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A Novel Hybrid Approach to Analyze Cost of Quality: Balanced Scorecard and Fuzzy Logic

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ABSTRACT

In this paper, a new methodology in the area of cost of quality (COQ) is proposed to determine the optimal investment allocation to all costs. The goal is to minimize costs involved in achieving a required level of quality. The contribution of this paper is fivefold: (I) considering two types of weights for each part of COQ, in which the first type is determined by the cost volume and the second is obtained by applying a decision-making technique; (II) participating shareholders' opinions through the balanced scorecard method; (III) presenting a mathematical programming model to maximize the investment effectiveness; (IV) considering a continuous improvement cycle to tune the model parameters, and (V) developing COQ technique in fuzzy environment to enhance the accuracy of traditional methods of employing linguistic variables. To demonstrate the applicability of the presented methodology, a case study is investigated in automotive parts industry in Asia.

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1. INTRODUCTION

In today's competitive markets, many quality control techniques are used to recognize the reasons behind producing nonconforming items and preventing them to occur. Many companies promote quality as the central customer value and take it into account as a crucial success factor for attaining competitiveness [1]. However, any serious effort to amend quality must consider the costs involved. Besides, the goal of constant improvement plans is not only to fulfill customer needs, but also to do it at the lowest cost. In order to reduce relevant costs and achieve quality simultaneously, this type of costs should be indentified and measured. One of the most well-known techniques for computing the costs and producing price competitive quality product is cost of quality (COQ) [2].

The COQ technique is usually equated with the costs of poor quality due to finding and rectifying imperfect product and also with the costs of achieving good quality. However, from Juran's [3] perspective, COQ is not the price of creating a quality product or service, but it describes the expense of not creating a quality product. As a widely used explanation, COQ consists of the costs incurred in design, execution, operation, and maintenance of a quality management system, the cost of resources committed to constant improvement, the costs of system, product and service failures, and all other necessary costs. The non-value added actions required to attain a quality product or service [4]. Indeed, a COQ system can facilitate the recognition and hence the elimination of the organizational actions that do not provide or improve quality from customer's viewpoint. It helps to distinguish the reasons of hidden costs, which may be as much as 20 to 30% of earnings [5, 6].

COQ can be classified into two types: (I) control costs that cover the prevention and appraisal costs, and (II) failure costs that involve the internal and external failure costs [7]. Control expenses are inherent costs of providing acceptable products or services in a fully effectual way. Failure costs are incurred to amend the products that fail to create customer satisfaction or do

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not fulfill company quality requirements [8]. The COQ is not just associated with production; rather, it relates to all the actions in a company from primary research and development through customer service. The total quality cost that contains the aggregate of prevention, appraisal, internal and external failure costs can be very high unless a special attention is paid to this issue.

Several economic and mathematical models were introduced in the literature to indicate the nature, the performance, and the concept of COQ. These models are different in object, complexity and most have little practical application [9]. According to Schiffauerova and Thomson [1], the COQ models are classified into four generic groups: (I) prevention-appraisal-failure (P-A-F) model or Crosby's model, (II) opportunity cost models, (III) process cost models, and (IV) activity-based costing (ABC) models. However, the concentration of the most COQ models is on the classic P-A-F classification where it is the most widely used for determining the quality costs.

Juran [3], as a pioneer of quality costing, first initiated the concept of quality costs. Then, Feigenbaum [8] introduced prevention, appraisal, and failure costs as three categories for COQ. Feigenbaum's and Juran's P-A-F plan was approved by the American Society for Quality Control [10], and the British Standard Institute [11]. This plan is applied by most of companies that deal with quality costing [12]. Dale and Plunkett [4] presented a survey of published literature on the measurement, collection and uses of quality related costs. Williams et al. [13] provided a literature survey concerning the historical expansion of quality costing, different ideas on COQ definitions, the collection and usage of COQ data, and a view of COQ concepts. Schiffauerova and Thomson [1] carried out a literature review and discussion on various quality costing procedures.

Several researchers demonstrated the application of COQ in real-world case studies. Abdelsalam and Gad [14] proposed a P-A-F model to evaluate the quality costs and to determine its optimal value for residential construction projects. Castillo-Villar et al. [15] developed a model for supply chain design that considers COQ as a global performance measure for the whole supply chain rather than as an internal performance measure within companies.

The aim of this paper is presenting a hybrid optimization model to maximize the investment effectiveness in COQ. In this regard, the concept of balanced scorecard to consider shareholders' opinions, the AHP technique as a decision-making method for achieving the weight of quality costs, and fuzzy logic to handle the ambiguity and uncertainty nature of importance of quality costs are applied.

