THE CUMULATIVE EFFECT OF PREVENTION

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ABSTRACT

Quality Costs have been discussed widely in the literature. This discussion has not always agreed and it is possible to identify two basic schools of thought; one asserts the existence of a minimal level of quality cost for a given level of prevention and appraisal activities, and the other asserts that through prevention quality improvement is constant. This paper summarises these positions and outlines a behaviour model of quality costs that unifies and clarifies them. The behaviour model is based on the consideration of the cumulative effects of prevention. Ceteris paribus, continuous prevention activities should permit quality improvements whilst at the same time reducing the costs necessary to obtain them. The behaviour model introduces the effect of external quality requirements in an attempt to explain how, over time, quality improvement efforts do not necessarily result in decreased quality costs as customer's quality requirements rise over the same period.

KEYWORDS: quality costs, quality management

INTRODUCTION

The first reference to quality costs appeared in Juran's Quality Control Handbook in 1951 (Lundvall and Juran, 1974). Juran posited the concept of quality costs as "gold in the mine" as he considered that once quality costs had been identified and were being reduced many associated costs could be reduced as well. Since then quality costs have been widely discussed in both academic and practitioner literature. A review of the literature on quality costs by Porter and Rayner (1992) shows that these costs oscillate between 4% and 25% of sales, the average being 18%. Abed and Dale (1987) show similar data with quality costs as a percentage of sales turnover averaging 9.2%, and ranging from 2 to 25%.

Quality costs refer as much to the cost of obtaining a desired level of quality as to those costs generated as a consequence of not obtaining it. If quality is understood as the satisfaction of customer requirements, obtaining the required level of quality will depend on product design and the execution of that design. When a product design does not meet customer requirements, the customer will usually choose a competitive product. On the other hand satisfying customer requirements also has a cost. Therefore, product design is affected by two antagonistic factors, the resolution of which will be related to the firm’s own capabilities and its position with respect to competitors. However, much of the quality literature asserts that those costs incurred through adapting the product to meet its design specifications can be reduced if a company has an adequate quality management system.

This paper will model the different positions on total quality cost (TQC) identified in the literature and show how quality improvement (defined as agreement to design specifications) relates to cost reduction.

QUALITY COSTS

According to Dale and Plunkett (1991) several ways of defining quality costs have been developed in the literature but the most widely accepted definitions are Feigenbaum's (1991) where quality costs are divided into two groups, each of which is then separated into two categories**.** These two groups are, costs of control and costs of failure of control. The former includes all those costs incurred to ensure a product meets its specifications, and the latter all those costs incurred as the result of a product not meeting its specifications. Costs of control are divided into prevention costs and appraisal costs, and costs of failure of control into internal failure costs and external failure costs.

In terms of specific definitions Harrington (1987) has compiled a comprehensive list of quality costs, identifying 101 prevention costs, 73 appraisal costs, 139 internal failure costs and 50 external failure costs. His explanation of each of the different cost categories follows, with some examples:

1) Prevention costs.

These include all the costs of quality activities in the planning stages of a project; for example, training of personnel, preventive maintenance of machinery, preventive studies and analysis, action to avoid the repetition of a problem, etc.

2) Appraisal costs.

These are the costs of those activities which ensure that product characteristics fit their specifications and meet customer requirements; for example, inspection to determine nonconformity, approval of documentation, inspection of designs and reports, processing of quality data and quality audits, etc.

3) Internal failure costs

These are the costs of scrap, rework, repairs and other related losses that are produced when a product does not conform to quality standards. Also included should be the cost of over producing in order to compensate for the uncertainty of producing all goods to the required quality standard.

4) External failure costs

These are the costs incurred when a product of inferior quality reaches the client. The costs are clearly measurable as; product returns, repairs and after-sales service, and withdrawn or obsolete product sets in the market. A less clearly measurable cost but with greatest potential effect is client loss.

Harrington (1987) introduces another type of cost that he calls equipment costs. He identifies these costs as those produced by investing in equipment used to measure, accept or control the product and the cost of the space this equipment occupies. Within the scope of this paper these costs will be treated as appraisal costs in accordance with their definition.

Two possible prevention costs not normally included as such are the cost of machinery that allows the substitution of human labour, and the cost of working with the least possible number of suppliers.

