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A Novel Fuzzy Knowledge-based System to Measure Cost of Quality

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Abstract

An In the recent years, Cost of Quality (CoQ), primarily referring to a measure of all the expenditures related to quality and the related imposed costs of not providing it, has been used widely as a technique to calculate the costs and create high quality level products. Depending on the different circumstances under which a competition is launched, uncertainty should be taken into account for CoQ models. In this paper, a novel approach based on a fuzzy knowledge-based system is presented to give increased precision to the traditional methods. Our proposed method evaluates the efficiency of CoQ project's implementation in different markets with their corresponding characteristics. To demonstrate the adequacy of the proposed methodology, a case study is also investigated in a company which plays a very prominent role in the manufacturing of sewing machines in Iran.

***Keywords*:** Cost of quality, Fuzzy Knowledge-Based Systems, Quality Measuring System.

1. Introduction

Nowadays, the global competition impels markets to take into account the quality as a critical and effective factor in their services. Quality of services indicates the inherent characteristics and features of a service which reveals how good or bad a service is. The quality of services is so important that it can distinguish a company from the others. Different components such as materials, technology, and etc. can affect the quality. On the other hand, the dynamic nature of costumers' requirements and demands urge companies to consider these changes in their services. It is remarkable that implementation of quality in providing a service has different levels and each level would impose costs to company. Hence, naturally companies would be seeking to meet the requirements of their customers at the lowest cost of quality. Measurement of costs related to quality which depends on defining the quality has an important role in reducing the costs. Cost of quality (CoQ) is usually understood as the sum of conformance (the price paid to prevent poor quality) and non-conformance (poor quality caused by product and service failure) (ASQC, 1970). In other words, quality costs are known as expenditures dedicated to designing, implementing, operating, and maintaining a quality management system in a given organization (Dale et al., 1995).

Since identifying and reporting the costs of quality can be used in order to improve the quality level and reduce the related costs, measuring of CoQ as a well-known quality management technique has been studied by many researchers in the recent years. In other words, CoQ measurement is important because the information obtained through this method helps companies to recognize their opportunities. All of the previous studies conducted into CoQ have added some parameters to CoQ models and evaluated their methodology with different tools. They employed this approach to develop an effective methodology to continuously improve quality and

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establish efficient quality systems. However, it is remarkable that they didn't consider different markets and conditions in different countries. They often assumed CoQ projects are established in the same condition and with the same efficiency and utility of establishing CoQ projects are the same in the different countries with different economical, markets, and other conditions.

It is possible that an organization has been founded in a country whose market is not competitive or its economic condition is not normal. These disturbing factors should be considered in the measurement system. Expert systems are well-known for the way the handle the complexities of the manufacturing environment as emphasized in the review paper of Kumar (2017). Fuzzy expert system can be used as a solution to overcome the challenges arisen by the complexities and disturbing factors (Zadeh, 1999). The solution has been widely applied in different fields of studies such as quality, classification, supply chain management, and clustering (Alinezhad and Yasi. 2020; Illbeygi and Kangavari. 2020 Parsanejad and Nayebi. 2020). In addition, Mehdizadeh et al. (2012) used a fuzzy expert system to analyze the productivity of a system. Hajipour et al. (2013) proposed a fuzzy expert system to give increased accuracy and precision to the measurement system analysis. The purpose of this paper is to present a methodology based on fuzzy expert system which evaluates the benefits of launching CoQ project in different markets and countries with their corresponding characteristics.

The rest of this paper is organized as follows. In Section 2, we provide a background on the CoQ and the related works on this area. In section 3, we present the basic concepts related to fuzzy expert systems and then propose our novel methodology. The fuzzy rule base of analyzing utility is also described in this section. In Section 4, a case study is used to evaluate the efficiency of the proposed model. Finally, in section 5, the conclusion and potentialities for future research are presented.

2. Related Work

Cost of Quality (COQ) is primarily a measurement of all costs related to the quality and the related costs of lack thereof. In other words, it is an integrated concept of the accepted costs to achieve the quality and those costs that occur due to quality issues. A graphical form of CoQ models was presented by Juran (1951). He initialized the concept of quality costs and developed the economics of quality levels. Four classifications can be recognized for CoQ models: Prevention-Appraisal-Failure (P-A-F), process cost models, activity-based models, and opportunity cost models (Schiffauerova et al., 2006).