The rest of the paper is structured as follows. In Section 2, some basic concepts and definitions are reviewed. The proposed hybrid method for optimizing investment effectiveness will be fully presented in Section 3. Section 4 contains a numerical example to clarify the capability of the proposed model. Finally, conclusions and further research directions are given in the last section.

2. CONCEPTS AND DEFINITIONS

In this section, some basic concepts and definitions on the balanced scorecard, multi-attribute decision making methods, and fuzzy logic are provided as backgrounds.

2. 1. Balanced Scorecard (BSC) Kaplan and Norton [16] developed BSC as a widely adopted strategic performance management tool that supplements traditional financial indicators with non-financial performance measures to aid an organization to monitor its performance towards strategic goals. Indeed, the aim of BSC is to retain score of a set of measures that keep a balance between short-term and long-term goals, between financial and non-financial measures, between lagging and leading indicators, and between internal and external performance perspectives [17]. Since its introduction, BSC has been used extensively in many businesses to align them to the new visions and strategies towards development opportunities based on more customized, value-adding products and services and away from simply cost improvement [18]. Moreover, some works on the integration of the BSC with other methods were performed. Banker et al. [19] carried out a study into the BSC performance perspectives and proposed a data envelopment analysis (DEA) model to examine the frontier tradeoff between the financial and non-financial performance measures. Yuksel and Dagdeviren [20] determined the performance level of a business according to its vision and strategies, by aggregating BSC using a fuzzy analytic network process (ANP) approach.

BSC breaks performance monitoring into four interconnected perspectives: financial, customer, internal business process, and learning and development. On one hand, financial perspective covers the traditional financial performance measures and determines its desired objectives from the managers and shareholders' point of view. Considering the fact that for achieving long-term financial goals the company must offer products and services valued by customers, in customer perspective, strategy and mission statements are translated into targeted market segment and customer-based objectives. On the other hand, since the path to success for any business varies over time, the capability of a company to introduce new products and new processes is crucial in achieving excellence. Internal business process perspective addresses operational objectives and specifies the key processes that are the most critical for satisfying customers and shareholders. The last perspective, learning and development, is to indicate how much a company must learn, improve and innovate to fulfill the objectives of the other three perspectives and to facilitate continuous improvement.

Since BSC has shown a strong perspective about stockholder organizations, it can be used as an indicator of comparison elements of COQ in P-A-F models. This link between BSC perspective and cost of quality elements is shown in the proposed methodology providing some questions for each perspective.

2. 2. Multi-attribute Decision-making (MADM)

Decision making is an essential and inseparable part of our lives. In most of real world situations, several qualitative and quantitative attributes should be taken into consideration in a decision process of choosing an appropriate option. Multiple attribute decision making (MADM) addresses the problem of finding the best option from a set of feasible options in the presence of multi-dimensional, incommensurate and often conflicting decision attributes. Indeed, MADM is to attain the best option that has the highest level of satisfaction for all of the relative attributes [21].

A number of methods as decision aids were developed in the literature to solve MADM problems. Analytic hierarchy process (AHP), firstly introduced by Saaty [22], is an appropriate technique for complex decision-making problems. This technique considers simultaneous assessments of both qualitative and quantitative variables in the evaluation process problems [20]. Since fuzziness and uncertainty are common features of many decision-making problems, the conventional AHP may not be suitable, since vagueness should be regarded in some or all paired comparison cases [23]. As a result, the fuzzy AHP (FAHP) seems to be more proper and sensible than the conventional AHP where data in the real-world are often imprecise, vague, or incomplete.

Many researchers carried out the application of AHP in solving MADM problems. Sohn et al. [24] applied the AHP technique to determine the relative weights for BSC performance measures. A dynamic decision technique based on BSC and AHP for vendor selection problems was developed by Chiang [25]. Lee et al. [26] proposed an approach based on fuzzy AHP and BSC to evaluatethe performance of departments involved in a manufacturing company. In general, AHP is based on three main principles, namely constructing a hierarchical structure, priority analysis, and consistency evaluation. Defining the decision problem as a hierarchical structure is followed by asking experts to assign a relative priority to each attribute in the hierarchy. Then, by collecting pair-wise comparison scores, a comparison decision matrix whose columns and rows are options formed for each attribute. Next, each comparison matrix is solved by an arithmetic mean method to determine the performance of options with respect to each attribute. The overall score for options are then calculated. Finally, the consistency ratio is computed. If the consistency test is failed, the judgments in the pair-wise comparison decision matrices must be revised by the experts.

