and the quality of material increases to 92 percent raw material conformance. However, if the expenditures for appraisal and prevention increase over US$0.60, the level of quality and failure cost slightly decrease but the total quality costs continuously increase. In other words, the minimum quality cost is found at approximately 92.50 percent of raw material conformance. Similar to the discussion on quality cost model for material input, the quality cost models for the machine and the company as a whole constantly behave in the same manner.

It is concluded that the minimum total quality cost is found when the appraisal cost plus the prevention cost curve and the failure cost curve intersect. To achieve a lower production cost per unit, it is desirable to have the organization operate at this point of minimum total quality cost. It can be concluded that an increase in prevention cost plus appraisal cost leads to an improvement in quality, as well a decrease in failure cost.

Implementing the quality cost model: implications for decision making

Based on this research, the total quality cost is 3.67 percent of the total sale. The cost of scrap and rework represent the biggest portion of the quality cost. The scrap cost contributes 37.78 percent and the rework cost accounts for 35.62 percent of the total quality cost. Most of the scrap costs (approximately 90 percent) are caused by excessive tolerances, equipment/machine downtime and process changes (machine set-ups between batches of two different products). Rework costs is mainly due to nonconforming products produced by the processes.

The quality cost model developed in this research provides a very meaningful guideline for decision making regarding production. As presented in Figures 3-5, the acceptable level of quality is found close to where the curve of appraisal cost plus prevention cost intersects the failure cost curve. In other words, to minimize the quality cost, the quality levels should be controlled at 92.50 percent conformance for material (approximately US$0.60 expense in appraisal and prevention activities per US$1,000 product), 82 percent for machine utilization (approximately US$0.40 invest in appraisal and prevention activities per US$1,000 product value).

As discussed above, this model makes it possible for management to identify the level of investment required to achieve the desired level of quality. The investments required to achieve the quality cost objectives may include diagnosis and other forms of analysis, training, redesign of products and processes, testing, and equipment (including maintenance for current equipment). The returns from such investments should reflect savings in the cost of poor quality, savings in process capability improvement, and increases in sales revenue due to a reduction in customer defections, and increases in new customers.

By increasing prevention costs, the level of quality can be improved due to the training of employees and maintenance of equipment. Also, appraisal costs may be decreased because of reduced inspection levels resulting from better quality products. Additionally, less inspection time is required to re input rejected lots because fewer lots are rejected. It is also noteworthy that, if the organization increases both prevention costs and appraisal costs, the internal failure costs and external failure costs decrease because of fewer errors.

Conclusions

This research confirms that the quality cost model, which shows that as appraisal cost plus prevention cost increases, quality increases and failure cost decreases can be applied for a wire and cable company. The shapes of the quality cost curves would be different under different manufacturing environments. Therefore, the quality cost model should be carefully considered in order to minimize quality cost and improve quality. The results significantly indicate the following:

- There is an inverse relationship between appraisal cost plus prevention cost and failure cost.
- There is a direct relationship between appraisal cost plus prevention cost and quality.
- There is an inverse relationship between failure cost and quality.

Although these relationships follow the same trend for material input, machine input and the company, the degree of the relationship varies slightly (as indicated by correlation coefficients).

This research benefits manufacturing companies in that it assists management in capacity planning, financial planning, and resource planning. The quality cost data can be used in an effort to be proactive, and to identify causes of problems. It provides a methodology for pinpointing improvement priorities. Once the causes are resolved, the defects do not occur and failure costs decrease. In essence, it is hoped that this research adds to the existing knowledge regarding quality cost and quality in manufacturing companies.

Although human input is a very important factor for an organization in order to improve quality and minimize quality cost, this study did not analyze human input separately from material input and machine input because of constraints in the data. In addition, there is so much subjectively in measuring the level of human quality. Based on both the experience gained in conducting this study and the literature reviewed, it is felt that some additional factors need to be considered. Therefore, the following recommendations for further research are suggested. First, study the relationship among quality cost, quality and productivity for both manufacturing and service sectors. Second, include human input as another input in the study to find the relationship among quality cost, quality and productivity.

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