

A Review of Research on Cost of Quality Models and Best Practices

Andrea Schiffauerova *, Vince Thomson **

* *École Polytechnique de Montréal, Department of Mathematics and Industrial Engineering, Montreal*

** *Department of Mechanical Engineering, McGill University, Montreal, Canada*

Article Reference:

Schiffauerova, A. and Thomson, V., “A review of research on cost of quality models and best practices”, *International Journal of Quality and Reliability Management*, Vol.23, No.4, 2006

Abstract:

This article presents a survey of published literature about various quality costing approaches and reports of their success in order to provide a better understanding of cost of quality (CoQ) methods. Even though the literature review shows an interest by the academic community, a CoQ approach is not utilized in most quality management programs. Nevertheless, evidence is presented which shows that companies that do adopt a CoQ concept are successful in reducing quality costs and improving quality for their customers. The survey shows that the method most commonly implemented is the classical prevention-appraisal-failure (P-A-F) model; however, other quality cost models are used with success as well. The selected CoQ model must suit the situation, the environment, the purpose and the needs of the company in order to have a chance to become a successful systematic tool in a quality management program.

Keywords: Cost of quality, CoQ models, best practices

Introduction

Many companies promote quality as the central customer value and consider it to be a critical success factor for achieving competitiveness. Any serious attempt to improve quality must take into account the costs associated with achieving quality since the objective of continuous improvement programs is not only to meet customer requirements, but also to do it at the lowest cost. This can only happen by reducing the costs needed to achieve quality, and the reduction of these costs is only possible if they are identified and measured. Therefore, measuring and reporting the cost of quality (CoQ) should be considered an important issue for managers.

There is no general agreement on a single broad definition of quality costs (Machowski and Dale, 1998). However, CoQ is usually understood as the sum of conformance plus non-conformance costs, where cost of conformance is the price paid for prevention of poor quality (for example, inspection and quality appraisal) and cost of non-conformance is the cost of poor quality caused by product and service failure (for example, rework and returns). According to Dale and Plunkett (1995), it is now widely accepted that quality costs are: the costs incurred in the design, implementation, operation and maintenance of a quality management system, the cost of resources committed to continuous improvement, the costs of system, product and service failures, and all other necessary costs and non-value added activities required to achieve a quality product or service.

CoQ analysis links improvement actions with associated costs and customer expectations, and this is seen as the coupling of reduced costs and increased benefits for quality

improvement. Therefore, a realistic estimate of CoQ and improvement benefits, which is the tradeoff between the level of conformance and non-conformance costs, should be considered an essential element of any quality initiative, and thus, a crucial issue for any manager. A number of organizations are now seeking both information on the theoretical background of quality related costs as well as practical evidence about the implementation of quality costing systems. The literature that provides advice on this topic is usually centered on one of the existing CoQ approaches, and only a limited number of articles review all the quality costing methods and present data from industry on their success. The objective of this paper is to give a survey of research articles on the topic of CoQ, focusing specifically on the references describing, analyzing or developing various CoQ models and on the papers providing evidence of the successful use of these methods by companies.

A few reviews of quality cost literature have been conducted. Plunkett and Dale (1987) have carried out a literature survey, which provides guidance on the most authoritative reading on the subject. They have summarized published information on the measurement, collection and uses of quality related costs. Plunkett and Dale suggest that there is a surprising lack of references on quality costing in both papers and books. Particularly interesting is the shortage of such references from Japanese sources, given the Japanese reputation in quality management. Moreover, Plunkett and Dale argue that only a few of the references are required to encapsulate almost everything worth saying on the subject. Williams et al. (1999) survey the literature regarding the historical development of quality costing, the different opinions on CoQ definitions, the collection and use of CoQ data, and the view of the CoQ concept in accounting literature. Moreover, published quality-cost data from corporations, industries and industry groups as well as CoQ experience from individual companies are presented including several references reporting on the case studies with successful CoQ experience. This work represents a good starting point for anybody surveying best practices in the quality costing literature. Shah and FitzRoy (1998) present the surveys of quality costs conducted in various countries. The authors conclude that the concept of reporting quality cost data is not widely accepted by firms in any part of the world. They focus on the collection and measurement of CoQ experiences and also point out the shortage of quality cost surveys.

Some papers surveying CoQ models have already been published. For example, Tsai (1998) in his article on CoQ under activity-based costing carries out a review of the known CoQ models and the literature related to them. The main focus is however put on the prevention-appraisal-failure (P-A-F) scheme. Porter and Rayner (1992) make a more comprehensive survey of the published literature and present a detailed review of quality cost models, focusing again mainly on the P-A-F category and its limitations. Nevertheless, attention is drawn to other approaches such as Juran's scheme or process cost models, and the use of the models that would integrate both the costs and benefits of quality improvement. Plunkett and Dale (1988a) propose categorization of all P-A-F models found in the literature into five groups, discuss them in the light of their research experience, and conclude that many of the published models are inaccurate and misleading. Burgess (1996) later examined this classification and reduced the five types of CoQ models into three categories. In the latter two references, a survey was made of various models that follow the P-A-F approach emphasizing the many differences between these models in terms of the relationships between major quality cost categories; however, other quality cost models were not discussed at all.

Otherwise, no other literature reviews surveying CoQ models have been found. Moreover, so far no work has been published, which would attempt to present, analyze and summarize a greater number of the case studies discussing the published evidence of successful best practices in the CoQ field. This paper intends to fill this gap. It opens by presenting a literature review focused on existing CoQ models; then, it briefly discusses the choice of CoQ parameters and the metrics used for measuring CoQ effort. Finally, there is a summary and an analysis of the published cases of CoQ best practices.

Review of CoQ Models

Plunkett and Dale (1987) suggest that the most striking feature of their literature review is the preoccupation with the prevention-appraisal-failure (P-A-F) model. Indeed, most of the literature reviewed in the current paper report on the classical P-A-F model. However, as Table I suggests, the P-A-F concept is not the only one, since other models were found to be developed, discussed and used as well. This work classifies CoQ models into four groups of generic models. These are: P-A-F or Crosby's model, opportunity cost models, process cost models and ABC (activity based costing) models. Obviously, models within one group are not identical; as a matter of fact, they can differ quite substantially and the suggested categorization only denotes the common underlying principles.

Table I: Generic CoQ models and cost categories

<i>Generic model</i>	<i>Cost/activity categories</i>	<i>Examples of publications describing, analyzing or developing the model</i>
P-A-F models	prevention + appraisal + failure	Feigenbaum, 1956; Purgslove and Dale, 1995; Merino, 1988; Chang et al., 1996; Sorquist, 1997b; Plunkett and Dale, 1988b; Tatikonda and Tatikonda, 1996, Bottorff, 1997; Israeli and Fisher, 1991, Gupta and Campbell, 1995; Burgess, 1994; Dawes, 1989; Sumanth and Arora, 1992; Morse, 1983; etc.
Crosby's model	conformance + non-conformance	Suminsky, 1994; Denton and Kowalski, 1988
Opportunity or intangible cost models	prevention + appraisal + failure + opportunity	Sandoval-Chavez and Beruvides, 1998; Modarres and Ansari, 1987
	conformance + non-conformance + opportunity	Carr, 1992; Malchi and McGurk, 2001
	tangibles + intangibles	Juran et al., 1975
	P-A-F (failure cost includes opportunity cost)	Heagy, 1991
Process cost models	conformance + non-conformance	Ross, 1977; Marsh, 1989; Goulden and Rawlins, 1995; Crossfield and Dale, 1990
ABC models	value-added + non-value-added	Cooper, 1988; Cooper and Kaplan, 1988; Tsai, 1998; Jorgenson and Enkerlin, 1992; Dawes and Siff, 1993; Hester, 1993