2. 3. Some Definitions in Fuzzy Environment

Fuzzy sets theory, initially introduced by Zadeh [27], is ideally proper for confronting ambiguity and imprecision. While most of practical and industrial applications and problems involve imprecise or incomplete data, fuzzy techniques are helpful tools for making methods more accurate. The required definitions and backgrounds to employ the fuzzy AHP technique of this research are as follow [27]:

Definition 1: Let U be the universe set. A fuzzy set $\tilde{A}$ of U is defined by a membership function $\mu_{\tilde{A}}(x) \in [0,\ 1]$, where $\mu_{\tilde{A}}(x),\ \forall x \in U$ indicates the degree of membership function of x in $\tilde{A}$.

Definition 2: A fuzzy set $\tilde{A}$ is normal if and only if its satisfies $Sup_X\, \mu_{\tilde{A}}(x) = 1$.

Definition 3: A fuzzy set $\tilde{A}$ of U is convex if and only if for every pair of points x_1 and x_2 in U, its membership function satisfies the following inequality $\mu_{\tilde{A}}\left(\lambda x_1 + (1-\lambda) x_2\right) \geq \min\left(\mu_{\tilde{A}}(x_1),\ \mu_{\tilde{A}}(x_2)\right)$ where $\lambda \in [0,\ 1]$.

Definition 4: A fuzzy number $\tilde{A}$ is a fuzzy set that is both normal and convex in the universe set U.

Definition 5: A triangular fuzzy number $\tilde{A}$ can be defined by (a, b, c) shown in Figure 1, where its membership function $\mu_{\tilde{A}}(x)$ is presented by:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-a)/(b-a); & a \leq x \leq b \\ (c-x)/(c-b); & b \leq x \leq c \\ 0 \quad ; & otherwise \end{cases}$$

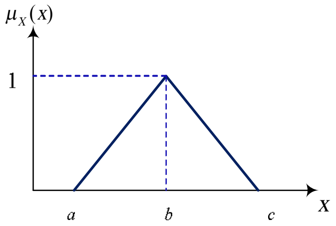

Figure 1. Membership function of triangular fuzzy number

3. THE PROPOSED HYBRID METHOD

The proposed hybrid methodology consisting COQ, BSC, mathematical programming model to maximize the investment effectiveness. A continuous improvement cycle to tune the model parameters is addressed in this section.

3. 1. COQ Identification The costs of quality based on Jouran's model are determined in this section. These costs are associated with the cost of none conformance (CONC) and cost of conformance (COC), which are illustrated in the following subsections.

3. 1. 1. Cost of Nonconformity (CONC) As mentioned previously, the concentration of CONC is on the following costs:

- Internal failure costs, $IF_i \rightarrow \{i = 1,..., I\}$,are relevant to identification of flaws and defects before product shipment to customers. Reworks, delays, shortages, re-designing and failure analysis are some examples of these costs.
- External failure costs, $EF_j \rightarrow \{j = 1,..., J\}$, are losses that occur when a defective product is delivered to a customer. These costs can lead to loss of future business due to customer dissatisfaction. Examples include the costs for customer complaints, repairing products and redoing services, replacement of non-conforming products, and warranties.

3. 1. 2. Cost of Conformity (COC) The conformity cost that consists of prevention costs, $P_k \rightarrow \{k = 1,..., K\}$, are those resulting from quality activities taken to evade the deviations and errors in a process [28]. Costs related to capability evaluations, quality education and training, supplier selection, error proofing and process improvement projects are some examples of these costs.

Appraisal costs, $A_l \rightarrow \{l = 1,..., L\}$, contain all losses associated with evaluating and measuring products to ensure a high quality level in process and performance requirements [29]. Examples of these costs occur in-process and final inspections, material reviews, and calibration of measuring and test equipment.

It should be noted that financial departments are usually responsible to calculate all the above costs within a manufacturing company.

3. 2. Selecting Experts Based on BSC As improving the quality level of products enhances expert's satisfaction, utilizing the BSC method is recommended in this research for selecting corresponding experts. The experts are chosen through the BSC perspectives (namely financial, customer, internal business process, and learning and development) as follows

Financial perspective: These experts can be the main shareholder $(F_q \rightarrow \{q = 1,..., m\})$.

Customer perspective: According to this perspective, the experts can be some customers with high purchase $(C_p \rightarrow \{p = 1,..., m\})$.

