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Ranking factors involved in product design using a hybrid model of Quality Function Deployment, Data Envelopment Analysis and TOPSIS technique

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A B S T R A C T

Quality function deployment (QFD) is one such extremely important quality management tool, which is useful in product design and development. Traditionally, QFD rates the design requirements (DRs) with respect to customer requirements, and aggregates the rating to get relative importance score of DRs. An increasing number of studies emphasize on the need to incorporate additional factors, such as cost and environmental impact, while calculating the relative importance of DRs. However, there are different methodologies for driving the relative importance of DRs, when several additional factors are considered. TOPSIS (technique for order preferences by similarity to ideal solution) is suggested for the purpose of the research. This research proposes new approach of TOPSIS for considering the rating of DRs with respect to CRs, and several additional factors, simultaneously. Proposed method is illustrated using by step-by-step procedure. The proposed methodology was applied for the Sanam Electronic Company in Iran.

1. Introduction

In the global era, only organizations are successful that can meet their customers' requirements. In today's competitive world, the main condition of competition is to offer products and services consistent with customers' needs. The success of products and services is a variable of how they meet customers' needs. In its modern sense, quality is used to mean features of a product or service, which meet customers' expectations. According to Total Quality Management (TQM) literature, the quality of a product is primarily associated with the question of "customer needs". Quality Function Deployment (QFD) is a suitable tool to address the above question. It is one of the techniques that help organizations gain customers' satisfaction from the early stages of the product life cycle, i.e., design (Akao & Mazur, 2003), QFD is used as a team process for planning and designing new

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products or developing existing products. With a systematic and precise framework, it determines the needs and expectations of customers and manifests them in technical features of the product, which gives the organization a proactive position in dealing with issues and problems associated with the quality and customer's' satisfaction (Hunt & Xavier, 2003). Accordingly, this paper studies customer' needs and their relationship with technical specifications in terms of multiple organizational factors such as cost, ease of implementation and harmful environment effects of the specifications.

To have a comprehensive evaluation of data, the model proposed by Ramanathan and Yanfeng (2009) was used. However, given the inherent flaw of their proposed model, this study draws on Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to rank technical specifications with respect to multiple organizational factors. We hope that by incorporating this information in the projection matrix of the product, the decision-making about prioritizing customers' demands is reinforced and therefore proper specifications are selected.

2. Theoretical Foundations of Research

2.1. Quality Function Deployment

The word "quality function deployment" has its root in a Japanese word composed of three following parts (Van De Poel, 2007):

1. Hin Shitsu, which means "quality", "feature", "specification" or "attributes"
2. Kin, which means "performances" or "mechanisms"
3. Ten Kai, which means "expansion", "development" or "evolution"

Before the presentation of QFD, Quality Tables were used to contribute to the conversion of customers' demands into technical specifications of a product. The matrices of these tables established a connection between the qualitative features of a product and manufacturing operations of the organization. This novel approach, i.e. the development of qualitative features, extended to all stages of product development from design to final production. Quality tables were first used in Kobe Shipbuilding Industry by Professor Yoji Akao in1972 to design ship tankers. Quality function deployment is the development and expansion of specifications, features and functions that influence the quality of a product or service. This process enhances the quality of goods or services according to customer needs; that is, the quality is defined based on customer needs (Hwang & Teo, 2002).

QFD is step-by-step development of operations and work performances that ensure the intrinsic quality of components through systematization of goals. QFD is a way to hear customer's voice. It provides a systematic process for receiving customers' requirements and translating them into necessities reached along the supply chain (Tang et al., 2002). As a planning tool, the aim of QFD is to reduce two kinds of inconsistency in the organization. The first one is when product features are inconsistent with the predefined necessities of the target customers and the second one is associated with the inconsistency between the final product and the technical features of the product. QFD resolves the former by linking product features to the voice of customers and reduces the latter by modifying and transferring technical specifications to the implementation, details processes and production features (Kahraman et al., 2006). It allows planning groups to develop high-quality products or services to meet customer needs. With the development and widespread use of QFD, the scope of its application in fields such as designing, planning, decision-making, engineering, management, teamwork, timing, costs, etc. has also extended considerably. It offers a specific approach to guarantee the quality at every stage of the product development process, which starts with the design.