Most CoQ models are based on the *P-A-F* classification (Plunkett and Dale, 1987; Machowski and Dale, 1998; Sandoval-Chávez and Beruvides, 1997). It was Armand Feigenbaum, who in 1943 first devised a quality costing analysis when he and his team developed a dollar-based reporting system (Harrington, 2002). Joseph Juran (1951) initiated the concept of quality costing, the economics of quality and the graphical form of the CoQ model. and Armand Feigenbaum (1956) later proposed the now widely accepted quality cost categorization of prevention, appraisal and failure (internal and external) costs. Prevention costs are associated with actions taken to ensure that a process provides quality products and services, appraisal costs are associated with measuring the level of quality attained by the process, and failure costs are incurred to correct quality in products and services before (internal) or after (external) delivery to the customer. Juran later highlighted the traditional tradeoff that contrasts prevention plus appraisal costs with failure costs (Juran, 1962). The basic suppositions of the P-A-F model are that investment in prevention and appraisal activities will reduce failure costs, and that further investment in prevention activities will reduce appraisal costs (Porter and Rayner, 1992; Plunkett and Dale, 1987). The objective of a CoQ system is to find the level of quality that minimizes total cost of quality. Feigenbaum's and Juran's P-A-F scheme has been adopted by the American Society for Quality Control (ASQC, 1970), and the British Standard Institute (BS6143, 1990), and is employed by most of the companies which use quality costing (Porter and Rayner, 1992).

The above-mentioned classical view of quality cost behavior in the P-A-F model holds that an optimum economic quality exists at the level at which the cost of securing higher quality would exceed the benefits of the improved quality (BS 4778, 1987). This concept is, however, often challenged, and it is argued that there is no economic level of quality, that the spending on prevention could be always justified and that optimum quality level in fact equals zero defects (for example, Fox 1989; Plunkett and Dale 1988a; Price, 1984; Schneiderman 1986). These and other numerous references (for example, Porter and Rayner, 1992; Cole, 1992, Shank and Govindarajan, 1994) discuss the two conflicting views of the economic level of quality costs that are shown in Figure 1. The results of the quality cost simulation study of Burgess (1996) suggest that both views can be reconciled within one model. Burgess supports the classical view in certain time constrained conditions, whereas under an infinite time horizon the modern view prevails. Similarly, Fine (1986), Dawes (1989), Marcellus and Dada (1991) and Love (1995) suggest that the traditional trade-off model may be an accurate, static representation of quality cost economics, but that in dynamic, multiperiod settings, failure costs can continue to decline over time with no corresponding increase in prevention and appraisal costs. Ittner (1996) provides empirical evidence to support this behavior. Despite the continuing discussion on economic quality levels, the basic principles of the P-A-F categorization are still generally recognized and accepted.

The cost categories of **Crosby's model** (Crosby, 1979) are similar to the P-A-F scheme. Crosby sees quality as "conformance to requirements", and therefore, defines the cost of quality as the sum of price of conformance and price of non-conformance (Crosby, 1979). The price of conformance is the cost involved in making certain that things are done right the first time, which includes actual prevention and appraisal costs, and the price of non-conformance is the money wasted when work fails to conform to customer requirements, usually calculated by quantifying the cost of correcting, reworking or scrapping, which corresponds to actual failure

costs. The model is used in companies that measure quality costs; however, most of the time it is only a different terminology describing a P-A-F model (Goulden and Rawlins, 1995), and the two costing structures are used interchangeably.

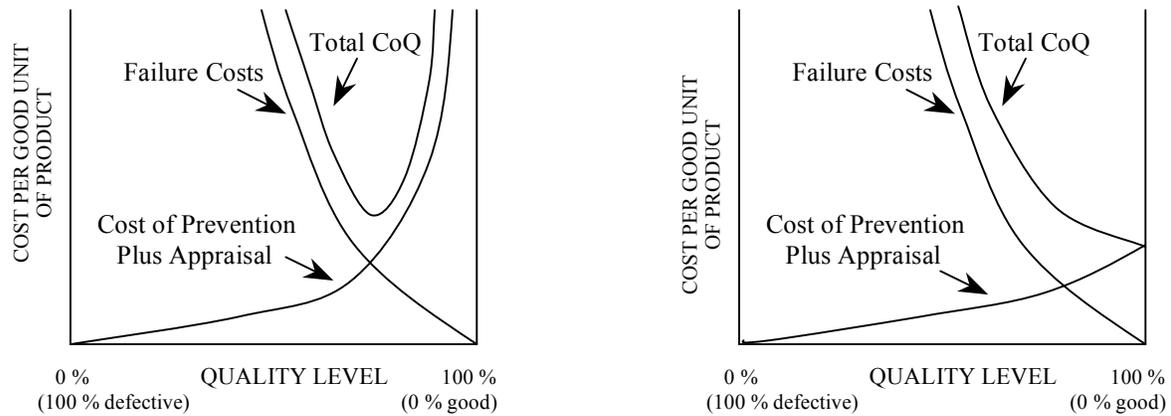


Figure 1: Classical view on the left and the modern view on the right

The importance of **opportunity and intangible costs** has been recently emphasized. Intangible costs are costs that can be only estimated such as profits not earned because of lost customers and reduction in revenue owing to non-conformance. Sandoval-Chavez and Beruvides (1998) incorporate opportunity losses into traditional P-A-F quality expenses. According to them, opportunity losses may be broken down into three components: underutilization of installed capacity, inadequate material handling and poor delivery of service. They express total CoQ as revenue lost and profit not earned. Modarress and Ansari (1987) also advocate that the P-A-F model be expanded to accommodate extra dimensions that are identified as the cost of inefficient resource utilization and quality design cost. Carr (1992) includes opportunity cost and reports evidence of its successful use in a quality program. Quality costs are defined in three categories: the cost of conformance, the cost of non-conformance and the cost of lost opportunity. Other authors address the cost of lost customers derived from product failures that reach the market (Tatikonda and Tatikonda, 1996; Heagy, 1991). Juran's model (Juran et al., 1951) also recognizes the importance of intangibles. His CoQ scheme includes two measurable cost categories: tangible factory costs and tangible sales costs, and he suggests the inclusion of intangible internal benefits. Albright and Roth (1992) have proposed Taguchi's quality loss function as a means of estimating quality costs that are hidden by accounting systems. Kim and Liao (1994) have extended the usefulness of this concept by developing various forms of quality loss functions and have showed how different loss functions can be used for measuring hidden quality costs for any variation of the actual value from the target value of designated characteristics of a product.

The **process cost model** developed by Ross (1977) and first used for quality costing by Marsh (1989) represents quality cost systems that focus on process rather than products or services. Process cost is the total cost of conformance and non-conformance for a particular process. The cost of conformance is the actual process cost of producing products or services first time to the required standards by a given specified process, whereas cost of non-conformance is the failure cost associated with the process not being executed to the required

standard. These costs can be measured at any step of the process. Accordingly, it can be determined whether high non-conformance costs show the requirement for further expenditure on failure prevention activities or whether excessive conformance costs indicate the need for a process redesign (Porter and Rayner, 1992).

The process modeling method called IDEF (the computer-aided manufacturing integrated program definition methodology) developed by Ross (1977) is useful for experts in system modeling; nevertheless, for common use by managers or staff it is too complex. Simpler methods were developed to overcome this limitation. Crossfield and Dale (1990) suggest a method for the mapping of quality assurance procedures, information flows and quality-related responsibilities. Goulden and Rawlins (1995) utilize a hybrid model for process quality costing where flowcharts are used to represent the main processes.