Internal business perspective: This part of experts can be high level managers $(IB_r \rightarrow \{r = 1,..., m\})$.

Learning and development perspective: These experts can be different mangers like quality managers, human resource managers, and education managers $(IL_s \rightarrow \{s = 1,..., m\})$.

3. 3. Designing Questionnaires After the experts are selected, they are posed with some questions regarding their perspective categories. The first two questions that are related to the financial perspective are "Which costs of quality consume more financial resources" and "Which costs of quality provide more benefit." According to the customer perspective, the question is stated as "Investigation into which costs of quality has more impact on product usage and final quality." The next question that is about the internal business perspective is "Which costs of quality have more relationship with core competencies," and the last question that is in the area of the learning and development perspective is "Which costs of quality can be ignored when learning is achieved."

3. 4. Determining Weights Associated with the Identified COQ The implementation of the previous steps is followed by determining the related weights. The first type of weights corresponding to the quality costs are calculated by dividing the cost of each element by the total costs of quality. The second type is obtained by applying an AHP technique. This decision technique is to determine fuzzy weights concerning the aforementioned questions for each expert set. The outputs of this part are the fuzzy weights in terms of each cost of quality in comparison with others. The hierarchical graph of the second type of weight calculation is shown in Figure. 2.

3. 5. Optimizing Investment Effectiveness (IE) To enhance the effectiveness of the proposed methodology, the budget allocation to the costs of quality subject to different constraints is optimized in this section. The goal of IE is to determine the optimal budget allocation to each cost elements in order to achieve the most reduction in total costs of quality after executing an improvement plan. For this purpose, the parameters and the decision variables of the model are first introduced and then the mathematical programming model is presented.

C_{IF_i} : Type-I weight for internal failure i

C_{EF_j} : Type-I weight for external failure j

C_{P_k} : Type-I weight for prevention failure k

C_{A_l} : Type-I weight for appraisal failure l

U_{IF_i} : Type-II weight for internal failure i

U_{EF_j} : Type-II weight for external failure j

U_{P_k} : Type-II weight for prevention failure k

U_{A_l} : Type-II weight for appraisal failure l

x_{IF_i} : Fraction of budget in terms of internal failure i as a decision variable

x_{EF_j} : Fraction of budget in terms of external failure j as a decision variable

x_{P_k} : Fraction of budget in terms of prevention failure k as a decision variable

x_{A_l} : Fraction of budget in terms of appraisal failure l as a decision variable

BG : Available budget

S_{IF_i} : Lower bound of internal failure i

S_{EF_j} : Lower bound of external failure j

S_{P_k} : Lower bound of prevention failure k

S_{A_l} : Lower bound of appraisal failure l

Then, the mathematical programming model becomes

$$Maximize \sum_{i=1}^{N} C_{IF_i} U_{IF_i} x_{IF_i} + \sum_{j=1}^{M} C_{EF_j} U_{EF_j} x_{EF_j} + \sum_{k=1}^{K} C_{P_k} U_{P_k} x_{P_k} + \sum_{l=1}^{L} C_{A_l} U_{A_l} x_{A_l}$$

$$\begin{aligned} &\text{Subject to: } \sum_{i=1}^{N} x_{IF_i} + \sum_{j=1}^{M} x_{EF_j} + \sum_{k=1}^{K} x_{P_k} + \sum_{l=1}^{L} x_{A_l} \le BG \\ &x_{IF_i} \ge S_{IF_i}; && \forall i = 1,\dots,N \\ &x_{EF_j} \ge S_{EF_j}; && \forall j = 1,\dots,M \\ &x_{P_k} \ge S_{P_k}; && \forall k = 1,\dots,K \qquad (1) \\ &x_{A_l} \ge S_{A_l}; && \forall l = 1,\dots,L \\ &x_{IF_i}, x_{EF_j}, x_{P_k}, x_{A_l} \ge 0 \end{aligned}$$

3. 6. Implementing Improvement Plan After budget allocation to each quality cost, the improvement plan is implemented to reduce costs of quality. It is worth noting that while an improvement plan observes the allocated budget to each cost of quality, the improvement plans of different loops can be different from each other.

3. 7. Analyzing Improvement Plan and Redesigning Model In this step, based on the results obtained by implementing an improvement plan, some elements of COQ can be omitted from the optimization model. Indeed, if the current cost is less than or equal to the previous one, then it must be detected in the proposed model. Otherwise, it should be withdrawn. In short, the flowchart of the steps involved in the proposed hybrid model is depicted in Figure 3.