To ensure the quality of services and products, not only the results of “negative quality” comments expressed in customer’s complaints, but also “good quality” opinions stated in the demands of the customers should also be taken into account (Özgener, 2003).

2.2 House of Quality

Home Quality consists of important and useful contents that if prepared and regulated properly, can provide highly valuable information about a product or service, acting as the end point of large scale quality function projects. Different parts of a house of quality are shown in Fig. 1. As can be seen, the house of quality can be simply seen as a matrix of customer requirements (What) and technical specifications (How) (Van De Poel, 2007). Correlation matrix – technical requirements – competitors’ evaluation – relationship matrix – qualitative demands requirements of customers – target values

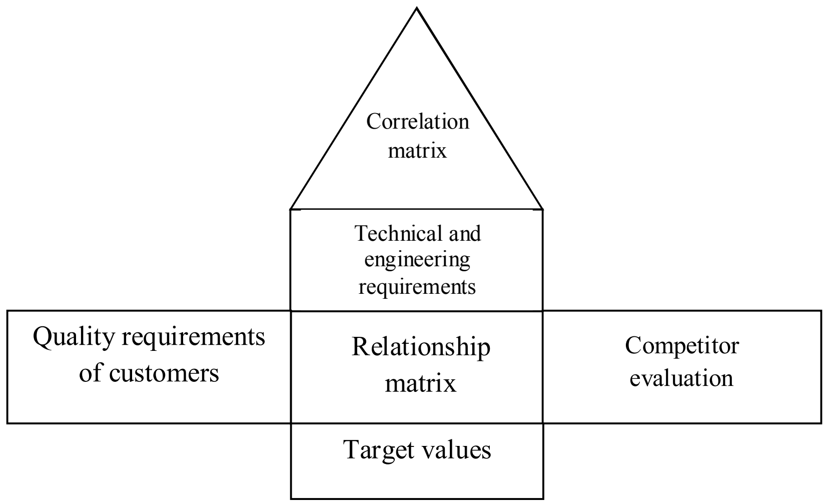

Fig. 1. House of Quality

2.2.1 Determining the demands and needs of the customers

QFD begins with identifying customers and asking this question: “What do customers need?” (Fung et al., 2003). Oftentimes, the needs of customers are determined through marketing and sales. However, other sources can also be used to determine customer needs including surveys, customer complaints, standards, employee ideas, the performance of product upon usage and sales records. These cases help determine the qualitative demands of customers about the desired product (Chan & Wu, 2002).

2.2.2 Determining the importance of customer needs and their prioritization

As it is not possible to meet all the demands of customers due to the technical and budgetary constraints, customers’ demands need to be prioritized so that the main demands are considered in the product design. The company should ignore certain demands and postpone their fulfillment to other times. To determine the relative importance of each need of customers, 1-10 scales can be used.

2.2.3 Competitors’ evaluation

To be able to compete and act effectively in the market, many firms need to know the position and ranking of their products in the eye of customers in terms of their desired qualitative specifications. To incorporate this in the house of quality, the desired product has been compare with similar products of competitors in the right side of the matrix (Chan & Wu, 2002).

2.2.4 Translating demands into technical specifications of the product

Marketing unit is in charge of identifying, evaluating and developing customer demands, specifications and “What” requirements of the product. Then, the technical unit determines “How” the product should be produced in accordance with the desired specifications. Therefore, in the upper section of matrix, the technical and engineering features of a product, which are somehow associated with quality requirements of customers, are inserted. Before and under each engineering feature of the product, three symbols of ↑↓ and ● are inserted. Symbols ↑ and ↓ signify the desire of product designers to increase or decrease the intended features and symbol ● indicates the reluctance of product designers to make any change in the target feature where only reaching the target value is importance for the feature.