Machinery that substitutes human labour can be considered a prevention cost because it avoids human error. However, perhaps because of the polemic nature of this type of measure the different authors consulted rarely cite this as a possible prevention cost. Thus, in Harrington's (1987) list it is included as a general "automation to improve quality"; it is not considered at all by Lundvall and Juran (1974), Feigenbaum (1991), or Crosby (1987), each respected authors on this subject.

It is another quality proponent, Deming (1986) who proposes the use of the least possible number of suppliers to ensure the quality of supplies, but the cost that this implies, that of possible higher prices due to negotiating on the basis of quality not price is not normally included as a prevention cost. Neither Lundvall and Juran (1974), nor Feigenbaum (1991), nor Harrington (1987), nor Crosby (1987) take it into account.

Nandakumar et al. (1993) consider it is necessary to include as quality costs the cost of increased production time with its consequent increase in storage costs, and the cost of slippage in delivery times due to the manufacture of defective products[1]. They argue that to omit these costs can lead to a significant under valuation of quality costs. This is due to the fact that, although these costs tend not to be the most important items in terms of total cost, in the case of products with long lead times it is a reduction in these costs which would give the greatest total cost decrease when the level of defects goes down. Their inclusion allows a greater range of products to be included in quality cost calculations and thus targeted for prevention activities. If they are not included improvement efforts may not be focused on those products which will yield the greatest decrease in quality costs. In particular their inclusion opens up the possibility of targeting improvement efforts on products with high lead times and high levels of capacity use even though those products are sold in less competitive markets. For the purposes of this paper such costs are accepted as quality costs and categorised as internal failure costs.

Werrebrouck (1993) proposes that in the same way that quality costs should be used as a management instrument, management should also calculate and use what he calls hidden costs ("coûts caches"). Werrebrouck defines these hidden costs as those derived from factors like "over-consumption, excessive wages, overtime, non-production and non-creation of potential and risk", in fact, "management malfunctions". Hidden costs include things not envisaged as classic costs of quality but rather those costs incurred through an organisation's internal activities. Because of this, Werrebrouck considers that hidden costs are potentially more accurate than quality costs in organisations such as public services or monopolies where the satisfaction of client requirements is not paramount. The authors agree that it would be useful to estimate and work on an organisation's hidden costs. Furthermore, the authors propose that even though they are not specifically included within product quality costs, some instruments of quality management and the use of quality circles can help to reduce hidden costs. Also, through focusing quality costs on the process rather than the product it should be possible to identify an organisation's hidden costs.

Dale and Plunkett (1991) propose a complementary way to divide quality cost, in order to offer information more closely related to the way companies work. They suggest categorising them under "supplier", "company" and "customer" heads. They argue that this categorisation applies to both manufacturing and service organisations. Although this categorisation is potentially useful for reasons of simplicity it will not be used in the development of this model.

THE DIFFERENT APPROACHES

Basically, the different points of view concerning quality costs fall into two categories: one which asserts that there is a level of quality at which cost is minimised (the minimum cost approach) and the other which asserts that quality improvement leads to continuous cost reduction (the continuous improvement approach).

The minimum cost approach is based on Juran's (Lundvall and Juran, 1974) quality cost theory. He proposes that all quality costs are mutually related so an increase in some will cause a decrease in others. The level of costs of control (prevention and appraisal) is determined by the firm as it is the firm which decides on appropriate prevention and appraisal activities. The level of costs of failure of control (internal and external failure) will be determined by what the firm may have decided to spend on activities to ensure quality and by the implementation of those activities. Nevertheless, increasing costs of control does not guarantee a reduction in the costs of failure of control as there is the possibility that prevention and appraisal activities may not be implemented adequately. However, supposing prevention and appraisal activities are implemented properly the expected relationship between costs would be:

a) An increase in prevention costs should reduce every other cost. Appraisal costs will be reduced as such activities become less necessary. Internal and external failure costs will be reduced as less failures will be produced.

b) An increase in appraisal costs should cause an increase in the cost of internal failures as a greater number of failures should be detected. Nevertheless, the total number of errors made will be constant, and there should be a decrease in the number of external failures. Harrington (1987) therefore considers the combined balance to be positive as the increase in internal failure costs should be more than compensated by the decrease in external failure costs.