The use of a process cost model is suggested as a preferred method for quality costing within total quality management (TQM) as it recognizes the importance of process cost measurement and ownership, and presents a more integrated approach to quality than a P-A-F model (Porter and Rayner, 1992). Goulden and Rawlins (1995) also suggest that analysts place emphasis on the cost of each process rather than on an arbitrarily defined cost of quality under a P-A-F model. Moreover, the quality cost categorization is simpler and some researchers (Porter and Rayner, 1992) argue that it is also more relevant than the P-A-F scheme. The process model has wider application in that it facilitates the collection and analysis of quality costs for both direct and indirect functions. However, the process cost model is not in widespread use (Goulden and Rawlins, 1995).

Existing accounting systems are usually considered as poorly fitted for generating reports on quality measurements (Tatikonda and Tatikonda, 1996; Sorqvist, 1997a, Mandel, 1972). They do not provide appropriate quality related data, and benefits resulting from improved quality are not measured (Merino, 1988). Although most CoQ measurement methods are activity/process oriented, traditional cost accounting establishes cost accounts by the categories of expenses instead of activities. Thus, many CoQ elements need to be estimated or collected by other methods. There is no consensus method on how to allocate overheads to CoQ elements and no adequate method to trace quality costs to their sources (Tsai, 1998). An **activity-based costing** (ABC) model was developed by Cooper and Kaplan (Cooper, 1988; Cooper and Kaplan, 1988) to solve this problem. Under ABC, accurate costs for various cost objects are achieved by tracing resource costs to their respective activities and the cost of activities to cost objects. The ABC approach is actually not a CoQ model. It is an alternative approach that can be used to identify, quantify and allocate quality costs among products, and therefore, helps to manage quality costs more effectively. Tsai (1998) proposes an integrated CoQ-ABC framework, in which ABC and CoQ systems are merged and share a common database in order to supply various cost and non-financial information for related management techniques. The long-term goal of ABC systems is to eliminate non-value added activities and to continuously improve processes, activities and quality so that no defects are produced.

Other methods for collecting quality costs and establishing a quality costing system have been proposed in the literature. For instance, a less formal method based on collecting quality costs by department is described by Dale and Plunkett (1999), and a method based on a team

approach, in which the aim is to identify the costs associated with things which have gone wrong in a process is outlined by Robison (1997).

CoQ Parameters

There are many possible parameters that can be used in CoQ models and BS 6143 lists the cost elements to be included in the P-A-F model. Also Johnson (1995) or Atkinson et al. (1991) suggest exhaustive lists of example CoQ elements. However, any recommended list can serve only as a guideline and for provoking thoughts. A suggested list is particularly useful if it is industry-related because each particular industrial sector has its unique quality cost elements (Plunkett and Dale, 1986). For example, Abed and Dale (1987) have outlined a list of typical quality cost elements relevant to textile manufacturing organizations. Since there is no set structure and no accounting standard for quality costing, the decision on the cost structure of the CoQ model is left to the judgment of quality managers or even quality data collectors. Therefore, the elements included in CoQ models of various companies differ substantially. The same elements are often placed into different cost categories or they are even defined in a different way in order to fit the particular needs of a company (Sorqvist, 1997a; Johnson, 1995). In order to identify cost of quality elements, some organizations benchmark or borrow elements from other companies, which have established CoQ programs (Bemowski, 1991). Nevertheless, most quality experts say that CoQ programs should be tailor-made for each organization such that they are integrated into a company's organizational structure and accounting system rather than just being borrowed (Campanella, 1990; Johnson, 1995; Salm, 1991; Purgslove and Dale 1996). Campanella (1990) emphasizes that decisions regarding which cost elements should be part of CoQ and to which cost category they should belong are not as important as consistency. According to him companies should have a consistent set of comparisons that are made from period to period as the CoQ program evolves; quality cost elements should be developed, deleted, modified, or combined as seems reasonable.

CoQ Metrics

CoQ measurement systems should contain good feedback metrics as well as a mixture of global and detailed metrics. The latter actually represent the elements of CoQ and how the performance of these elements is measured. Some examples of detailed metrics are given in Table II. Global quality metrics measure global performance. Some examples are given in Table III. Return on quality (RoQ), defined as the increase in profit divided by the cost of the quality improvement program, is the most frequently mentioned global metric in the context of CoQ (Tatikonda and Tatikonda, 1996; Slaughter et al., 1998). The other metrics in Table III are suggested by the authors of this paper. Tatikonda and Tatikonda (1996) claim that successful companies (for instance, AT&T) measure RoQ as a basis for accepting quality improvement projects. Return on quality also serves as a tool to select a better alternative among competing improvement programs. Slaughter et al. (1998) modify RoQ for use in the software environment and introduce three new quality metrics: return on software quality, cost of software quality, and software quality probability index. Otherwise, very little has been published on metrics for CoQ.

Use of CoQ Models in Practice

No matter how great the interest of the academic community in CoQ models is, and how much theoretical information and practical advice can be found, the situation in the real world is different. The results of numerous industry surveys or research studies confirm that CoQ is not a

widely used concept (for example, Shah and FitzRoy, 1998; Plunkett and Dale, 1987; Morse, 1991, Wheldon and Ross, 1998; Duncalf and Dale, 1985; Plunkett and Dale, 1986). Quality cost calculations are not common even among the recipients of the Malcolm Baldrige National Quality Award (Batz, 1992). Quality guru Philip Crosby states that nothing in his 30 years of work as a quality professional has disappointed him as much as the way the concept of CoQ is not used. He adds that he “has never seen a company that had its cost of quality figured out right or used properly” (Crosby, 1983).

Table II: Examples of detailed metrics for CoQ

Detailed Metrics
cost of assets and materials
cost of preventive labor
cost of appraisal labor
cost of defects per 100 pieces
cost of late deliveries
% of repeat sales
time between service calls
of non-conforming calls
of complaints received

Table III: Global metrics for CoQ

Metric
RoQ = $\frac{\text{increase in profit}}{\text{cost of quality improvement program}}$
Quality rate = $\frac{\text{input} - (\text{quality defects} + \text{startup defects} + \text{rework})}{\text{input}}$
Process quality = $\frac{\text{available time} - \text{rework time}}{\text{available time}}$
First time quality (% product with no rework)

Companies rarely have a realistic idea of how much profit they are losing through poor quality. Smaller firms most often do not even have any quality budget and do not attempt to monitor quality costs (Porter and Rayner, 1992; Plunkett and Dale, 1983). Large companies usually claim to assess quality costs (Schmahl et al., 1997; Allen and Oakland, 1988; Chen, 1992); however, according to Tatikonda and Tatikonda (1996) and Morse (1991), even though most managers claim that quality is their top priority, only a small number of them really measure the results of quality improvement programs. Even in companies that do measure results, quality costs are grossly understated (Porter and Rayner, 1992; Schmahl et al., 1997; Tatikonda and Tatikonda, 1996). Few of the companies claiming that they monitor quality costs have an established framework for the collection across the full range of quality cost categories (Duncalf and Dale, 1985). Moreover, companies measure visible and quantifiable costs such as scrap and warranty, but ignore significant costs such as lost sales due to customer defection (Porter and Rayner, 1992; Schmahl et al., 1997; Tatikonda and Tatikonda, 1996). A high proportion of the costs have proven difficult to measure and have therefore remained hidden (Sorqvist, 1997b).