2.2.5 Relationship matrix

QFD executive team determines relationships based on the opinions of experiences of professionals, customers, statistical data, etc. The following symbols are commonly used in relationship matrix:

● Strong relationship (9)
○ Moderate relationship (3)
Δ Weak relationship (1)

The lack of a logical relationship between a technical specification and qualitative demands of customers is indicative of the fact that this specification is either useless or lacks some qualitative demands of customers. The lack of relationship between a certain demand of customers and technical specification of the product indicates that some properties have not been taken into account and therefore matrix columns should be developed and completed (Hunt & Xavier, 2003).

2.2.6 House of Quality Limit

In some cases, there is a direct relationship between two technical specifications of the product, and in other cases, there is a reverse relationship between two technical specifications of the product. House of quality limit reveals the correlation between technical specifications, which is characterized by the following symbols:

Ө Very positive   + Positive   - Negative   Ǿ Very negative

2.3 Data envelopment analysis (DEA)

In 1957, Farrell proposed the nonparametric methods for estimating efficiency for the first time. The case used by Farrell for measuring the efficiency consisted of an input and an output. Charnes et al. (1978) developed Farrell's model and presented a fractional and nonlinear mathematical programming model, which could measure effectiveness with multiple inputs and outputs. This model was later known as data envelopment analysis. In general, there are two strategies for improving inefficient units and reaching the threshold of efficiency (Sueyoshi & Goto, 2012):

A. Reducing input without decreasing output to reach the threshold of efficiency; that is, keeping the output constant and reducing the proportion of inputs. This view is called “input nature of performance improvement”

B. Increasing output to reach the threshold of efficiency without absorbing further inputs. This view is called “output nature of performance improvement”

The selection of each view depends upon the conditions. In similar cases where inputs are relatively constant, the output-based model is preferred and in cases where outputs are tightly consistent with organizational objectives, or limited by external factors, the output-based model is preferred. This method considers each section as a decision making unit, which requires a set of inputs and outputs for analyzing and calculating efficiency.

Suppose there are *n* decision-making units, and each of these units uses *m* inputs to produce *s* outputs. X_{ij} is the value of input *i* (i = 1,2, ..., m) that are used by $DMUj$ and Y_{ij} is the value of output *r* (r = 1,2, ..., s) produced by $DMUj$. Variables u_r and v_i are weights of input and output indicators. Technical efficiency of DMU_O is calculated as follows (Samoilenko & Osei-Bryson, 2013):

max $Z_0 = \sum_{r=1}^{s} u_r y_{r0}$

subject to:

$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0$
$\sum_{i=1}^{m} v_i x_{i0} = 1$
$u_r \geq 0,\ v_i \geq 0$
r=1, 2,…,s ; i=1,2,…,m ; j=1,2,…,n

2.3 TOPSIS technique

TOPSIS technique of decision-making was developed by Hwang and Yoon (1981) based on the principle according to which the selected option must have minimum distance from positive ideal solution and maximum distance from the negative ideal solution (Abo Sina & Amer, 2005). TOPSIS is one of the methods of compromising subgroups. In this group, there is a preferred option, which is the closest option to the ideal solution. Compromising model is also a subgroup compensatory model. This model deals with the exchange of indicators, i.e., the weakness of an index may be offset by other indices (Asgharpour, 2008). To apply the model in the algorithm of this technique, first the decision-making matrix should be converted to a dimensionless matrix by Euclidean norm (Mehregan, 2004).

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum f_{ij}^2}}$$

Then, based on coefficients of indicators, the diagonal weight matrix and harmonic dimensionless matrix are obtained.

$Vij = wi \times rij$

In the next step, the set of positive ideal solutions and negative ideal solutions are identified and the distance of each strategy is calculated according to the following equations.