Bearing the above in mind a firm’s task is thus to determine the optimum level of costs of control so as to minimise the sum of these costs and those of failure of control, as shown in Figure 1. Take in figure 1.

From Figure 1 it can be seen that, as prevention and appraisal costs rise, internal and external failure costs are reduced and there is a point at which the sum of both is minimised. Lundvall and Juran (1974) place this point on the far left, but this position will vary depending on a firm’s internal and external quality requirements.

Thus, according to the above, Lundvall and Juran posit that it is impossible to reach defect free production because quality cost is infinite. However, Crosby (1987) considers that quality improvement, with the intention of reaching 'zero defects' can always be justified economically. Leonard and Sasser (1982) substantiate this with several examples of quality improvement that resulted in productivity improvements. Two examples were:

<u>“One company’s installation of a new “clean room” reduced the contaminants on printed circuit boards and boosted output by almost 35%.</u>

<u>Elimination of rework stations at one tv factory forced assembly workers to find and solve their own quality mistakes. These adjustments resulted in an increased production rate per hour of direct labour and in the elimination of thousands of dollars of rework costs.”</u>

Gilmore (1990) considers that Lundvall and Juran's argument for the existence of a minimum cost of quality is valid in the short-term, but in the long term the successive minimal points of the total cost curves draw a curve with a downward trend. Douchy (1992) defends this idea based on the Japanese and American electronic components industries which simultaneously reduced the number of defects and prices during the period 1980 to 1985. Graphically this idea is expressed in Figure 2.

Take in figure 2.

Using this approach, starting quality improvement activities leads to the change in cost structure shown in Figure 3. From this it can be seen that an increase in the costs of control produces a decrease in internal and external failure costs, the overall change being positive as total cost is reduced. If Lundvall and Juran's (1974) theory is accepted this position would only be valid if a firm was producing at a lower than optimum level of quality. However, Feigenbaum (1991) concurs with prevention and continuous improvement proponents that an increase in prevention costs always means a decrease in total cost in the long term, including appraisal costs, as such expenditure becomes less necessary.

Take in figure 3.

Plunkett and Dale (1988) have carried out a wide review of the different ways in which quality costs are understood and they present a number of criticisms of which the authors agree with the following:

1) Different authors disagree on what should be included and omitted from quality cost calculations.

2) Prevention, appraisal and failure costs are combined in different ways by different authors. Thus, some authors represent prevention and appraisal costs together and compare them to failure costs, whilst others compare prevention costs to appraisal and failure costs combined.

They also criticise the fact that "although all the models ... use absolute cost or a simple variation of it as the ordinate, abscisae range from measures of quality dimensioned only at their extremes to undimensioned process capability, arbitrary quality management development stages, or time." These differences are almost certainly due to the existence of different models although these models do not appear to contradict each other, but rather appear to be mutually compatible. A further criticism would be the obvious arbitrary nature in the definition of abscisae measures.

The above models are intended simply to illustrate the different principles presented in the literature. However, this paper identifies most closely with those models which assert that decreases in total costs are procured through prevention activities.

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Lundvall and Juran's (1974) theory presents a static point of view, insofar as it does not take into account the effects that prevention and appraisal expenditure has on total future costs. To introduce this effect the following model has been developed. It is intended solely to be descriptive, its objective being to clarify the influence of different variables on quality costs.

For the purposes of the model let:

x_p: be the number of defective products

x_d: be the number of detected defects,

x_{nd}: be the number of non detected defects ($x_{nd} = x_p - x_d$),

p: be prevention cost,

a_c: be appraisal (evaluation) cost,

i_{fc} : be internal failure cost,

e_{fc}: be external failure cost,

q_{in}: be the quality internal needs level and

q_{en}: be the quality external needs level.

The number of defective products (x_p) will vary with:

a) Prevention, since the greater the amount of prevention, the smaller x_p will be.

b) Internal quality requirements. These will be determined by the firm's quality management policy and activities, such as the training level of personnel, the state of machinery and its maintenance plan, and the development of a quality department and manual.

c) External quality requirements. This will depend on the level of quality demanded of the firm by the market, which will be a function of customer demand and competitive position.

Ceteris paribus, if the rest of variables remain the same, the higher internal and external quality requirements are more defects will be produced. A product characteristic which causes it to be defective for one market may not necessarily be so for another market. The limits, pursuant to which the differentiation between correct and not correct is established will be a function of the market requirements.