Measuring return on quality is not a common practice (Tatikonda and Tatikonda, 1996). Spending money on quality improvement programs without ever estimating expected benefits leads to investment with little or no impact on the bottom line. Even though quality is now widely acknowledged as a key competitive weapon, it seems that there is a lack of quality vision and commitment among top management.

There is a reasonable amount of detailed advice available on CoQ, but there are only a few published, practical examples that give specifics about the costs that are included or excluded in quality costing, and how the costs are collected. Nevertheless, most examples confirm that quality improvement and cost measurement processes bring about a huge reduction in a company's cost of quality. A brief description of the documented cases of successful use of CoQ models and methods is given in Table IV.

Table IV shows that the majority of companies implement their CoQ programs in accordance with the universally accepted Feigenbaum's costing structure (Feigenbaum, 1956). Some examples of the case studies based on the use of the **P-A-F model** follow.

The successes of multinational corporation, ITT, that implemented a CoQ system are often cited in the literature. Grocock (1980) presents how ITT Europe headquartered in Belgium coped with the quality cost control and saved over \$150 million during 5 years, and both Hagan (1973) and Morse et al. (1987) describe the efforts of ITT New York towards reducing CoQ and report huge savings for the company. Another two examples of success stories come from the telecommunication industry. United Technologies Corporation, Essex Telecommunication Products Division, established CoQ measurement based on a P-A-F model, and five years of implementation have yielded a productivity improvement of 26%. Specific accomplishments as well as elements of the cost of quality calculation and their relationship to financial performance are examined in detail by Fruin (1986). Thompson and Nakamura (1987) also follow P-A-F quality costing structure and propose a plan, which is currently being used to collect and report CoQ data from several development projects at AT&T Bell Laboratories, Transmission Systems Division. They suggest that managing CoQ in the R&D process is an effective way to improve product development. The works of Purgslove and Dale (1995, 1996) discuss the development and operation of a system of quality costing at a manufacturer of coatings for industrial applications. They report that the investment made in quality improvement and in the CoQ measurement system was paid back within the first year. Denzer (1978) presents a description of a P-A-F cost of quality system used in an electronics manufacturing facility and indicates significant quality cost reduction. Moreover, he shows that the collection and use of quality costs are an aid to management and are accompanied by improvement of quality.

Table IV presents a lot of other successful cases of CoQ model implementation, where the classical P-A-F model was used. Many authors offer only a brief analysis of the studied case; however, some of the references provide an excellent source of information containing hands-on industrial experience. For example, Whitehall (1986) investigates many possible problems that could arise during the development and implementation of a quality costing system based on his experience at Ferranti Defence Systems. He discusses the crucial issues and suggests some alternative strategies. Purgslove and Dale (1996) give specific details on the development and setting up of a quality costing system, including the collection, reporting and analyzing of the quality cost data. The major difficulties that were encountered are discussed in detail. Hesford

Table IV: Documented cases of successful use of CoQ models and methods

<i>Company</i>	<i>Industry</i>	<i>CoQ calculation</i>	<i>Base for CoQ calculation</i>	<i>Reported gains</i>	<i>Reference</i>
P-A-F model					
United Technologies/ Essex Group, USA	telecommuni- cations	CoQ = P+A+F	% of total manufacturing cost % of cost of goods produced	<ul style="list-style-type: none"> • CoQ reduced from 23.3% to 17.2% in 5 years. • gain in productivity of 26% 	Fruin, 1986
AT&T Bell Laboratories	telecommuni- cations	CoQ = P+A+IF+EF	% of project budget		Thompson and Nakamura, 1987
Hydro Coatings, UK	industrial coatings manufacturing	CoQ = P+A+IF+EF	% of annual sales turnover % of raw material usage	<ul style="list-style-type: none"> • CoQ reduced from 4.1% to 2.5% in 4 years. • investment in quality paid back in the first year. 	Purgslove and Dale, 1995; Purgslove and Dale, 1996
Philips Power Semiconductor Business Group, UK	electronics	CoQ = P + A + CONC	% of factory turnover	<ul style="list-style-type: none"> • CoQ reduced from 35.8% to 18.1% in 4 years • workforce reduced by 25% in 18 months • output increased by 25% in 18 months 	Payne, 1992
York International, UK	air conditioning and refrigeration	CoQ = P+A+IF+EF	% to cost of sales	<ul style="list-style-type: none"> • CoQ reduced from 13.5% to 3.7% in 8 years • the cost of factory failures reduced by 96% 	Knock, 1992
British Aerospace Dynamics, UK	aerospace	CoQ = P+A+F	% of total manufacturing cost	<ul style="list-style-type: none"> • objective to reduce CoQ by one third in one year 	Hesford and Dale, 1991
ITT Europe, Belgium	information technology	CoQ = P+A+F	% of sales	<ul style="list-style-type: none"> • Savings from CoQ improvement program totaled over \$ 150 million in 5 years 	Grocock, 1980
Allis-Chalmers Corporation, US	machinery manufacturing	CoQ = P+A+IF+EF	% of product sales	<ul style="list-style-type: none"> • CoQ reduced from 4.5% to 1.5% in 3 years 	Kohl, 1976

<i>Company</i>	<i>Industry</i>	<i>CoQ calculation</i>	<i>Base for CoQ calculation</i>	<i>Reported gains</i>	<i>Reference</i>
Herbert Machine Tools, UK	machine-tool industry	CoQ = P+A+IF+EF	% of sales	<ul style="list-style-type: none"> CoQ reduced from 7.5% to 5.9% in 4 years 	Burns, 1976
Raytheon's Electronic Systems	software	CoQ = P + A + Rework Cost	% of total project costs	<ul style="list-style-type: none"> CoQ reduced from 65% to 15% in 8 years Rework Cost reduced from 40% to 6% the overall payoff was 7.5 times a 170% increase in software productivity 	Campanella, 1999
major electrical firm	electrical	CoQ = P+A+IF+EF	% of sales	<ul style="list-style-type: none"> CoQ reduced from 5.4% to 4.6% in first year 	Campanella, 1999
Ferranti Defense Systems, UK	electronics, electro-mechanical equipment	CoQ = P+A+F	% of total costs		Whitehall, 1986
National Cash Register Company, Germany	precision mechanics	CoQ = P+A+F	probably % of total manufacturing cost	<ul style="list-style-type: none"> CoQ reduced from 6,4% to 4,4% in 6 years 	Krzikowski, 1963
North American Philips Consumer Electronics	consumer electronics	CoQ = P+A+IF+EF	% of standard product cost % of direct labor		Morse et al. 1987
ITT Corp. New York, USA	information technology	CoQ = P+A+F	% of sales	<ul style="list-style-type: none"> CoQ reduced from 12% to 5,5% by reducing CoQ the company has saved hundreds of millions of dollars in first 5 years 	Hagan, 1973 Morse et al. 1987
Travenol Laboratories, USA	medical devices, pharmaceutical	CoQ = P+A+F			Tsiakals, 1983
Hermes Electronics	military electronics	CoQ = P+A+IF+EF	% of sales	<ul style="list-style-type: none"> scrap and rework reduced by 30% during one year 	Breeze, 1981