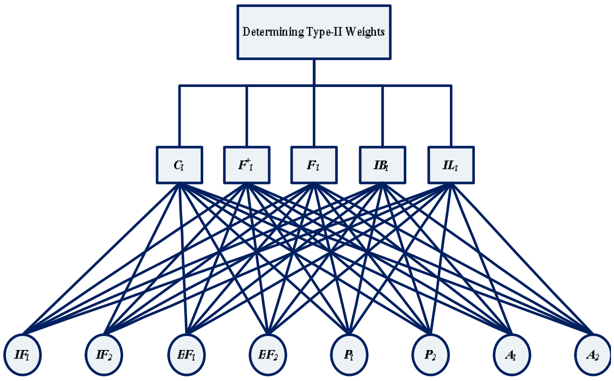

Figure 2. The hierarchical graph for determining type-II weights

4. A NUMERICAL EXAMPLE

In order to clarify the way, the proposed procedure works, a numerical example is provided in this section. The steps involved in the proposed methodology to analyze the cost of quality are as follow. According to the first step, CONC and COC parameters are first assumed as:

IF_1 : Scrapping cost that includes 49% of all quality costs

IF_2 : Reworking cost such as disassembling and reassembling cost consisted of 21% of all quality costs

EF_1 : Warranty cost as 2% of all quality costs

EF_2 : Sales return cost as 3% of all quality costs

P_1 : Quality planning cost that included 4.5% of all quality costs

P_2 : Capability analyses cost that consisted of 1.5% of all quality costs

A_1 : Test and inspection cost as 15% of all quality costs

A_2 : Auditing process cost that included 4% of all quality costs

Following this, to select the experts based on the BSC concept, four experts including a main customer (C_1), a main shareholder (F_1), a director (IB_1), and a quality manger (IL_1) are considered to participate in the decision making process, where the questions are:

- Which costs of quality has more effect on product usage and final quality?
- Which costs of quality consumes more financial resources?
- Which costs of quality provide more benefit based on investment?
- Which costs of quality have more relationship with core competencies?
- Which costs of quality can be ignored with learning?

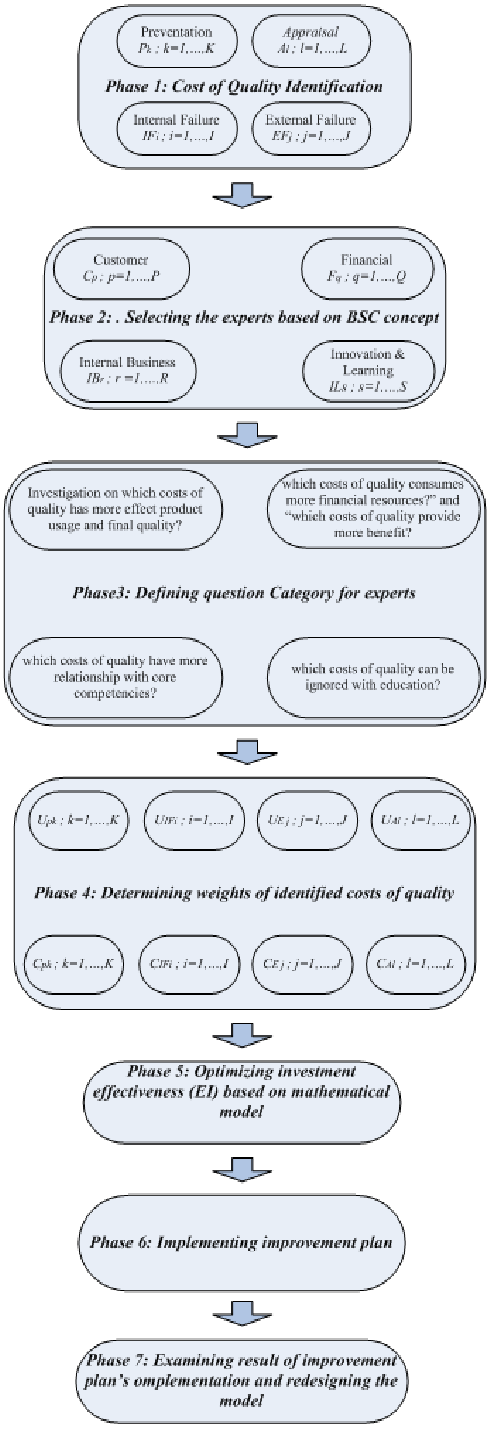

Figure 3. The flowchart of the proposed methodology

TABLE 1. Type-I weights given by the accounting department

Type-I Weight	Category	Type-I Wight	Category
0.045	P_1	0.49	IF_1
0.015	P_2	0.21	IF_2
0.15	A_1	0.02	EF_1
0.04	A_2	0.03	EF_2

