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A model for supply chain design considering the cost of quality

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ABSTRACT

Recent studies have shown that the cost of quality (COQ) is of more strategic and economic importance than previously conceived. Whereas previous works have applied COQ as an internal performance measure within companies, the purpose of this paper is to present a model for supply chain design that computes the COQ as a global performance measure for the entire supply chain. In addition, rather than assume an exogenously given COQ curve, our model computes COQ in terms of internal operational decisions such as the error rate at inspection and fraction defective at manufacturing. The model can be used to design a logistic route that achieves a minimum total cost while maintaining an overall quality level and to evaluate the impact of investment in quality to increase overall profits. The behaviour of the model is illustrated with numerical examples that show how the COQ function changes depending on various parameters.

1. Introduction

Cost of quality (COQ) or quality cost is based on tangible costs, which are recognised by the accounting system as expenses because they are based on actual transactions used in the production process. These costs constitute the widely used traditional prevention–appraisal–failure (PAF) model proposed by Feigenbaum [1]. The concept of cost of quality (COQ) has been applied successfully in manufacturing companies and service businesses [2]. Organizations that have instituted a system of quality cost measures have also experienced dramatic positive results. However, COQ has focused on in-house quality costs for an individual firm but not for an entire supply chain [3]. COQ represents a powerful measurement system that translates the implications of poor quality, activities of a quality program, and quality improvement efforts into a monetary language for managers. Moreover, COQ is a language that every stakeholder can understand which is important because it affects operating costs, profitability, and consumer need [3]. Thus, it is crucial to extend COQ as an external measure and integrate these costs into supply chain modelling.

Srivastava [3], who gives the first step towards estimating COQ in a supply chain, measures COQ in monetary terms at selected third-party contract manufacturing sites of a pharmaceutical company located in India. Another work focused on integrating COQ in the supply chain is the work by Ramudhin et al. [4]. This seminal study presents a model that integrates COQ into the modelling of a supply chain network for a single product, three-echelon system (suppliers, manufacturing plants, and customer groups). The model seeks to minimise the overall operational and quality costs. Ramudhin et al. [4] find that adding a known COQ function only for suppliers into the objective function gives a difference of approximately 16% in costs, and changes the solution. When COQ is not included, the final optimal network will choose key suppliers who have the lowest operational costs, but there is no information in regard to the quality non-conformance cost. Therefore, the selected supplier may run at a high quality non-conformance cost, and receive the same preference that a supplier which operates at

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a lower quality non-conformance cost because both suppliers have the same production cost. Thus, choices made solely on production cost could sacrifice quality and lead to additional quality non-conformance costs or corrective action costs in the next stages of the supply chain. More recently, Alzaman et al. [5] establish a mathematical model that incorporates a known COQ quadratic function incorporating a defect ratio at all supply chain nodes; COQ function is based on Juran's original model as assumed in their previous work. They consider binary variables for selected supply chain nodes and an n level bill of material. This model is applied to a case study from the aerospace industry.

In previous studies, the total quality cost function based on percentage of defective units is assumed to be given. This paper deals with the development of a model to compute the quality cost for a whole supply chain based on internal decisions within the supply chain, such as percent defective at the manufacturing plant and error rate at inspection. No previous work has addressed how the COQ curves are obtained by taking internal and operational decisions within the supply chain.

Ittner [6] states that 'few, if any, firms use experimentation to identify the shapes of their quality cost curves' and when a quality cost system is first established, it serves to observe ex post the choices made by management related to quality resources. It reflects the manager's perception of an adequate quality cost model at that time. Moreover, Campanella [7] states that some managers think that investment in quality programs will always give the company a positive impact on profit and that ignoring quality is really expensive. Other managers believe it is uneconomical working at zero defects. The real problem begins when managers from different areas, supposedly working together, operate with conflicting perspectives on quality. Usually, once quality costs are obtained, these are used to find specific improvement projects; however, this is not an easy task and it is not clear what action should be taken nor what impact it may have on the quality cost model. Since the traditional cost model represents the hypothesised shape of quality costs and relationships, it can only serve to evaluate the distribution of quality cost categories with respect to total quality costs, sales, and profit.

A planning model is needed to estimate the impact of the total cost of quality on profit when establishing new logistic routes; thus, a proactive approach is preferable rather than a reactive one (observing ex post quality data). The proposed model aims to serve as a decision making tool for engineering managers by helping with the design and quality planning of logistic routes for manufacturing plants in the design phase (i.e., not yet operating).

The remainder of this paper is structured as follows: first, a background on COQ models and operational definitions is presented. Next, a model for computing the COQ of a supply chain is provided, followed by an analysis of numerical examples. Finally, a summary of key insights and concluding remarks, as well as recommendations for future work, are presented.

2. Theory about COQ

This section presents a survey of published literature on various COQ models. According to research carried out by Sandoval-Chávez and Beruvides [8] six primary theories were found: (1) Juran's model, (2) Lesser's classification, (3) PAF model, (4) the economics of quality, (5) business management and the COQ, and (6) Juran's revised model. Schiffauerova and Thomson [9] classified COQ models into four groups of generic models: (1) PAF or Crosby's model, (2) opportunity cost models, (3) process cost models, and (4) ABC approach. Furthermore, Banasik [10] categorized the COQ models into: (1) Juran's model, (2) Lesser's contribution, (3) PAF model, (4) Harrington PQC, (5) Godfrey–Pasewak accounting COQ model, (6) Carr's service model, (7) Juran's revised COQ model, (8) Beruvides and Sandoval-Chávez opportunity cost model, and (9) Beruvides–Chiu capital budgeting model.

Modern COQ models and theory have been developed from the works of Juran, Feigenbaum, Crosby, and Freeman [3]. The COQ models that serve as the theoretical foundation for this study are the PAF classification as well as the revised Juran's model. A short background on the COQ models on which the proposed model is based is presented in the following paragraphs.

Joseph Juran's [11] analogy of 'Gold in the Mine' is defined as the 'total of avoidable costs of quality'. According to Juran et al. [12], this concept suggests that costs resulting from defects were a gold mine in which lucrative digging could be done. Juran [11] also categorises cost of quality elements as tangible and intangible.

Soon after, Feigenbaum [1] develops the prevention–appraisal–failure (PAF) classification. The PAF classification can add orderliness and uniformity to the ensuing reports. The PAF classification offers specific advantages, such as its universal acceptance, identification of different kinds of expenditures, and provision of criteria to help in deciding whether costs are quality related. The last-mentioned advantage may be the reason why neither Feigenbaum, nor the ASQC, defines the term *quality costs*. Matters are quality-related if they meet the criteria set by each category [13]. The premise behind Feigenbaum's classification [1] is the following:

> The reason for the favourable cost result of total quality control is that it cuts the two major cost segments of quality (which might be called failure and appraisal costs) by means of much smaller increases in the third and smallest segment (prevention costs) [p. 99].

The definitions for each of the categories of the PAF classification are stated by Campanella [7] as follows:

– Prevention costs are 'the costs of all activities specifically designed to prevent poor quality in products and services.'
– Appraisal costs are 'the costs associated with measuring, evaluating, or auditing products or services to assure conformance to quality standards and performance requirements.'