<i>Company</i>	<i>Industry</i>	<i>CoQ calculation</i>	<i>Base for CoQ calculation</i>	<i>Reported gains</i>	<i>Reference</i>
Banc One Corporation, USA	financial services	CoQ = P+A+IF+EF	% of operating expense	<ul style="list-style-type: none"> net income enhanced by \$20 million annually substantial improvements in service levels and operating costs 	Atkinson et al. 1991, Campanella, 1999
Cascade Engineering, USA	automotive supplies	CoQ = P+A+IF+EF	% of sales		Atkinson et al. 1991
electronic manufacturer	electronics	CoQ = P+A+IF+EF	% of sales		Denzer, 1978
Crosby's model					
Solid State Circuits		CoQ = COC + CONC	% of the revenue	<ul style="list-style-type: none"> CoQ reduced from 37% to 17% 	Denton and Kowalski, 1988
BDM International	software	CoQ = COC + CONC	in \$ per line of code	CoQ reduced by 50% in 8 years	Slaughter et al., 1998
Opportunity and alternative cost models					
US Marketing Group of Xerox, USA	service business	CoQ = P + A + IF + EF + ExR + OC	% of sales revenue	<ul style="list-style-type: none"> CoQ reduced by \$54 million in first year. 	Carr, 1992
Rank Xerox, UK	office equipment	CoQ = P + A + IF + EF + ExR + OC	% of total manufacturing cost	<ul style="list-style-type: none"> CoQ reduced from 6% to 1% in 5 years defects rate reduced by over 75% 	Huckett, 1985
Reprographic Manufacturing Operations Unit of Xerox, USA	office equipment	CoQ = P + A + IF + EF + ExR + OC	% of the standard cost of production	<ul style="list-style-type: none"> CoQ reduced by 50% 	Morse et al. 1987
pharmaceutical company	pharmaceutical	CoQ = Operating Cost + CONC + Alternative Cost		<ul style="list-style-type: none"> CoQ reduced by 11% 	Malchi and McGurk, 2001

<i>Company</i>	<i>Industry</i>	<i>CoQ calculation</i>	<i>Base for CoQ calculation</i>	<i>Reported gains</i>	<i>Reference</i>
Westinghouse Semiconductor Division, USA		CoQ = P+A+F (F includes opportunity costs)		<ul style="list-style-type: none"> overall productivity increased by 15% in 4 years scrap reduced by 58% resulting in savings of over \$2,4 million material returned by customer reduced by 69% resulting in savings of over \$600 000 	Forys, 1986
Lebanon Steel Foundry, USA	steel casting	CoQ = P+A+F (F includes Quality Image Loss)	% of sales	<ul style="list-style-type: none"> objective to reduce failure costs by 50% 	Moyer and Gilmore, 1979
Process model					
GEC Alsthom Engineering Systems		CoQ = COC + CONC			Goulden and Rawlins, 1995
ABC model					
Networked Computer Manufacturing Operation of Hewlett-Packard, USA	computer systems	CoQ = Process Quality + Board Test + Repair + Bench Test + Defect Analysis		<ul style="list-style-type: none"> CoQ reduced by 25% in 1 year 	Jorgenson and Enkerlin, 1992

CoQ cost of quality
 P prevention cost
 A appraisal cost
 F (IF+EF) failure cost (internal and external failures)
 ExR exceeding requirements
 COC cost of conformance
 CONC cost of non-conformance
 OC opportunity cost

and Dale (1991) describe their experience with the development and use of a quality costing model at British Aerospace (Dynamics) and give special attention to the analysis of the problems encountered.

Crosby's model (Crosby, 1979), in which CoQ is expressed as the sum of cost of conformance and cost of non-conformance, is documented to have been successfully used for quality improvement programs at several companies. Solid State Circuits, a manufacturer of printed circuits boards, has designed new methods of measuring conforming and non-conforming costs and the use of such methods has led to the identification of causes of error and the devising of means of correcting them. Denton and Kowalski (1988) describe this quality improvement and measurement process and report a drop from 37% to 17% in the company's cost of quality. Slaughter et al. (1998) have carried out a detailed study on the economics of software quality at BDM International, a major information technology company. They use marginal analysis of non-conformance costs to identify the greatest cost impacts of defect reduction during their quality initiatives and present their successful results. The paper includes a number of important insights for software managers who are interested in improving their decisions on software quality expenditures.

Use of **opportunity or intangible costs** for CoQ improvement programs has already provided sound results. Xerox was the first company to use opportunity cost in order to determine the CoQ. Quality cost figures include prevention, appraisal, internal and external failure costs, exceeding requirements (the costs incurred to provide unnecessary or unimportant information or service, for which no requirement has been established) and the cost of lost opportunity (profit not earned owing to lost customers and reduction in revenue because of non-conformance). Rank Xerox in England used this quality costing scheme and achieved an 83% reduction in CoQ and higher customer satisfaction. The quality improvement process at Rank Xerox is reviewed in detail by Huckett (1985). Morse et al. (1987) examine the development of the CoQ process at Reprographic Manufacturing Operations of Xerox headquartered in New York, which accepted the same quality costing concept, and reports a 50% reduction in CoQ. Carr (1992) describes the program based on the same costing categorization adopted by the US Marketing Group of Xerox. The program consists of a system of quality cost measures and cost of quality concepts specifically adapted to the service industry. A reduction in CoQ of \$54 million is reported in the first year of quality improvement efforts.

Xerox is not the only company that has achieved success with the use of the opportunity costs. Malchi and McGurk (2001) discuss the methodology of measuring CoQ, which includes so-called alternative costs in the total CoQ. Alternative costs are hidden costs, and examples are lost sales, extra inventory, delays and unidentified scrap. They present a case study of implementation of this CoQ program in a pharmaceutical manufacturing facility, where implementing this methodology resulted in an 11% reduction in the cost of quality. Moyer and Gilmore (1979) make an economic cost analysis at Lebanon Steel Foundry and reveal a potential for huge quality cost reductions. A classical P-A-F scheme is used; however, it includes an intangible category, Quality Image Loss, within failure costs, which should reflect the loss of business due to poor quality. Also Forsys (1986) reports a successful case of Westinghouse Semiconductor Division, where such intangible and opportunity costs as white collar lost time, interest lost on uncollected receivables or interest lost on invoicing delays are calculated or estimated in the company's CoQ model.

A quality costing system using the **process approach** has been successfully designed and implemented within the power systems division of GEC Alsthom Engineering Systems. Goulden and Rawlins (1995) describe this hybrid process model, which uses flowcharts. These were found to be most effective process modeling tools as they facilitated understanding and better interdepartmental communication.

Since **activity-based costing** (ABC) is considered more compatible with quality cost measurement systems than traditional accounting, its use for a CoQ determination is an appealing alternative. Jorgenson and Enkerlin (1992) describe how a Hewlett-Packard manufacturing operation utilized its ABC system to identify, quantify and allocate quality costs among its products. Having this information allowed product teams to simulate and reduce quality costs earlier in the product design phase.

Discussion of the Published Case Studies

Based on the documented cases, the model most frequently used at companies is the classical Feigenbaum's prevention-appraisal-failure model. Results of the literature review support this finding as well. If companies use quality costing, they usually employ the P-A-F model (Porter and Rayner, 1992). Nevertheless, the P-A-F categorization is only a basic concept and the concrete costing systems still differ considerably from company to company. Every model is usually adjusted according to the company's needs; different subcategories and groupings are used; and the various costs and elements are defined in a different way. The underlying principles of the P-A-F approach however remain unchanged.

There are only a few slight deviations observable in Table IV in the basic structure of the P-A-F model. For example, some of the mentioned firms combine both external and internal failure costs into one failure category. Even though most of the references avoid combining these two categories, many authors (for example, Hesford and Dale, 1991; Krzikowski, 1963; Fruin (1986; Payne, 1992; Groocock, 1980; Campanella, 1999; Whitehall, 1986; Hagan, 1973) report the existence of such costing systems. Hesford and Dale (1991) warn against the dangers in combining these costs, since some external quality costs may become hidden within the total failure cost figure, which could consequently result in the lack of appropriate action.