Feigenbaum (1965) proposed P-A-F model when his team was working on a dollar-based reporting system. This model is used as the basis for most CoQ models. P-A-F diagrams of Juran (1951) and Feigenbaum (1965) was approved by the American Society for Quality Control (ASQC, 1970) and the British Standard Institute (BSI, 1988). Juran and Gryna (1988) investigated two categories of costs: control costs which included prevention and appraisal costs, failure costs which included internal and external costs. Prevention cost comprises the activities which ensure that the process provides specific quality level for products and services, appraisal costs which are associated with activities that evaluate the quality level obtained by the process, and failure costs which refer to all costs paid for incorrect quality level before and after the delivery of products to customers. Crosby (1979) presented a model to categorize costs which is similar to the P-A-F scheme and described the cost of quality as an overall value of conformance and nonconformance costs. Abdelsalam and Gad (2009) introduced a P-A-F model to investigate the quality costs.

In the second type of evaluation, Ross (1977) presented process cost models. In this type of model, the concentration is on the process costs including total cost of conformance and non-conformance for a specific process instead of products and services costs. This kind of models called computer-aided manufacturing integrated program definition methodology, too. Conformance cost refers to the total process costs of producing products while meeting the expected standards based on customers' requirements which should be considered in the design of production process. On the other hand, non-conformance costs mean failure costs related to the process, which are not associated with the required standards. Usually total quality management (TQM) techniques concentrate on process cost models.

Cooper and Kaplan (1988) presented activity-based costing (ABC) model which can be considered as the third step of the evaluation. ABC is not actually a CoQ model but it supports an approach to identify and allocate cost of quality among products. One of the existing accounting systems' main problems is their disability in connecting with quality measurements and reporting based on them (Tatikonda and Tatikonda, 1996; Sorqvist, 1997; Mandel, 1972). In other words, they do not provide appropriate quality-related data, and benefits resulting from improved quality are not measured (Merino, 1988). Cooper and Kaplan (1988) presented ABC method to solve these problems. Based on their ABC method, the accurate costs for various cost objects were determined by tracing the resource of the costs of their associated activities and cost of activities to cost objects. According to ABC method the related cost of each activity can be recognized accurately, so the resource of each cost which is an activity can be identified easily.

In the last type of evaluation, Sandoval-Chavez and Beruvides (1998) developed P-A-F models by incorporating intangible costs into traditional P-A-F model and proposed opportunity and intangible costs model. Intangible costs cannot be calculated easily. One can estimate them by computing the unachieved profit because of losing customers which can be divided into three classes: underutilization of installed capacity, inadequate material handling, and poor delivery of service.

While most managers claim that quality is their top priority, only a small number of them really measure the outcome of quality improvement programs (Tatikonda and Tatikonda, 1996). CoQ can be calculated in different ways. Malchi and McGurk (2001) presented a methodology for measuring cost of quality by considering costs such as lost sales, extra inventory, and delay. In other words, cost of quality can be determined as a percentage of value-added or it can be calculated per unit of output (Gilmore, 1983). Taking a good approach to calculate these costs is so important. Merging these costs can be harmful because some external quality costs may become hidden in form of total failure cost which could consequently lead to inappropriate actions (Hesford and Dale, 1991). Modarres and Ansari (1987) believed that P-A-F model can be used to incorporate additional costs such as the cost of incompetent resource utilization and quality design cost. Thompson and Nakamura (1987) used P-A-F quality costing structure and designed a plan, which is currently being used at AT&T bell Laboratories, Transmission Systems Division to gather CoQ data from several development projects and report them. Tawfek et al (2012) employed artificial neural network model to evaluate the expected cost of quality in construction projects in Egypt.