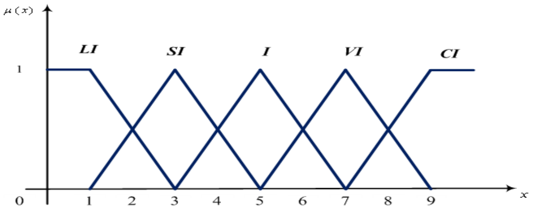

Figure 4. The membership function of linguistic variable

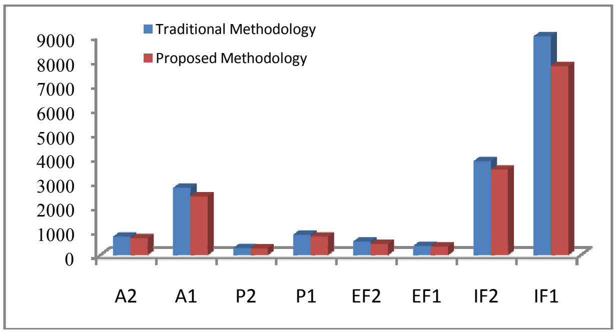

Figure 5. The performance of the proposed methodology in comparison with traditional one

The CONC and COC parameters data are applied to determine the first type of weight reported in Table 1. Moreover, linguistic terms with triangular fuzzy membership functions are presented in Figure 4. The fuzzy type-II weight is calculated using the AHP method using the expert opinions based on the BSC concept. These features are summarized in Tables 2 and 3.Finally, the mathematical programming model to maximize the investment effectiveness by minimizing the quality costs is constructed as:

$$\begin{aligned}&\mathit{Maximize}\ (0.132,0.130,0.164)\,x_{IF_1}+(0.475,1.015,1.375)\,x_{IF_2}+\\&(0.093,0.202,0.265)\,x_{EF_1}+(0.011,0.016,0.022)\,x_{EF_2}+\\&(0.008,0.009,0.007)\,x_{P_1}+(0.002,0.004,0.002)\,x_{P_2}+\\&(0.004,0.005,0.007)\,x_{A_1}+(0.001,0,0.001)\,x_{A_2}\end{aligned}$$

Subject to

$$\sum_{i=1}^{N=2} x_{IF_i}+\sum_{j=1}^{M=2} x_{EF_j}+\sum_{k=1}^{K=2} x_{P_k}+\sum_{l=1}^{L=2} x_{A_l}\le 150,000$$

$$x_{IF_1}\ge 24,000\ ,\ x_{IF_2}\ge 15,000\ ,\ x_{EF_1}\ge 11,000\ ,\ x_{EF_2}\ge 22,000$$

$$x_{P_1}\ge 6,000\ ,\ x_{P_2}\ge 1,000\ ,\ x_{A_1}\ge 18,000\ ,\ x_{A_2}\ge 7,000$$

$$x_{IF_i},x_{EF_i},x_{P_k},x_{A_l}\ge 0\ ;\ i=1,2$$

Moreover, the volume of investment to keep quality in one year is assumed $150,000. The results show an almost %12 reduction in total COQ in the first month (from &18,350 in the month before the improvement implication to &16,135 in the month after). Figure 5 shows the performance of the proposed methodology in comparison with a traditional one. As it can be seen from this figure, in a cycle of employing the proposed methodology, the COQ is reduced during different iterations.

TABLE 2. The AHP process implementation

	IF_1	IF_2	EF_1	EF_2	A_1	A_2	P_1	P_2	Combined fuzzy number
IF_1	(1, 3, 5)	(5, 7, 9)	(1, 1, 3)	(1, 1, 3)	(1, 1, 3)	(1, 1, 3)	(3, 5, 7)	(3, 5, 7)	(1.61, 2.18, 4.54)
IF_2	(1/9, 1/7, 1/5)	(1, 3, 5)	(1, 1, 3)	(1, 1, 3)	(1, 1, 3)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(1.13, 1.43, 3.00)
EF_1	(1/3, 1, 1)	(1/3, 1, 1)	(1, 3, 5)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(1.71, 3.03 , 4.21)
EF_2	(1/3, 1, 1)	(1/3, 1, 1)	(1/3, 1, 1)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(7, 7, 9)	(7, 7, 9)	(1.68, 3.03, 3.66)
A_1	(1/3, 1, 1)	(1/3, 1, 1)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/7)	(1, 3, 5)	(7, 7, 9)	(1, 3, 5)	(5, 7, 9)	(0.68, 1.31, 1.66)
A_2	(1/3, 1, 1)	(1/3, 1, 1)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/7)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(0.49, 0.89, 1.11)
P_1	(1/7, 1/5, 1/3)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/7)	(1/5, 1/3, 1)	(1/9, 1/7, 1/5)	(1, 3, 5)	(1, 3, 5)	(0.21, 0.35, 0.55)
P_2	(1/7, 1/5, 1/3)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/7)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1/5, 1/3, 1)	(1, 3, 5)	(0.16, 2.18, 0.24)

