Identifying, refining, measuring and analyzing the cost of quality (CoQ) (real case: a manufacturing firm)

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Abstract - This article is dedicated to identifying, screening and calculating quality costs items based on the traditional 'Prevention–Appraisal–Failure' (PAF) model in all four categories of prevention cost, appraisal cost, internal failure cost and external failure cost; for this purpose, the quality cost items are listed according to the BS 6143 standard, Juran's quality handbook and opinions of the experts; this list are refined using the Lawshe technique. In order to calculate the quality cost items in the four groups, formulas based on expert opinions have been developed and the quality cost items have been calculated and analyzed for two consecutive years.

Keywords: cost of quality (CoQ), P.A.F. model, BS 6143, Lawshe method, manufacturing firm.

Introduction

In order to improve quality, an organization must take into account the costs associated with quality since one of the goals of the improvement program is to reduce quality costs. In order to reduce quality costs, it is necessary to identify and measure quality costs [1].

CoQ is understood as the sum of conformance plus non-conformance costs, where cost of conformance is the cost paid for prevention of poor quality and defect(s) in products or services (as inspection and quality appraisal) and cost of non-conformance is the cost of poor quality (CoPQ) caused by product and service failure (as rework, returns and customer complaint). Identification, measuring, reporting and analysis the cost of quality (CoQ) is an important issue to achieve high quality.

Quality costs are not only an indicator of the quality level of a product/service, but also an indicator of how much to measure or increase a given level of quality. Quality costs are the costs of preventing, identifying and removing defects in materials, products, services, or processes, while any costs incurred due to poor quality [2] [3] [1]. To measure and anallyze quality costs of an organization needs to classify costs [1];

In previous research, several CoQ models have been presented which are: P-A-F model, Crosby's model, Opportunity or intangible cost model, Process cost model and ABC model. [3]. P.A.F. include four categories: prevention costs (costs of any action taken to investigate, prevent or reduce defects and failures, appraisal costs (costs of assessing the quality achieved, internal failure costs (costs associated with defects found before the customer receives the product/service), external failure costs (costs associated with defects found after the customer receives the product/service) [1] [4]. The quality costs in the P.A.F. model are as follows.

Table 1: PAF Quality Cost Categories [4]

Types	Description		Samples
Prevention Cost	Related to activities designed and trained to guarantee good quality and prevent poor quality in services or products		Process design/change, Quality education and training, Knowledgeable human resource recruitment, Preventive maintenance, New product review
Appraisal Cost	Related to measuring or inspecting services or products to achieve performance requirements and quality standards		Sampling and measurements, Evaluations and assessments, Problem analysis, In-process and final inspection/test, Product or service audits and detection
Failure Cost	Internal	Affected by products or services not conforming to customer/user needs and are identified before delivery	Retesting, Rework and Repair, Unscheduled and unplanned service, Defect removal, Lost process time/Delay and shortages
	External	Affected by deficiencies which are found after delivery of services or products to external customers, which causes customer to be dissatisfied	Complaints/Liability claims, Repairing goods and redoing services, Losses due to sales reductions, Warranties, Returned products and customer's bad will, Poor safety/availability

Some researchers like Tsai (1998), believe that measuring CoQ can be made more accurate by including overhead costs. This improvement could be implemented by activity-based costing (ABC) approach developed by Cooper and Kaplan. ABC approach concentrates on the accurate assignment of overhead costs to products [3] [5].

In the literature of quality costs, various researches can be seen. The following table summarizes some of the research on cost of quality (CoQ). Some researchers, such as Ramdeen et al. (2007), have specifically performed the calculation and analysis of quality costs in a particular firm; they have applied the cost of quality (COQ) concepts in a hotel restaurant environment using the P.A.F. model [6].