Karg et al. (2011) surveyed a literature review of software quality cost researches. Castillo-Villar et al. (2012) considered cost of quality in a supply chain design problem in which CoQ can be calculated as an overall performance measure for the entire supply chain. Castillo-Villar et al. (2012) presented a supply chain design problem and considered CoQ as a measure in their problem. Audebaud et al. (2009) applied randomized algorithm in CoQ in order to approximate complex problems. Aydemir et al. (2007) presented an axiomatic nominal approach to variable bindings in CoQ, using a lambda-calculus. Youngdahl et al. (1997) evaluated the relationship between service customers' quality assurance behavior from CoQ's point of view. Schiffauerove and Thomson (2006) presented a survey on various costing procedures. Psomas et al. (2018) dealt with measuring cost of quality in food industry using a conceptual modeling. Gologovac and Philipovic (2017) tried to enhance the associated knowledge in the context of quality costing in practice. The results of conducting an empirical study on the manufacturing as well as service-based companies, revealed that there existed a significant level of awareness related to the cost of quality. The study also analyzed how different factors of ISO 9001:2015 could influence the cost of quality in the target companies.

3. The Proposed Methodology

Nowadays, the uncertainty of the environments which cannot be solved by crisp insights inspires researchers to consider this ambiguity in their computations. In the viewpoint of CoQ projects, the qualitative nature of parameters in evaluating efficiency of CoQ which is based on linguistic variables of decision makers cannot be calculated by deterministic mathematical functions. To formulate these qualitative factors, Zadeh (1965) proposed the fuzzy logic concept. We apply the fuzzy logic in a fuzzy expert system to evaluate the efficiency of CoQ projects implementation under different circumstances. In order to explain our fuzzy expert system, we first introduce the preliminary concepts and then describe the steps to implement the system.

3.1. Preliminaries

In this subsection some basic definitions of fuzzy logic are described (Zadeh ,1965; Zadeh, 1999):

Definition1. Let *U* be a universe set. A fuzzy set *X* of *U* is defined by a membership function $\mu_x \in [0,1]$ where $\mu_x \forall x \in U$ indicates the degree of *x* in *X*.

Definition2. Let *X* be a fuzzy set of *U*, where *U* is a universe set. *X* is normal, if and only if $sup_{x\in U}\ \mu_X(x)=1$.

Definition3. Let *X* be a fuzzy set of *U*, where *U* is a universe set. *X* is convex, if and only $\mu_x(\lambda x+(1-\lambda)y)\geq(\mu_x(X)\wedge\mu_y(X)),\forall x,y\in U,\forall\lambda\in[0,1]$

Definition4. A fuzzy number *X* is a fuzzy set which is both normal and convex in the universe set *U*.

Definition5. Let *U* be a universe set. Fuzzy set of $A_1, A_2, \ldots$ in the *U* are completeness of fuzzy sets if for each $x \in U$ there is at least one A^j as $\mu_{A^j}(x) > 0$.

Definition6. A triangular fuzzy number *X* can be defined by (a, b, c) as shown in Fig. 1. The membership function $\mu_X(x)$ is presented as Eq. (1).

$$\mu_X(x)=\begin{cases}\dfrac{x-a}{b-a} & a\leq x\leq b\\ 1 & x=b\\ \dfrac{c-x}{c-b} & b\leq x\leq c\end{cases} \tag{1}$$

Defitition7. A trapezoidal fuzzy number *Y* can be defined by (a, b, c, d) as shown in Fig 2. The membership function $\mu_X(X)$ is presented as Eq. (2).

$$\mu_X(x)=\begin{cases}\dfrac{x-a}{b-a} & a\leq x< b\\ 1 & b\leq x< c\\ \dfrac{c-x}{c-b} & b\leq x\leq c\end{cases} \tag{2}$$