Another slight difference consists in the naming of the categories in the P-A-F models. Payne (1992) reports on a quality costing model which includes prevention, appraisal and non-conformance costs. Similarly, prevention, appraisal and rework categories were used for the CoQ model described by Campanella (1999). In neither case, is it explained why the usual "failure cost" category was omitted and substituted by other. Moreover, two of the case studies (Denton and Kowalski, 1988; Slaughter et al., 1998) using Crosby's conformance and non-conformance cost classification technically follow the same P-A-F costing concept only with different terminology.

The results show that some companies are realizing the importance of opportunity and intangible costs (especially a loss of company's reputation), since they attempt to include them in the costing scheme. Several references (Burns, 1976; Dale and Wan, 2002) acknowledge these costs; however, they usually consider it too difficult to quantify them (Moyer and Gilmore, 1979) and these costs are at the end excluded from their calculations.

However, Heagy (1991) claims that in order for the CoQ model to be appropriate for today's business environment, it has to include certain opportunity costs, as the cost of lost sales. Heagy suggests that incorporating the cost of lost sales increases optimum quality cost and ignoring this cost can lead to poor decisions as to how much to spend on the various components of quality cost. Moreover, the loss of the company's image could be much more costly than is usually expected, and it is the intangible perception of the customer which is the main determinant. Research has shown that companies perceived by customers to have superior quality are up to three times more profitable than those perceived to have inferior quality (Malchi and Gurk, 2001). The lost reputation and the perception of the company's inferiority consequently make customers leave for another competitor. Reichheld and Sasser (1990) give evidence of the surprisingly powerful impact of customer defections on the bottom line. They suggest that companies can boost profits by almost 100% by retaining just 5% more of their customers. The importance of the intangibles therefore should not be underestimated.

Table IV suggests that there is considerable variation in measured CoQ percentages at various companies. The inconsistency in quality cost figures should be explained by the fact that the structure of the CoQ models often differs substantially among companies. The most visible difference observed in Table IV is the variety of the selected bases for CoQ calculation. The most frequently used among the studied companies is a calculation of CoQ as a percentage of total sales or company turnover; however, other bases such as percentage of total manufacturing cost, percentage of operating cost, percentage of total product cost or percentage of total labor cost are used as well. Also other CoQ calculation bases, for example quality cost as a percentage of value-added or quality cost per unit of output is reported as being used in industry (Gilmore, 1983).

Even if the same calculation base is used, there are still wide variations in published figures, because every quality costing system is usually adjusted according to every company's specific needs, and different elements are included or deemed unimportant and left out of the calculations. This depends mostly on the element's significance in the total quality cost figure and on the difficulty of its measurement and collection. The CoQ calculations in reported cases were often preceded by Pareto analysis of the cost elements, which pointed out the "important few", and the calculations were then customized accordingly. Therefore, it is infeasible to get an exact figure of the CoQ for a company, and the results at various companies will always be inconsistent.

Another finding of this research is in the area of the industry segments. The results suggest that quality cost measurements are more frequently made in electronics and other high-tech industries. The business environment for an industry sector and product line dictates somewhat the amount of effort that is put into a continuous quality program. It could be supposed that companies that work in industries that require very high levels of quality would have quite elaborate quality and productivity improvement systems, that they manage to obtain satisfying results from these programs, and that they report their successes. Other companies work within certain determined quality limits that are deemed to be sufficient without even considering implementation of a CoQ strategy. However, a closer look at Table IV reveals that companies from other industries implement CoQ programs as well. For instance, the case studies from the steelmaking industry (Moyer and Gilmore, 1979) or service companies (Carr, 1992; Atkinson, 1991 or Bohan and Horney, 1991) report evidence of the successful use of the CoQ

methodology. The CoQ approach is universal, flexible and could be adapted to any business setting.

The documented examples of CoQ improvement programs were successful. They brought about sufficient savings to justify CoQ measurement expenses, and they yielded a good productivity gain and reduction in quality costs. More importantly, they identified target areas for cost reduction and quality improvement. But which CoQ system was the best? Even though some references present a detailed account of the methodology of quality cost collection, some of the authors give only a brief outline sufficient to explain their results. Without any detailed knowledge of the company's concrete methodology and ability to make an analysis of every mentioned quality costing method, it is difficult to evaluate the results of a company's effort. Percentage reductions in cost mentioned in Table IV do suggest the level of the success using the CoQ methodology; nevertheless, it is impossible to make any conclusion as to which quality costing program was superior, and it must be concluded that any CoQ method has a chance to succeed if it suits the purpose and the needs of the company. This conclusion corresponds with Dale and Wan's results of the study of an evaluation of four separate quality costing methods in one company (Dale and Wan, 2002). They suggest that the chosen quality costing method must suit a company's situation, be based on the concept of continuous improvement, be applicable to all departments and employ a team approach. Dale and Plunkett (1995) propose a detailed checklist of the issues which should be considered by an organization in deciding the approach to be taken to quality costing.

Concluding Remarks and Future Directions

Many research papers on CoQ propose quality cost models, methods and techniques, and provide abundant information on the topic. The literature review of the practical use of CoQ suggests that even though quality is considered to be an important issue, the CoQ approach is not fully appreciated by organizations and only a minority of them use a formal quality costing method. Nevertheless, companies usually do have quality systems and continuous improvement programs, but approach quality improvement and cost containment in many other ways. Thus, although not using CoQ as a method to drive quality costs down, they achieve the required result with different techniques.

The published examples of best practices indicate that companies that use CoQ programs have been quite successful in reducing CoQ and in improving quality for the customer. The model most commonly implemented in practice is the classical P-A-F approach; however, other quality cost categorizations are documented as being used with success. Even though the P-A-F categorization serves as a basic concept, the individual costing systems still differ considerably from company to company. Every model is usually adjusted according to the company's needs, which results in the various CoQ structures. Different subcategories and groupings are used and the various costs and elements are defined and named in a different way. Also, a variety of elements is included or deemed unimportant and left out of the calculations. Moreover, the selected bases for CoQ calculation vary as well, which causes an inconsistency in quality cost figures and makes it even more difficult to compare the results of the CoQ programs among companies. The underlying principles of the P-A-F approach however remain generally unchanged throughout the researched companies.

Further research into how successful companies take decisions with regard to quality improvement and how they reduce quality costs should be conducted. Specifically, more detailed surveys on collection and measurement of quality costs in practical settings should yield useful information about CoQ best practices, encourage companies to report quality cost data, and help them implement comprehensive quality cost systems.

CoQ measurement should be part of any quality management program. The methodology is not complex and is well documented. CoQ programs provide a good method for identification and measurement of quality costs, and thus allow targeted action for reducing CoQ. Further education on the practical level is needed for managers to understand better the CoQ concept in order to appreciate fully the benefits of the approach, to increase their ability to implement a CoQ measurement system and to save money.