Table 2: A review of some published works

Author(s)- Year	Description
Jeffery (2004) [7]	presenting a quality cost model
Schiffauerova & Thomson (2006) [8]	providing evidence of cost management
Vaxevanidis et al. (2009) [1].	literature review
Antonaras et al. (2010) [9].	quality cost measurement
Tawfek et al. (2012) [10].	Establishing a neural network model to assess cost of quality
Arabian et al. (2013) [4]	Comparing different COQ models
Omar & Murgan (2014) [11].	proposing a model for quantifying the cost of quality
Sailaja et al. (2015) [12].	making analysis to identify the hidden elements of quality costs
Chatzipetrou and Moschidis (2016) [13].	studying the CoQ of supermarkets in Greece
Lee et al. (2016) [14].	Establishing a CoQ management system for power generation firms
Murumkar et al. (2017) [15]	Surveying the literature and models
Teli et al. (2018) [16]	Analyzing the COQ in Indian auto industry
Schmidt and Pearson (2019) [17].	Developing methods to estimate the COQ errors

In this paper, the results of the study of quality costs in a manufacturing company are reported. The company specializes in designing and manufacturing customized parts for aerospace, automotive and other areas as a supplier.

To manage quality costs in the company, first a list of quality costs for all four categories of P.A.F. has been created; so, this list was refined and calculated according to the conditions of the company under study and the results were analyzed. The steps followed are described in the research methodology below.

The research methodology

The following steps have been taken to conduct the research and achieve its goals including identification, calculation and analysis of the quality costs in the industry under study.

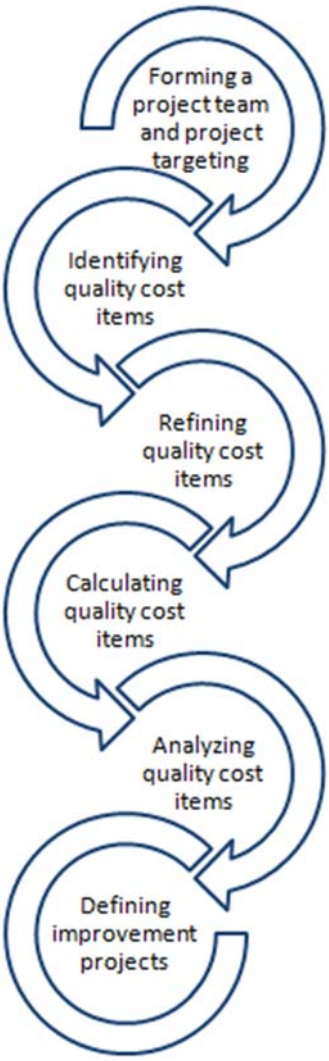

Figure 1: the steps of the research

The following steps have been taken to conduct the research and achieve its goals including identification, calculation and analysis of the quality costs in the industry under study:

Step 1- Forming a project team and project targeting

In the first step, the Quality Cost Management Project team was established as a multi-sectoral team with the management of the company's quality deputy consisting of representatives from various sectors of production, design and planning, sales and marketing, warehousing as well as quality. The purpose of the project was outlined and related plans were provided to cover the necessary information and resources. The important questions that were addressed during the initial project team meetings were as follows:

- Why is it necessary to identify and analyze the quality costs of the company? (Goal review)
- In which parts of the company will the project be implemented? (Implementation domain)
- At what time periods should the report be made? (Reporting timing)
- How and by which sectors should the information needed to calculate quality costs be provided? (Data and information supply)
- Which sections should prepare the report? (Reporter providers)
- Who and what parts of the company should be given the final results and analyses? (Issueing of results and analyses)

Step 2- Identifying quality cost items

In order to identify CoQ elements, some companies benchmark or borrow elements from other companies, which have established CoQ programs. However, it is recommended that costs be tailor-made for each organization [3].

The important point is that the quality cost components and examples are different in various companies and organizations, and not necessarily a fixed list of cost components will apply everywhere and these cost components must be tailored to each organization.

In this study the P.A.F. model is used to identify and analyze quality costs. Various sources such as the Juran's Quality Handbook [2] and BS 6143 standard [18] were used to identify quality cost items and to provide an initial list of cost items. Attached to this standard are examples of each of the four groups including costs of prevention, evaluation, internal failure and external failure. The initial list consisted of 166 cost items.