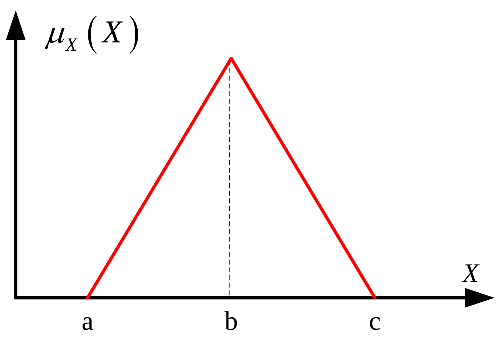

Fig. 1. Membership function of trapezoidal fuzzy number

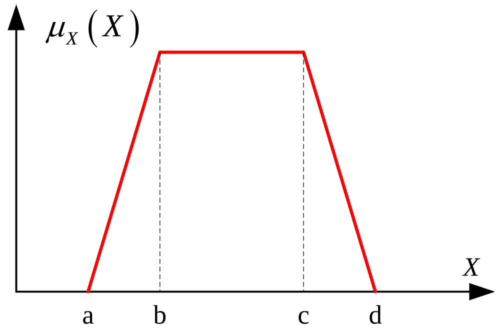

Fig. 2. Membership function of trapezoidal fuzzy number

3.2. *Defining the Inputs and Output variables*

In order to evaluate the utility of establishing CoQ project in different situations, in this paper a fuzzy expert system including multiple inputs and single output (MISO) is employed. Linguistic terms are in three types: low (l), medium (m) and high (h). They are defined by triangular and trapezoidal fuzzy numbers. Membership functions of these linguistic terms are shown in Fig. 3.

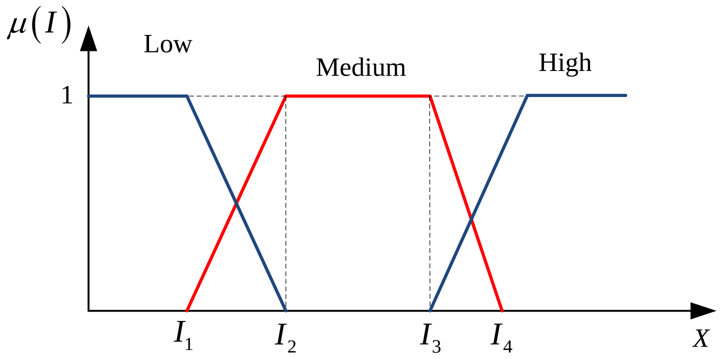

Fig. 3. Terms of input and output of variables

3.3. *The fuzzy rule base for analyzing utility*

A fuzzy expert system provides the ability to formulate ambiguous data by means of human knowledge. This is achieved by formulating a set of fizzy rules. A fuzzy rule consists of two main parts:

1. 'If' part which describes premise section of the fuzzy rule.
2. 'Then' part which describes conclusion section of fuzzy rule.

In our proposed fuzzy system, 'If' part consists of 'Market share (MS)', 'Rate of competition (C1)', 'Rate of downturn (D)', 'Rate of consumption of goods (C2)' as input variables and 'Then' part comprises 'Rate of utility of establishing CoQ project (U)' as output variables. A general form of fuzzy rule is as fallow:

If $input_1$ is $<$ linguistic variables $>$ and $input_2$ is $<$ linguistic variables $>$ then $output_1$ is $<$ linguistic variables $>$.

Any input can be defined by three linguistic variables; therefore, there are 81 rules for a predefined fuzzy expert system as shown in Table 1.

Table 1. Rules of the fuzzy expert system

Rule No.	Condition Part				Then Part	Rule No.	Condition Part				Then Part
	MS	C1	D	C2	U		MS	C1	D	C2	U
1	H	H	H	H	M	42	L	M	H	L	M
2	H	H	H	M	H	43	M	M	M	M	M
3	H	H	H	L	H	44	M	M	M	H	M
4	H	H	M	H	M	45	M	M	M	L	M
5	H	H	L	H	L	46	M	M	H	M	M
6	H	M	H	H	L	47	M	M	L	M	M
7	H	L	H	H	L	48	M	H	M	M	H
8	M	H	H	H	M	49	M	L	M	M	L
9	L	H	H	H	H	50	H	L	M	M	L
10	M	L	H	H	L	51	L	H	M	M	H
11	L	M	H	H	M	52	M	M	H	L	H
12	H	H	M	L	M	53	M	M	L	H	L
13	H	H	L	M	M	54	H	M	L	M	L
14	M	H	L	H	M	55	L	M	H	M	H
15	L	H	M	H	H	56	M	H	L	M	H
16	H	M	H	L	M	57	M	L	H	M	L
17	H	L	H	M	L	58	H	M	M	L	M
18	M	H	H	L	H	59	L	M	M	H	H
19	L	H	H	M	H	60	M	H	L	M	M
20	H	M	L	H	L	61	M	L	H	M	M
21	H	L	M	H	L	62	H	H	L	L	L
22	L	L	L	L	M	63	H	H	M	M	L
23	L	L	L	M	M	64	L	L	H	H	H
24	L	L	L	H	L	65	L	L	M	M	H
25	L	L	H	L	M	66	M	M	H	H	M
26	L	L	M	L	M	67	M	M	L	L	M
27	L	H	L	L	H	68	H	L	H	L	L
28	L	M	L	L	H	69	H	M	H	M	M
29	H	L	L	L	L	70	M	L	M	L	M
30	M	L	L	L	M	71	M	H	M	H	M
31	M	H	L	L	M	72	L	H	L	H	H
32	H	M	L	L	M	73	L	M	L	M	M
33	L	L	H	M	M	74	H	L	L	H	L
34	L	L	M	H	M	75	H	M	M	H	M
35	H	L	M	L	L	76	M	H	H	M	M
36	M	L	H	L	H	77	M	L	L	M	M
37	L	H	L	M	H	78	L	H	H	L	H
38	L	M	L	H	H	79	L	M	M	L	M
39	H	L	L	M	L	80	M	H	M	L	H
40	M	L	L	H	M	81	M	L	M	H	L
41	L	H	M	L	H						