$A^* = (V_1^*, \dots, V_i^*) = (\max V_{ij} \mid i \in I'), (\min V_{ij} \mid i \in I")$
$A^- = (V_1^-, \dots, V_i^-) = (\max V_{ij} \mid i \in I'), (\min V_{ij} \mid i \in I")$

The distance of each strategy is calculated according to the following equation.
$D_j^* = \sqrt{(V_{ij} - V_i^*)^2}$
$D_j^- = \sqrt{(V_{ij} - V_i^-)^2}$

Then, the value of CC_j^* is calculated according to the following equation.

$$CC_j^* = \frac{D_j^-}{D_j^- + D_j^*}$$

Finally, based on the descending order of CC_j^* , the available options can be ranked.

3. Material and methods

This study, which is classified among applied research in terms of its objective, seeks to incorporate the scientific achievements of fundamental research in the field of technology. In terms of data collection, this is a descriptive study, which is based on a case study. In this study, three questionnaires were designed. The first one identified customer needs and determined the importance of each demand through some open-ended questions. The second one surveyed the views of experts with the aim of prioritizing technical specifications based on four factors of customer satisfaction, implementation, costs and harmful environmental impacts. The third one sought the opinions of customers regarding the effect of each of these specifications on improving their satisfaction. In this study, simple random sampling was used, which followed Eq. (1) for experts and Eq. (2) for customers (Azar & Momeni, 2006):

$$\frac{N * \left(Z \frac{\propto}{2}\right)^2 * pq}{(\varepsilon)^2 * (N-1) + \left(Z \frac{\propto}{2}\right)^2 * pq} \quad (1)$$

$$n = \frac{(Z \frac{\propto}{2})^2 * pq}{(\varepsilon)^2} \quad (2)$$

Thus, a sample size of 26 and 96 subjects were selected for experts and customers population respectively. To increase the validity of questionnaire, KMO index and the Bartlett test were used. In this study, the KMO value of 0.00, and the sig value of 0.83 were obtained, which indicated the suitability of factor analysis for identifying the appropriate structure.

In addition, Cronbach's alpha coefficient was used to calculate the reliability. The value of alpha coefficient was 0.8737, which indicated the acceptable reliability of questionnaires' data.

3.1 Introducing research model

Generally, a house of quality consists of six sections (matrix A to F). In Section A, customer needs are identified and the relative importance of individual needs is determined based on feedbacks taken from customers. Technical specifications are determined in matrix B and the degree of relationship between customer needs is calculated in matrix C. In this study, customer needs and technical specifications are referred to as CR and DR respectively. Absolute and relative importance of DR is calculated in matrix E and matrix F is used for modeling. Ramanathan and Yanfeng (2009) did a comprehensive study on house of quality. In their proposed method, three factors of cost, ease of implementation and harmful environmental impacts were investigated. However, their proposed model had two basic problems:

1. In their proposed model, they only used relationship matrix and technical matrix for calculating DR efficiency whereas in house of quality modeling and correlation matrices also play a pivotal role in determining the relative importance of DRs.

2. When the relative importance of technical specifications of DRs are calculated by Data Envelopment Analysis model, the efficiency score of multiple DRs would be equal to one, which confuses the organization in DR selection.

Thus, to overcome the above two problems, TOPSIS technique has been proposed in this paper.

3.2 The procedure based on the proposed model

First, all CRs and DRs are listed. Then, the appropriate numerical values for all relationship, correlation, technical and modeling matrices are assigned. In the next step, using the classic QFD method, matrices A, C and E and correlation matric, the relative importance of each DR is calculated. Then, using data envelopment analysis (DEA), inputs and outputs are accounted for and efficiency score and ranking of each DR is calculated. To compensate for the weakness of the model by TOPSIS technique, it suffices to compute CC_j^* for each DR. In the next step, to compute the final score of each DR, CC_j^* is multiplied by the relative importance. Finally, having computed the final score for each DR, they are ranked in descending order.