Step 3- Refining quality cost items

The initial list of quality cost components in all four cost areas should be refined and tailored to the requirements and conditions of the company under study. For this purpose, project team members were asked to rewrite the titles of project components as necessary, and then the list was refined using the Lauche method. In order to refine costs using the CVR index, project team members were asked to rate each quality cost item in three classes of being "essential", "useful, but not essential" and "not necessary" in their company. Continuation of the analysis was performed using CVR values and Lauche table. From the initial list of cost items (166 cost items) 68 items remained after refining. The following equation was exploited to calculate the content validity ratio (CVR) index [19]:

$$CVR = \frac{n_e - n/2}{n/2}$$

Where n_e is the number of panel members who have identified the dimension or question as "essential" and n is the total number of panel members. The minimum acceptable value of the table provided by Lawshe is as follows:

Table 3: The minimum acceptable CVR based on the number of scoring specialists

Number of Professionals	CVR	Number of Professionals	CVR	Number of Professionals	CVR
5	0.99	11	0.59	25	0.37
6	0.99	12	0.56	30	0.33
7	0.99	13	0.54	35	0.31
8	0.75	14	0.51	40	0.29
9	0.78	15	0.49		
10	0.62	20	0.42		

After filling out the Lauche Method Questionnaire by project team members (10 members) and reviewing the results and considering cost items with CVR of greater than 0.62, the list of quality cost items was obtained, examples of which are introduced in the following table. Also, according to calculations related to Cronbach's alpha test and entering questionnaire information in SPSS software, Cronbach's alpha value of 7.840 is obtained which is greater than 0.7. As a result, the questionnaire is reliable and the internal consistency of the questions can be assured.

After the Lawshe's method questionnaire were completed by the 12 members of the panel, the CVR calculation results for the 15 dimensions in question were obtained as is expressed below.

Table 4: Examples of refined cost items

Examples of refined prevention cost items
• **The costs of Quality training**
The cost of providing educational equipments
The cost of out-of-organization training
The trainers/consultants' fee
• **The costs of design and manufacturing of measurement and testing equipments**
The costs of designing and manufacturing gauges
The costs of preparing speciao laboratories
The costs of purchasing/renting measurement and test equipments
The costs of training required for use of measurement and test equipments
Examples of refined appraisal cost items
• **The costs of raw material test**
The costs of inspection of input items
The costs of inspection (& test) at supplier location
The costs of testing of raw materials in the warehouse
Examples of refined internal failure cost items
• **The costs of reworks and corrective actions**
The costs of reworking on modifiable defective items
The costs of re-inspection after reworking & corrective action
Examples of refined external failure cost items
• **The costs of after-sales services**
The costs of transporting, handling and returning defevtive (nonconforming) products from the customer's location to the factory
The costs of customer complaints

Step 4- Calculating quality cost items

Each of the refined quality cost components has been carefully reviewed in the project team meetings, and in consultation with the company's finance experts and other experts in the project team, efforts have been made to formulate cost item calculations by proper definition of the parameters. The following table provides examples of cost components and their formulas. Also, table ... shows the parameter definitions.