3.4. The Fuzzy Expert System

In order to convert input variables to output variables one can use fuzzy expert system. To implement the proposed fuzzy expert system, the following cases have been considered.

1. Fuzzification interface by using a singleton fuzzifier
2. Inference the fuzzy system by using Mamdani implication engine (Iancu, 2012)
3. Defuzzification interface by using a centroid defuzzifier

According to MISO, (four inputs and an output) types of the proposed fuzzy rule-based system, x_0, y_0, z_0, r_0 are considered as fuzzy singleton of 'Market share', 'Rate of Competition', 'Rate of Consumption', 'Rate of Downturn' respectively. Fuzzy interface procedure is illustrated in following steps:

Step 1: Involving inputs fuzzy singleton into their universe sets
Step 2: Combining fuzzy sets which consist of fuzzy singleton and obtain the active rules.
Step 3: Calculating $\mu_X(x_0), \mu_Y(y_0), \mu_Z(z_0), \mu_R(r_0)$ as Eq. (1) and Eq. (2) named h_1, h_2, h_3, h_4 respectively.
Step 4: Determining matching degree (δ_j; j = 1, 2, 3…,J) for each active rules Eq. (3).

$$\delta_j = \min(h_1, h_2, h_3, h_4) \tag{3}$$

Step 5: Implementig Max-Min operator to transform the outputs ($u_j^{'}$) into the crisp values by centroid defuzzification in Eq. (4).

Let $\bar{u}^j$ be in the middle of $u_j^{'}$.

$$u_0 = \frac{\sum_{j=1}^{J} \bar{u}^j \times \delta_j}{\sum_{j=1}^{J} \delta_j} \tag{4}$$

At the end, the obtained value of the latest step (u_0) is considered as utility index in Fig. 4.

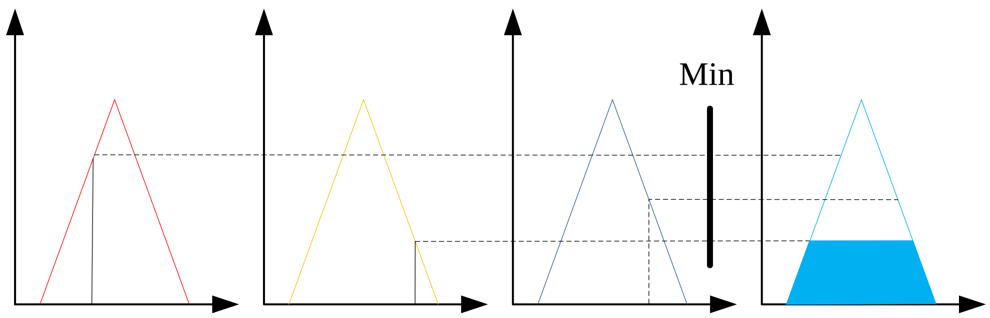

Fig. 4. Mamdani inference system

4. CASE STUDY

In order to evaluate the efficiency and adequacy of a CoQ project, in this section, a real case study in Kachiran Company is presented. This company is a well-known Iranian manufacturer which designs and manufactures some of the most technologically advanced home sewing machines in the world. The goal of this company is getting higher levels of sewing techniques. To achieve this, the company is constantly trending to enhance the quality of its products and concentrate on cost of quality. Therefore, we attempted to present a new methodology to increase products quality.