TABLE 3. Type-II weights of the proposed methodology

Type-II Weight	Category	Type-II Weight	Category
(0.051, 0.062, 0.050)	P_1	(0.296, 0.266, 0.334)	IF_1
(0.044, 0.110, 0.041)	P_2	(2.265, 4.834, 6.548)	IF_2
(0.095, 0.129, 0.153)	A_1	(4.663, 10.105, 13.234)	EF_1
(0.069, 0.063, 0.067)	A_2	(0.354, 0.535, 0.741)	EF_2

As mentioned previously, this improvement occurred regarding to two key features: (I) not only the minimum quality level of the product is maintained, but also the quality is maximized by employing the investment assignment; (II) when the quality level is significantly reduced, the proposed methodology can achieve a desired quality level with more investment assignment.

The investment improving plan has been effective regarding the updated weights at each improvement loop, where its effectiveness in a loop is better than the ones in the previous loops. In other words, the performance of the proposed methodology to analyze COQ is promising. Besides, the results obtained implementing the proposed approach to the case study provides encouraging results by indicating that the automotive and supportive industries in Asia are in the right track towards improving their performance.

5. CONCLUSION AND FUTURE RESEARCH

Achieving an expected quality level at the lowest cost is considered as a critical factor to create competitive advantages. Thus, for keeping market share in today's competitive world, companies should include quality expenses in their improvement plans. In this paper, a hybrid methodology was proposed in which two weights for the quality costs were identified. These weights determine the importance of each quality cost in the final quality level of products. The first type of weight was obtained by dividing each cost element by the total costs of quality and the second one was determined using a decision-making method in which the organization shareholders' opinions were considered through the balanced scorecard method. Moreover, due to the ambiguity and fuzziness nature of the costs importance, fuzzy logic was applied for determining the second type of weight for the quality costs. Then, an investment allocation model with the goal of reducing costs of quality was constructed. The model was updated in several iterations to lead a manufacturing company into reductions in the costs of quality more effectively. As future research, a fuzzy expert system is recommended to be developed to make the decisions more accurate.

6. REFERENCE

1. Schiffauerova, A. and Thomson, V., "A review of research on cost of quality models and best practices", ***International Journal of Quality & Reliability Management***, Vol. 23, No. 6, (2006), 647-669.
2. Foster, S.T., "Managing quality: An integrated approach. 3rd ed, (2006).
3. Juran, J.M., *Quality control handbook*, Quality Control Handbook, McGraw-Hill.. (1962),
4. Dale, B.G. and Plunkett, J.J., "Quality costing, Springer, (1991).
5. Carr, L.P., "Applying cost of quality to a service business", ***Sloan Management Review***, Vol. 33, No. 4, (1992), 72-77.
6. Greising, D., "Quality: How to make it pay", ***Business Week***, Vol. 8, No. 8, (1994), 54-59.
7. Juran, J. and Gryna, F., Juran's quality control handbook, , McGraw-Hill, New York (1988).
8. Feigenbaum, A.V., "Total quality-control", ***Harvard Business Review***, Vol. 34, No. 6, (1956), 93-101.
9. Yasin, M.M., Czuchry, A.J., Dorsch, J.J. and Small, M., "In search of an optimal cost of quality: An integrated framework of operational efficiency and strategic effectiveness", ***Journal of Engineering and Technology Management***, Vol. 16, No. 2, (1999), 171-189.