Table 5: The Parameters of computational formulas

Parameter	Description
A	The cost of educational equipments
A15	The rent of training location cost
B15	The cost of booklets & pamphlets
C15	The cost of eating and drinking services
B	The trainers' fee
C	The overhead training costs (travel etc.)
D	Hourly fee of teaching / consultation
E	The hours of cource
F	The average hourly wage for trainees
J	The average hourly wage for involved staffs
L	The cost of consumables
Z	The man-hours spent for internal audit
A1	The man-hours spent for designing and manufacturing gauges
B1	The cost of gauges (material, testing, verification)
I11	The man-hours spent for inspection of input items
J11	The cost of out-of-organization tests for input items
K11	The man-hours spent for testing and inspection at supplier's place
C1	The cost of equipping special laboratories (calculated based on depreciated service life for the calculation period of quality costs such as monthly or annual)
D1	The cost of purchasing (or renting) measurement and testing equipment (calculated based on depreciated service life for the calculation period of quality costs such as monthly or annual)
E1	The trainer's fee for training the use of measurement and test instruments
R12	The man-hour spent for reworking of defective items
S12	The number of hours of the machine utilization for reworking
T12	The cost of one hour of the machine utilization for reworking
V12	The man-hours spent for reinspection (after reworking)
C14	The man-hours spent for transporting, handling and returning defevtive (nonconforming) products
D14	The cost of shipping and returning the defevtive (nonconforming) products from the customer's location to the factory
I14	The man-hour spent for customer complaints
K14	The costs of staffs traveling to the customer's location for customer complaints
M11	The cost of tests performed at supplier's location
N11	The man-hours spent for testing raw materials in the warehouse
O11	The cost of testing raw materials in the warehouse
L11	The cost of traveling for inspection personnels and transporting measurement equipments to supplier's location

Table 6: Examples of formulas for preventive cost items

• **The costs of Quality training**	
The cost of providing educational equipments	*A+A15+B15+C15*
The cost of out-of-organization training	*B+C*
The trainers/consultants' fee	*A+A15+B15+C15*
The costs of design and manufacturing of measurement and testing equipments	
The costs of designing and manufacturing gauges	*(A1×Z)+B1*
The costs of preparing speciao laboratories	*C1*
The costs of purchasing/renting measurement and test equipments	*D1*
The costs of training required for use of measurement and test equipments	*(E×F)+E1*

Table 7: Examples of formulas for appraisal cost items

• **The costs of raw material test**	
The costs of inspection of input items	*(J×I11)+L+J11*
The costs of inspection (& test) at supplier location	*(J×K11)+L+L11+M11*
The costs of testing of raw materials in the warehouse	*(J×N11)+L+O11*

Table 8: Examples of formulas for internal failure cost items

Examples of refined internal failure cost items	
• **The costs of reworks and corrective actions**	
The costs of reworking on modifiable defective items	*(J×R12)+(S12+T12)*
The costs of re-inspection after reworking & corrective action	*(J×V12)*

Table 9: Examples of formulas for external failure cost items

• **The costs of after-sales services**	
The costs of transporting, handling and returning defevtive (nonconforming) products from the customer's location to the factory	*(J×C14)+D14*
The costs of customer complaints	*(J×I14)+K14*

Step 5- Analyzing quality cost items

The data analysis from the calculations of the quality cost items is performed on the basis of table 10. ratios using Excel software. Also, quality cost trend analysis was performed for two consecutive periods.

Table 10: Symbols and formulas of CoQ and related ratios

Cost title	Symbol / calculation
Quality Costs (COQ)	*COQ (= PC+AC+IFC+EFC)*
Company Annual Revenue (R)	*TR (Total Revenue)*
The ratio of total quality costs to annual revenue	$\frac{COQ}{TR}$

The costs and ratios of quality costs have been calculated for two consecutive periods, the results of which are presented in table 11.

Table 11: The quantity and trend of quality costs

Cost title	First year	Second year
Quality Costs (COQ)	*131,413,363*	*150,028,675*
Company Annual Revenue (R)	*777,593,864*	*949,548,576*
The ratio of total quality costs to annual revenue	***0.169***	***0.158***

Based on the analyzes cited in some references, such as Kumar et al. (2018), the relationship between CoQ / R and the sigma level of process can be determined (below table). The ratios of both two years indicate the sigma level of corporate processes of around 4, which by focusing on reducing this ratio, the sigma level of corporate processes tending to six sigma.