After evaluating the above-mentioned case, the following results were achieved: 'Market share' is high, 'Competition' is low, 'Downturn' is medium and 'Rate of product consumption' is low. To illustrate the results of this case study, fuzzy toolbox of MATLAB software is used. The rate of utility is as shown in Fig. 5.

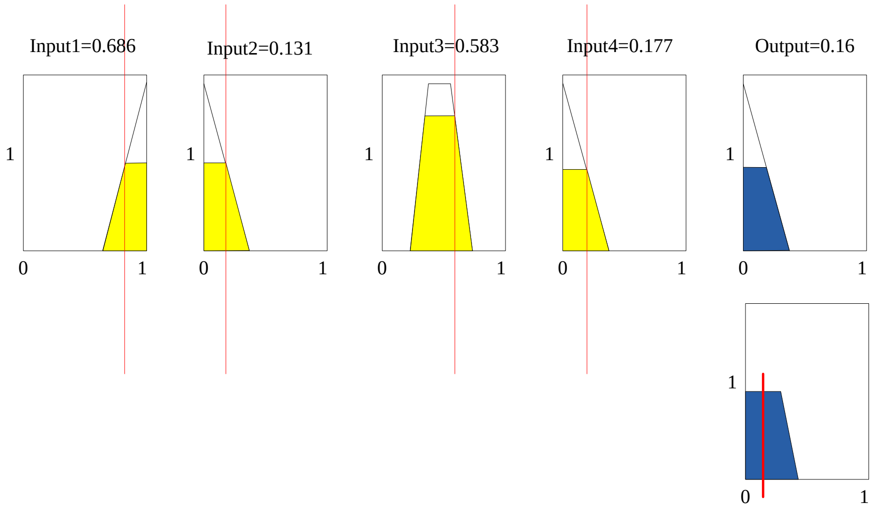

Fig. 5. Output of the proposed fuzzy inference system

Input 1 is considered high which means its range is in [0.7,1] interval. Input 2 is considered low which means its range is in $[0,0.3]$ interval. Input 3 is considered medium which means its range is in $[0.3,0.7]$ interval and 'medium' is defined in trapezoidal fuzzy number. Input 4 is considered low which means its range is $[0,0.3]$ interval. Hence inputs are assumed 0.962, 0.115, 0.5, and 0.146 respectively. Based on these values of input, the output will be 0.113 which means it is 'low'.

Fig. 6 and Fig. 7 indicate that increasing in market share of the organization, leads to decreasing in the utility of establishing a COQ project. If rate of competitiveness of market is situated in both low and high areas, the utility of establishing CoQ projects will be increased and if it is situated in the middle area, this utility should be placed in the middle region. Besides, if the consumption rate of the product is situated in both low and middle areas, the utility of establishing CoQ projects should be placed in the middle area and if it is situated in the high area, the utility should be decreased proportionally.

The influence of downturn on utility of establishing CoQ projects is the same as the influence of consumption rate of the product. If the rate of downturn is in both low and middle areas, the utility of establishing CoQ projects should be placed in the middle area and if it is situated in the high area, the utility increases proportionally.