References

- Abed, M.H. and Dale, B.G. (1987), *Quality Assurance*, Vol.13, No.2, p.41
- Albright, T.L. and Roth, H.P. (1992), "The Measurement of Quality Costs: An alternative Paradigm", *Accounting Horizons*, June, p.15
- Allen, N. and Oakland, J.S. (1988), "Quality assurance in the textile industry: part I.", *International Journal of Quality and Reliability Management*, Vol.5, No.5, p.25
- ASQC (1970), "Quality Costs – What and How", *American Society for Quality Control*, pp.54
- Atkinson, J.H., jr., Hohner, G., Mundt, B., Troxel, R.B. and Winchell, W. (1991), *Current Trends in Cost of Quality: Linking the Cost of Quality and Continuous Improvement*, NAA Publication, Montvale
- Baatz, E.B. (1992), "What is return on quality, and why you should care", *Electronic News*, October, p.60
- Bemowski, K. (1991), "The benchmarking bandwagon", *Quality Progress*, Vol.24
- Bohan, G.P. and Horney, F.N. (1991), "Pinpointing the real cost of quality in a service company", *National Productivity Review*, Vol.10, No.3, p.309
- Bottorff, D.L. (1997), "CoQ Systems: The right stuff", *Quality Progress*, March, p.33
- Breeze, J.D. (1981), "Quality cost can be sold: part 1", *ASQC Technical Conference Transactions*, p.795
- BS 4778 (1987), "*Quality Vocabulary*", British Standards Institute, London, 1987
- BS 6143 (1990), "*Guide to Determination and Use of Quality Related Costs*", British Standards Institute, London, 1981, p.16
- Burgess, T.F. (1996), "Modeling quality-cost dynamics", *International Journal of Quality & Reliability Management*, Vol.13, No.3, p.8
- Burns, C.R. (1976), "Quality costing used as a tool for cost reduction in the machine-tool industry", *Quality Assurance*, Vol.2, No.1, p.25

- Campanella, J. (1990), *Principles of Quality Costs. Principles, Implementation and Use*, 2nd edition, ASQC, Milwaukee
- Campanella, J. (1999), *Principles of Quality Costs. Principles, Implementation and Use*, 3rd edition, ASQC, Milwaukee
- Carr, L.P. (1992), "Applying cost of quality to a service business", *Sloan Management Reviews*, p.72, Summer
- Chang, S.J., Hyun, P.Y. and Park, E.H. (1996), "Quality costs in multi-stage manufacturing systems", *Computers & Industrial Engineering*, Vol.31, p.115
- Chen, F. (1992), "Survey of quality in Western Michigan firms", *International Journal of Quality & Reliability Management*, Vol.9, No.9, p.46
- Cole, R.E. (1992), "The quality revolution", *Productions and Operations Management*, No.1, p.118
- Cooper, R. (1988), "The rise of activity-based costing – Part I: What is an activity-based cost system?", *Journal of Cost Management*, Vol.2, No.2, p.45
- Cooper, R. and Kaplan, R.S. (1988), "Measure costs right: Make the right decisions", *Harvard Business Review*, Vol. 66, No. 5, p.96
- Crosby, P.B. (1979), *Quality is Free*, New York: McGraw-Hill
- Crosby, P.B. (1983), "Don't be defensive about the Cost of Quality", *Quality Progress*, April, p.38
- Crossfield, R.T. and Dale, B.G. (1990), "Mapping quality assurance systems: a methodology", *Quality and Reliability Engineering International*, Vol.6, No.3, p.167
- Dale, B.G. and Plunkett, J.J. (1995), *Quality Costing*, 2nd edition, Chapman and Hall, London
- Dale, B.G. and Plunkett, J.J. (1999), *Quality Costing*, 3rd edition, Gower Press, Aldershot
- Dale, B.G. and Wan, G.M. (2002), "Setting up a quality costing system. An evaluation of the key issues", *Business Process Management Journal*, Vol.8, No.2, p.104
- Dawes, E.W. (1989), "Quality costs - new concepts and methods, quality costs: ideas & applications", In Jack Campanella, Ed., *Quality costs: Ideas and applications*, Vol.2, Milwaukee: ASQC Quality Press:, p.440
- Dawes, E.W. and Siff, W. (1993), "Using quality costs for continuous improvement", *ASQC Annual Quality Congress Transactions*, p. 444
- Denton, D.K. and Kowalski, T.P. (1988), "Measuring nonconforming costs reduced manufacturer's cost of quality in product by \$200 000", *Industrial Engineering*, Vol.20, p.36
- Denzer, H.O. (1978), "Quality cost system in electronics" *Proceedings of the 5th Annual National Conference on Nuclear Power*, p.B3/1
- Duncalf, A.J. and Dale, B.G. (1985), "How British industry is making decisions on product quality", *Long Range Planning*, Vol.18, No.5, p.81
- Feigenbaum, A.V. (1956), "Total quality control", *Harvard Business Review*, Vol.34, No.6, p.93

- Fine, C.H. (1986), "Quality improvement and learning in productive systems", *Management Science*, October, Vol.31, No.10, p.1301
- Forys, J.R. (1986), "Redefining quality awareness", *Quality Progress*, January, p.14
- Fox, M.J. (1989), "The great economic quality hoax", *Quality Assurance*, Vol.15, No.2, p.72
- Fruin, R.E. (1986), "Productivity gains from company-wide quality achievements", *IEEE International Conference on Communications '86. ICC '86: Integrating the World through Communications. Conference Record*, p.163
- Gilmore, H.L. (1983), "Consumer product quality control cost revisited", *Quality Progress*, Vol.16, No.4, p.28
- Goulden, C. and Rawlins, L. (1995), "A hybrid model for process quality costing", *International Journal of Quality & Reliability Management*, Vol.12, No.8, p.32
- Groocock, J.M. (1980), "Quality cost control in ITT Europe", *Quality Assurance*, Vol.6, No.3, p.37
- Gupta, M. and Campbell, V.S. (1995), "The cost of quality", *Production and Inventory Management Journal*, Vol.36, No.3, p.43
- Hagan, J.T. (1973), "Quality costs at work", *ASQC Technical Conference Transactions*, p.307
- Harrington, H.J. (2002), "The Real Cost of Poor Quality", *Quality Digest*, June
- Heagy, C.D. (1991), "Determining optional quality costs by considering costs of lost sales", *Journal of Cost Management for the Manufacturing Industry*, p.67, Fall
- Hesford, M.G. and Dale, B.G. (1991), "Quality costing at British Aerospace Dynamics", *Proceedings of the Institution of Mechanical Engineers*, Vol.205 (G5), p.53
- Hester, W.F. (1993), "True quality cost with activity based costing", *ASQC Annual Quality Congress Transactions*, p. 446
- Huckett, J.D. (1985), "An outline of the quality improvement process at Rank Xerox", *International Journal of Quality & Reliability Management*, Vol.2, No.2, p.5
- Israeli, A. and Fisher, B. (1991), "Cutting quality costs", *Quality Progress*, January, p.46
- Ittner, C.D. (1996), "Exploratory evidence on the behavior of quality costs", *Operations Research*, Vol.44, No.1, p.114
- Johnson, M.A. (1995), "The development of measures of the cost of quality for an engineering unit", *International Journal of Quality & Reliability Management*, Vol.12, No.2, p.86
- Jorgenson, D.M. and Enkerlin, M.E. (1992), "Managing quality costs with the help of activity-based costing", *Journal of Electronics Manufacturing*, Vol.2, p.153
- Juran, J.M. (1951), *Quality Control Handbook*, 1st edition, McGraw-Hill, New York
- Juran, J.M. (1962), *Quality Control Handbook*, 1st edition, McGraw-Hill, New York
- Juran, J.M., Gryna, F.M. and Bingham, R. (1975), *Quality Control Textbook*, 3rd edition, McGraw-Hill, New York