Therefore,

$x_p = x_p(p, q_{in}, q_{en})$ where,

$\delta x_p/\delta p < 0$,

$\delta x_p/\delta q_{in} > 0$,

$\delta x_p/\delta q_{en} > 0$.

The number of detected defects, x_d , will depend on:

a) Appraisal level, since the stricter it is, the greater the level of detection will be.

b) The number of defects produced, since the greater this is, the greater x_d will be.

As x_p depends on p, q_{in} and q_{en}, x_d will also depend on them. Therefore we can say:

$x_d = x_d (a_c, x_p) = x_d (a_c, p, q_{in}, q_{en})$ where,

$\delta x_d / \delta a_c > 0$,

$\delta x_d / \delta x_p > 0$ and $\delta x_d / \delta p < 0$, $\delta x_d / \delta q_{in} > 0$, $\delta x_d / \delta q_{en} > 0$.

The levels of p and a_c will be determined by the management of the firm. The level of internal failures will depend directly on x_d since internal failures are originated when defects are detected in production. Consequently, i_{fc} will depend indirectly on those variables on which x_d depends. Therefore,

$i_{fc} = i_{fc} (x_d) = i_{fc} (p, a_c, q_{in}, q_{en})$ where

$\delta i_{fc} / \delta x_d > 0$ and $\delta i_{fc} / \delta p < 0$, $\delta i_{fc} / \delta a_c > 0$, $\delta i_{fc} / \delta q_{in} > 0$, $\delta i_{fc} / \delta q_{en} > 0$.

The level of external failures will depend directly on the non detected defects, since it is those which reach the consumer and originate cost. These, at the same time depend on the difference between x_p and x_d which in turn depend on those variables already identified. Therefore,

$e_{fc} = e_{fc} (x_{nd}) = e_{fc} (x_p - x_d) = e_{fc} (p, a_c, q_{in}, q_{en})$ where,

$\delta e_{fc} / \delta x_d > 0$ and $\delta e_{fc} / \delta p < 0$, $\delta e_{fc} / \delta a_c > 0$, $\delta e_{fc} / \delta q_{in} > 0$, $\delta e_{fc} / \delta q_{en} > 0$.

With respect to the relationship between prevention and external failure, it seems reasonable to suppose that a decrease in the level of defects produced does not imply a decrease in the percentage of those which are detected. Therefore, when prevention costs are increased, x_p and x_d will be reduced in proportion such that the difference x_{nd} will also be reduced. Otherwise one would have to assume that as the number of defects produced is reduced the number which reach the customer increases.

The total cost of quality (TCQ) will be the sum of all the sources of cost:

$TCQ = p + a_c + i_{fc} + e_{fc}$

So, since i_{fc} and e_{fc} are a function of p, a_c, q_{in} and q_{en}, the TCQ will be a function of these same variables:

TCQ = TCQ (p, a_c, q_{in}, q_{en})

Given q_{in} and q_{en} and deriving TCQ with respect to p and a_c, it could be determined whether there is a level of these variables that minimised the value of TCQ. The result of this operation could be different for each firm. Theoretically it is possible that the level of p that minimises TCQ is high and x_p is equal to or approximates to 0. However, it is also possible that the level of p is small and it gives us a very high x_p. If it is assumed that the present level of q_{en} is extraordinarily high, it can also be assumed that the necessary level of p will also be high.

If the number of defects produced, x_p, is related to TCQ, p, a, i_{fc} and e_{fc} the following relationships arise:

a) As p rises, x_p will decrease

b) As x_p rises, i_{fc} and e_{fc} will increase

c) Appraisal level, a_c, does not influence x_p but is influential on the i_{fc} and e_{fc} curves. An increase in a_c will make the i_{fc} curve move upward and the e_{fc} curve downward if Harrington's theory is accepted. This is because the decrease in e_{fc} more than compensates for the increase in i_{fc}. What cannot be assumed is that the balance (decrease in e_{fc} less the increase in i_{fc}) will be greater than the increase in a_c. Therefore a reduction in TCQ cannot be guaranteed by a raise in a_c. For a fixed level of a_c the relationship between x_p and TCQ can be shown graphically as in Figure 4.