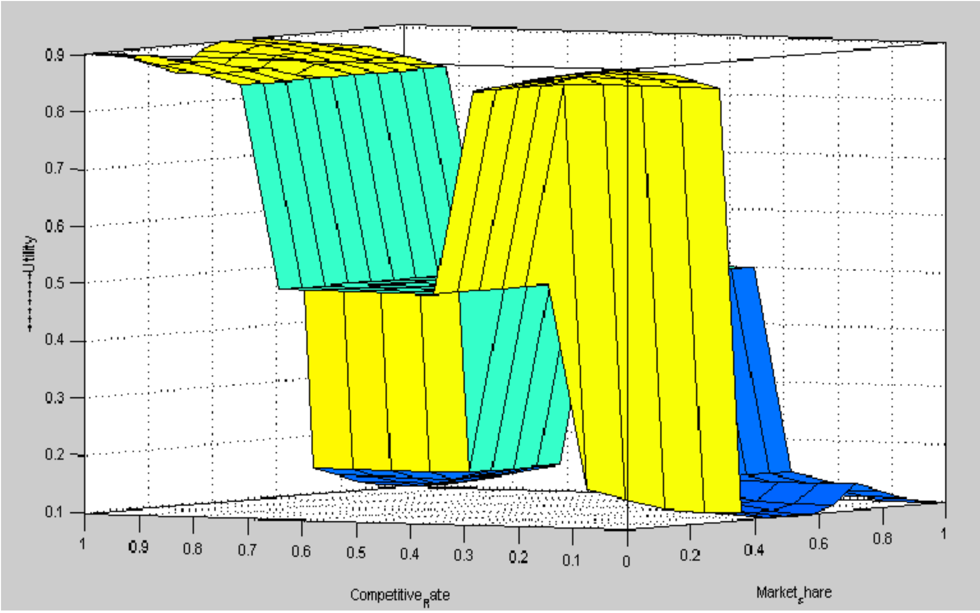

Fig. 6. Sensitive analysis of market share and competition inputs on the output

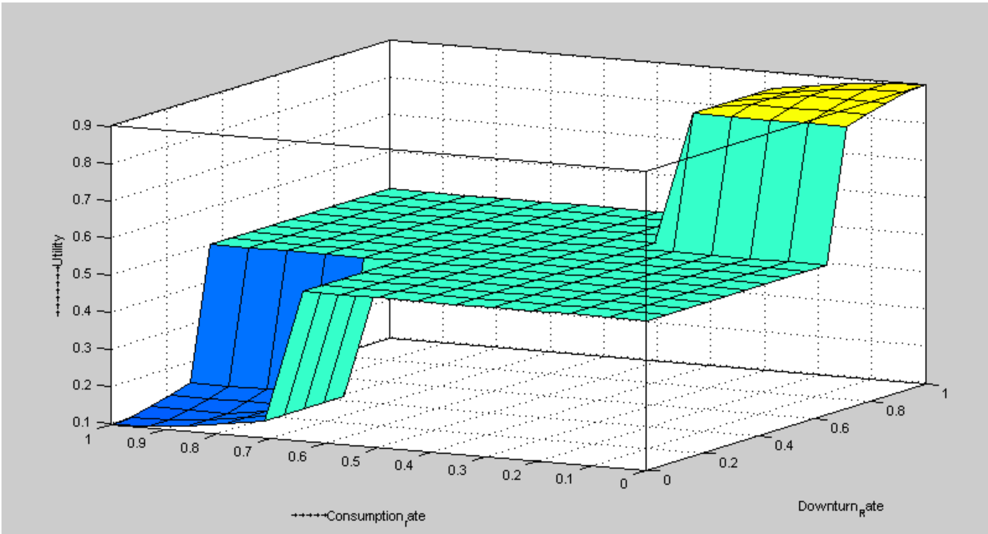

Fig. 7. Sensitive analysis of consumption and downturn inputs on the output

5. Conclusion

Uncertainty is an important element that must be considered in CoQ models taking into account the different competition conditions in various environments. In this paper, a novel approach based on a fuzzy knowledge-based system was presented which evaluates the efficiency of CoQ project's implementation in different markets. The proposed method can be used to increase the precision of the traditional CoQ modeling methods. In our proposed system, market share, rate of competition, rate of downturn, and rate of goods consumption were considered as input variables for the system in order to estimate system output which is called rate of utility to launching CoQ projects. A case study was also performed to demonstrate the performance of the proposed system in real world. We evaluated the efficiency and adequacy of CoQ project using the case study.

For future research, one can work on presenting a system with more applicability and efficiency in measuring cost of quality. In this regard, the applicability of the proposed model could be justified by considering a stochastic programming approach and exploring the output results with the current fuzzy-based one. It is also worthwhile to study the influence of warranty costs on the CoQ projects that has been neglected in our paper.

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