- Kim, M.W. and Liao, W.M. (1994), "Estimating hidden quality costs with quality loss function", *Accounting Horizons*, March, p.8
- Knock, A. (1992), "Information is the key", *TQM Magazine*, Vol.4, No.2, p.99
- Kohl, W.F. (1976), "Hitting quality costs where they live", *Quality Assurance*, Vol.2, No.2, p.59
- Krzikowski, G.A. (1963), "Quality control and quality costs within the mechanical industry", *Proceedings of the 7th European Organization for Quality Conference*, Copenhagen, p.129
- Machowski, F. And Dale, B.G. (1998), "Quality Costing: An examination of knowledge, attitudes and perceptions", *Quality Management Journal*, Vol.5, No.3, p.84
- Malchi, G. and McGurk, H. (2001), "Increasing value through the measurement of the cost of quality (CoQ) – A practical approach", *Pharmaceutical Engineering*, Vol.21, No.3, p.92
- Mandel, B.J. (1972), "Quality costing systems", *Quality Progress*, Vol.5, No.12, p.11
- Marcellus, R.L. and Dada, M. (1991), "Interactive process quality improvement", *Management Science*, November, Vol.37, No.11, p.1367
- Marsh, J. (1989), "Process modeling for quality improvement", *Proceedings of the Second International Conference on Total Quality Management*, p.111
- Merino, D.N. (1988), "Economics of quality: Choosing among prevention alternatives", *International Journal of Quality & Reliability Management*, p.13, September
- Modarres, B. and Ansari, A. (1987), "Two new dimensions in the cost of quality", *International Journal of Quality & Reliability Management*, Vol.4, No.4, p.9
- Morse, W.J. (1983), "Consumer product quality control cost revisited. Measuring quality costs.", *Cost and Management*, July/August, p.16
- Morse, W.J., Roth, H.P. and Poston, K.M. (1987), *Measuring, Planning and Controlling Quality Costs*, NAA Publication, Montvale
- Morse, W.J. (1991), "A handle on quality costs", *CMA Magazine*, February, p.22
- Moyer, D.R. and Gilmore, H.L. (1979), "Product conformance in the steel foundry jobbing shop", *Quality Progress*, Vol.12, No.5, p.17
- Payne, B.J. (1992), "Accounting for improvement", *TQM Magazine*, Vol.4, No.2, p.95
- Plunkett, J.J. and Dale, B.G. (1983), "Quality costing: a study in the pressure vessel fabrication section of the process plant industry", *Quality Assurance*, Vol.9, p.93
- Plunkett, J.J. and Dale, B.B. (1986), "Quality costing: A summary of research findings", *Quality Assurance*, Vol.12, No.2, p.40
- Plunkett, J.J. and Dale, B.G. (1987), "A review of the literature on quality-related costs", *International Journal of Quality and Reliability Management*, Vol.4, No.1, p.40
- Plunkett, J.J. and Dale, B.G. (1988a), "Quality costs: A critique of some 'economic cost of quality' models", *International Journal of Production Research*, Vol.26, p.1713
- Plunkett, J.J. and Dale, B.G. (1988b), "Quality-related costing: Findings from an industry-based research study", *Engineering Management International*, No.4, p.247

- Porter, L.J. and Rayner, P. (1992), "Quality costing for total quality management", *International Journal of Production Economics*, Vol. 27, p.69
- Price, F.(1984), *Right First Time*, Gower, Aldershot
- Purgslove, A.B. and Dale, B.G. (1995), "Developing a quality costing system: Key features and outcomes", *Omega: International Journal of Management Science*, Vol.23, No.5, p.567
- Purgslove, A.B. and Dale, B.G. (1996), "The influence of management information and quality management systems on the development of quality costing", *Total Quality Management*, Vol.7, No.4, p.421
- Reichheld, F.F. and Sasser, W.E., jr. (1990), "Zero defections: Quality comes to services", *Harvard Business Review*, September/October, p.105
- Robison, J. (1997), "Integrate quality cost concepts into team problem-solving efforts", *Quality Progress*, March, p. 25
- Ross, D.T. (1977), "Structured analysis (SA): A language for communicating ideas", *IEEE Transactions on Software Engineering*, Vol.SE-3, No.1, p.16
- Salm, J.L. (1991), "Examining the cost of quality", *Manufacturing Systems*, Vol.9, No.4
- Sandoval-Chavez, D.A. and Beruvides, M.G. (1998), "Using opportunity costs to determine the cost of quality: A case study in a continuous-process industry", *Engineering Economist*, Vol.43, p.107
- Schmahl, K.E., Dessouky, Y. and Rucker, D. (1997), "Measuring the cost of quality", *Production and Inventory Management Journal*, Vol.38, p.58
- Schneiderman, A.M. (1986), "Optimum quality costs and zero defects", *Quality Progress*, November, p.28
- Shah, K.K.R. and FitzRoy, P.T. (1998), "A review of quality cost surveys", *Total Quality Management*, Vol.9, No.6, p.479
- Shank, J.K. and Govindarajan, V. (1994), "Measuring the cost of quality: A strategic cost management perspective", *Cost Management*, Summer, p.5
- Slaughter, S.A., Harter, D.E. and Krishnan, M.S. (1998), "Evaluating the cost of software quality", *Communications of the ACM*, Vol.41, p.67
- Sorqvist, L. (1997a), "Difficulties in measuring the cost of poor quality", *European Quality*, Vol.4, No.2, p.40
- Sorqvist, L. (1997b), "Effective methods for measuring the cost of poor quality", *European Quality*, Vol.4, No.3, p.42
- Sumanth, D.J. and Arora, D.P.S. (1992), "State-of-the-art on linkage between quality, quality costs and productivity", *International Journal of Materials and product Technology*, Vol.7, No.2, p.150
- Suminsky Jr., L.T. (1994), "Measuring cost of quality", *Quality Digest*, Vol.14, No.3, p.26
- Tatikonda, L.U. and Tatikonda, R.J. (1996), "Measuring and reporting the cost of quality", *Production and Inventory Management Journal*, Vol.37, p.1

Thompson Jr., W.G. and Nakamura, S. (1987), "Measuring cost of quality in the development process", *IEEE International Conference on Communications '87: Communications-Sound to Light. Proceedings*, p.1770

Tsai, W.H. (1998), "Quality cost measurement under activity-based costing", *International Journal of Quality and Reliability Management*, Vol.15, No.6, p.719

Tsiakals, J.T. (1983), "Management team seeks quality improvement from quality costs", *Quality Progress*, Vol.16, No.4, p.26

Wheldon, B. and Ross, P. (1998), "Reporting quality costs: Improvement needed", *Australian CPA*, Vol.68, No.4, p.54

Whitehall, F.B. (1986), "Review of problems with a quality cost system", *International Journal of Quality and Reliability Management*, Vol.3, No.3, p.43

Williams, A.R.T., van der Wiele, A. and Dale, B.G. (1999), "Quality costing: a management review", *International Journal of Management Reviews*, Vol.1, No.4, p.441

Autobiographical Note

Andrea Schiffauerova

PhD student

For her PhD, Ms. Schiffauerova is studying the structures of innovative networks, knowledge flows and the performance of the firms within industrial clusters. She has also participated in projects in cost of quality, technical information transfer, risk management, quality function deployment and engineering change.

École Polytechnique de Montréal
Department of Mathematics and Industrial Engineering
C.P. 6079, Succ. Centre ville
Montreal, QC, Canada, H3C 3A7
tel: 1-450-462-5778
Email: andrea.schiffauerova@polymtl.ca

Vince Thomson

Werner Graupe Professor of Manufacturing Automation

Dr. Thomson has been involved in manufacturing and information technology related research for the past 25 years at McGill University and the National Research Council (Canada). His research has ranged from shop floor control and production scheduling to the present interest in real-time control and process management in manufacturing. His process management research has focused on new product introduction, concurrent engineering and manufacturing support in terms of coordination, metrics, and process principles.

McGill University
Department of Mechanical Engineering
817 Sherbrooke Street West
Montreal, QC, Canada, H3A 2K6
tel: 1-514-398-2597, fax: 1-514-398-7365
Email: vince.thomson@mcgill.ca