Table 12: The relationship between CoQ/TR ratio and sigma level [20]

Sigma Level	Defect Rate (PPM)	Yield in %	Cost of Quality (% of sales)	Competitive Level
6	3.4	99.99966	< 10 %	World Class
5	233	99.97670	10 to 15 %	
4	6210	99.37900	15 to 20 %	Industry Average
3	66807	93.31930	20 to 30 %	
2	308537	69.14620	30 to 40 %	Non-competitive
1	690000	31.00000	> 40 %	

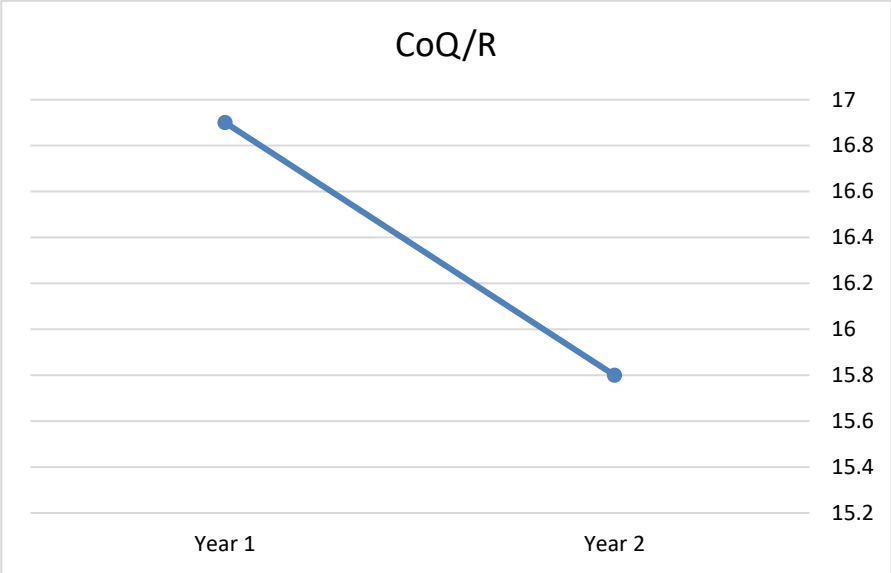

Figure 2: the trend of CoQ / TR ratio in two consecutive years

The figure above shows the trend for the CoQ / TR ratio. This ratio has decreased during the first to second period (year), which is a valuable achievement. With further improvements, this ratio is expected to decline again in the subsequent periods. In fact, by increasing investment in prevention and appraisal costs, internal and external failure costs can be reduced.

Step 6- Defining Improvement Projects

Based on the results of the calculations and the analysis of quality costs, a set of improvement actions and projects are needed to reduce failure costs (nonconformance). The task of defining and leading improvement projects is the responsibility of the quality management sector of the company. Implementing of improvement projects are the responsibility of different sectors of the company in the form of cross functional teams (CFTs) or functional teams. In order to accomplish improvement projects in the company, there are three important steps:

- Forming the improvement project team
- Using improvement methodology like Deming Cycle (PDCA) (plan-do-check-act or plan-do-check-adjust)
- Finding the results and getting the end result (finalizing)

It is important for the company that the definition and implementation of improvement projects should never stop in order to improve quality and reduce nonconformance costs.

Conclusion

In this paper, a list of quality cost items based on the P.A.F. was provided at a manufacturing company and refined by the Lawshe's method. The formulas were developed by the company experts to calculate the refined cost items, and then, the items of quality costs were calculated and analyzed for two consecutive years. The following measures are suggested to improve the quality and reduce the costs of poor quality (COPQs) in the company under study:

- Preparing and publishing quality cost reports in shorter than annual periods (such as semiannually)
- Creating quality cost management software to receive online information, automate related calculations, and monitor results and analyses by company experts and decision makers
- Investing and planning to expand preventive activities (using techniques like FMEA or Failure modes and effects analysis)

Also, two other important improvements should be made in the future on the quality management system of the company under study; firstly, there must be a mechanism to ensure the accuracy of the data and information provided by the various departments. Moreover, additional ratios and indices need to be considered for quality cost analysis in order to produce more accurate and effective analyzes.

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