Take in figure 4.

The previous illustrations clarify the Lundvall and Juran (1974) perspective, albeit from the point of view of produced defects, rather than defects which reach the customer. The following introduces the effect that measures of prevention and appraisal have over a period of time.

Let:

p_t: be the prevention cost during the period t

a_{ct}: be the appraisal cost during the period t

i_{fct}: be internal failure cost during the period t,

e_{fct}: be external failure cost during the period t,

q_{int}: be the level of quality internal needs at the beginning of the period t,

q_{ent}: be the level of quality external needs during the period t,

TCQ_t: be the total cost of quality during the period t and,

x_{pt}: be the number of produced defects during the period t.

The relationship between the different variables is maintained for the period t. However, the more prevention activities undertaken in the time period t-1, the less the internal quality needs of period t will be, as many of the problems which caused defects no longer exist (e.g. training of personnel will have been improved). This relationship can be expressed as:

$q_{in} = q_{in} (p_{t-1}, p_{t-2}, p_{t-3} ...)$

So, with the same level of appraisal costs it will be possible to reach a lower level of defects, thus lowering the minimum of TCQ_{t+1}. Therefore, continuous prevention activities will always result in lower quality costs. See Figure 5.

Take in figure 5.

In fact, it is possible to consolidate both the model which asserts the existence of a minimum TCQ and that which asserts the existence of continuous improvement through prevention. However, in spite of the fact that through prevention quality cost is reduced over time, in practice rising external quality requirements (q_{en}), which in this model were considered to be constant, mean that it will not be possible to reach zero defect level with lower quality costs. That is to say, given an organisation with fixed q_{en}, if prevention activities are implemented effectively then as time goes by the level of produced defects should approximate to zero and TCQ should be quite low. However, as q_{en} rises due to the effect of competition and increasing customer requirements, internal and external failure costs will increase for the same level of defects. Graphically, moving up the i_{fc}+e_{fc} curve the optimum level of x_p gets closer to 0, but TCQ rises. So, TCQ will only be reduced if the effects of prevention activities are realised more quickly than the increase in q_{en}. In any case, through the implementation of prevention activities the level of defects that minimise TCQ will decrease. This theory is affirmed in the literature by Garvin (1983) who shows examples of how Japanese firms, by greater prevention effort, have lower TCQ than their American competitors due to the fact they produce less defects.

Figure 6 shows the case in which the decrease in prevention levels, brought about over a period of time by improvement in meeting internal quality requirements, is less than the increase in external failure costs brought about by the increase in external quality requirements over the same period of time.

Take in figure 6.

Figure 7 shows the opposite case. Thus, in the first case the optimum level of quality rises, whilst in the second it falls. In both cases the level of defects is reduced.

Take in figure 7.

CONCLUSIONS

This paper explores further the relationship between quality and cost. The literature focuses on Juran's theory of an optimum level of quality, which has been used here as an initial basis for exploring this relationship. This theory assumes that all variables within the quality and cost relationship remain constant. The effect of varying levels of prevention activity is then investigated and it is shown that, if the remaining factors are fixed, continuous prevention will lead to improvements in quality and reduce the costs necessary to maintain the improved level of quality.

Specifically however, the paper explores the effect of external quality requirements. The model expressed by Figure 6 shows how over time continuous prevention efforts may not necessarily result in a reduction in quality costs as external quality requirements may rise over that period of time. If the cost of meeting this rise in requirements is greater than the cost reduction obtained through producing less defects there will be no overall cost reduction. The model could also provide companies with a means of determining whether they are targeting their improvement activities appropriately to meet external customer requirements.

Further development of the model to investigate the relationship between quality improvement efforts and their results could be used to determine which particular variables affect results. What must be borne in mind is that in order to demonstrate a negative relationship between the level of improvement effort and the level of TQC it would be essential to take into account both internal and external quality requirements, which is allowed for in this model. Not taking both internal and external quality requirements into account could potentially mislead the investigator.

Thus, the next stage of development for the model would be the development of scales to measure the level of particular variables; level of prevention effort, level of TQC and internal and external quality requirements and most importantly, the time factor.

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[1] Nevertheless, their analysis is interesting and the conclusions they reach seem to be more independent than others, particularly their reference to the importance of competitors when appraising which products should be targeted for improvement.