10. Committee, A.Q.C., "Quality costs-what and how", ***American Society for Quality Control, Milwaukee WI***, (1974).
11. BS6143. Guide to determination and use of quality related costs. British Standards Institute, L., UK, (1990).
12. Porter, L.J. and Rayner, P., "Quality costing for total quality management", ***International Journal of Production Economics***, Vol. 27, No. 1, (1992), 69-81.
13. Williams, A., Van der Wiele, A. and Dale, B., "Quality costing: A management review", ***International Journal of Management Reviews***, Vol. 1, No. 4, (1999), 441-460.
14. Abdelsalam, H.M. and Gad, M.M., "Cost of quality in dubai: An analytical case study of residential construction projects", ***International Journal of Project Management***, Vol. 27, No. 5, (2009), 501-511.
15. Castillo-Villar, K.K., Smith, N.R. and Simonton, J.L., "A model for supply chain design considering the cost of quality", ***Applied Mathematical Modelling***, Vol. 36, No. 12, (2012), 5920-5935.
16. Kaplan, R. and Norton, D., "The balanced scorecard: Measures that drive performance", ***Harvard Business Review***, Vol. 70, (1992), 71-79.
17. Kaplan, R.S. and Norton, D.P., "The balanced scorecard: Translating strategy into action, Harvard Business Press, (1996).
18. Martinsons, M., Davison, R. and Tse, D., "The balanced scorecard: A foundation for the strategic management of information systems", ***Decision Support Systems***, Vol. 25, No. 1, (1999), 71-88.
19. Banker, R.D., Chang, H., Janakiraman, S.N. and Konstans, C., "A balanced scorecard analysis of performance metrics", ***European Journal of Operational Research***, Vol. 154, No. 2, (2004), 423-436.
20. Yuksel, I. and Dagdeviren, M., "Using the fuzzy analytic network process (anp) for balanced scorecard (bsc): A case study for a manufacturing firm", ***Expert Systems with Applications***, Vol. 37, No. 2, (2010), 1270-1278.
21. Yang, T. and Hung, C.-C., "Multiple-attribute decision making methods for plant layout design problem", ***Robotics and Computer-integrated Manufacturing***, Vol. 23, No. 1, (2007), 126-137.
22. Satty, T., "The analytic hierarchy process. ", McGrawHill, New York., (1980).
23. Yu, C.-S., "A gp-ahp method for solving group decision-making fuzzy ahp problems", ***Computers & Operations Research***, Vol. 29, No. 14, (2002), 1969-2001.
24. Sohn, M.H., You, T., Lee, S.-L. and Lee, H., "Corporate strategies, environmental forces, and performance measures: A weighting decision support system using the k-nearest neighbor technique", ***Expert Systems with Applications***, Vol. 25, No. 3, (2003), 279-292.
25. Chiang, Z., A dynamic decision approach for long-term vendor selection based on AHP and BSC, **in *Advances in Intelligent Computing***., Springer , (2005) 257-265.
26. Lee, A.H., Chen, W.-C. and Chang, C.-J., "A fuzzy ahp and bsc approach for evaluating performance of it department in the manufacturing industry in taiwan", ***Expert Systems with Applications***, Vol. 34, No. 1, (2008), 96-107.
27. Zadeh, L.A., "Fuzzy sets", ***Information and Control***, Vol. 8, No. 3, (1965), 338-353.
28. Oberlender, G.D., "Project management for engineering and construction, McGraw-Hill New York, Vol. 2, (1993).
29. Crosby, P.B., "Quality is free: The art of making quality certain, McGraw-Hill New York, Vol. 94, (1979).

A Novel Hybrid Approach to Analyze Cost of Quality: Balanced Scorecard and Fuzzy Logic

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چکیده

در تحقیق پیش‌رو، یک روش نو در هزینه‌یابی کیفیت، برای تخصیص سرمایه بین هزینه های کیفیت پیشنهاد شده‌است. هدف این روش دستیابی به یک سطح کیفیت تعیین شده با حداقل هزینه‌های کیفیت است. در روش مذکور ابتدا دو نوع وزن برای اجزای هزینه محاسبه می‌شود، وزن اول از اطلاعات مالی و وزن دوم از روش تصمیم‌گیری به دست می‌آید. در روش تصمیم گیری بر اساس کارت امتیازی متوازن نظرات سهامداران به کار گرفته می‌شود. سپس بر اساس یک مدل برنامه ریزی ریاضی با هدف حداکثر کردن اثربخشی سرمایه‌گذاری، تخصیص بهینه سرمایه تعیین می‌شود. در نهایت پارامترهای مدل به صورت پویا در چرخه بهبود مستمر تنظیم می‌شود. به منظور افزایش دقت، از این روش در محیط فازی استفاده شده است و برای نمایش نحوه عملکرد روش، یک مطالعه موردی در صنعت قطعه سازی خودرو مورد مطالعه قرار گرفته است.

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