3.3 Case Study: Sanam Electronic Company

Sanam Electronic Company (Sanam Service) was established in 2008 with the aim of increasing the capability and operationalizing the opportunities in service sector. Given the operation of Sanam Co. in the field of product production and distribution and years of experience in the domain of manufacturing activities, the development of a professional instrument in service sector to take advantage of opportunities and available capacities and create fresh opportunities was a strategic action. The chief executives of this company believe that the realization of customer satisfaction primarily depend on the empowerment of the company. With the mission of gaining the satisfaction of customers, shareholders and investors of the company in the competitive environment, this company began its activity in the following sectors:

A: After sale services, this company is one of the specialized companies in offering guarantee services in Iran with a powerful network of service and support all over the country in three fields of electric, power and cooling products, mechanized reception systems and process control in the head office, spare parts supply and support system and customer relationship management system. Over 480 representatives of this company are active in all parts of Iran within Sanam service network. In addition to Sanam products, the products of other companies are also covered by warranty and support of Sanam service.

B: in technical and business services sector, the design and implementation of surveillance and security systems, access control, central video system, large indoor displays, advertising boards, interactive whiteboard and ordering and procurement of goods are carried out in accordance with customers' requirements. Considering the importance of support and maintenance services of goods, the availability of warranty and support service by Sanam service nationwide has created a competitive advantage for the clients.
C: in supply and commerce service, the ordering and supply of high quality parts and products are offered at competitive prices.

4. Results

In this section, we examine whether the combination of TOPSIS and QFD technique along with the integration of design requirements in line with organizational and environmental factors in goods and products can act as a contributing factor and improve the decision makings of the managers.
To this end, we used Wilcoxon signed rank test for paired comparisons.

Table 1
Wilcoxon signed rank test for paired comparisons

	Test statics
Z	-0.135
Asymp.sig.(2-tailed)	0.893

In this test, the significance level was 0.893, which was greater than 0.05, suggesting that the use of proposed model could lead to proper prioritization of effective solutions in satisfying the needs and demands of customers. In the next step, the degree of importance of each factor in ensuring customer satisfaction is discussed and solutions are prioritized based on aggregate opinions of customers, as shown in Table 2.

Table 2
Ranking in the view of customers

Options	Ranking	Options	Ranking
Image transparency	1	Robustness of TV cabinet	7
Sound clarity	2	Number of tuners	8
Speakers output	3	Quality and quantity of outputs	9
Signal power	4	TV memory	10
TV weight	5	Sound intensity	11
Number of color sensors	6	Number of images per second	12

Finally, based on the proposed model and with the aim of integrating organizational factors in computation of relative importance of technical specifications, TOPSIS technique was used. The results of this ranking are shown in the Table 3 as follows,

Table 3
House of quality of the case study (researchers' computations)

Relative importance of CR		Image transparency	Reception power	Sound intensity	Speakers output	Sound clarity	Quantity and quality	No. tuners	No. pages	No. of sensors	TV memory	TV weight	Resistance	Organizational performance	Rival's performance	Organizational goals	improvement ratio	Sale points	Absolute importance
Image transparency	0.173	☺	Δ						Δ	Δ	Ø			4	5	5	1.25	1.5	9.37
Sound clarity	0.173		Δ	☺	Δ	Δ		Ø			Ø			4	5	5	1.25	1.5	9.37
PC connectivity	0.11						☺							4	4	4	1	1.2	6
Multi-channel display	0.147		Δ					Δ	Δ	Δ	Δ			3	5	5	1.66	1.2	7.97
Fixed image	0.104								Ø	Δ	☺			2	4	4	1.5	1.25	5.63
Ease of transport	0.183											☺		3	5	5	1.66	1.2	9.96
Cabinet power	0.11												☺	3	4	5	1.66	1.2	5.98
Value of relative efficiency with DEA		1.03	0.98	1.03	0.0344	0.0344	0.0656	0.0521	0.705	0.843	1.142	1.09	0.656						
Efficiency ranking based on DEA		3	4	3	11	11	8	10	7	6	1	2	9						
Cost		4	3	5	3	4	5	1	3	5	3	2	3						
Ease of implementation		2	2	2	3	2	1	2	3	4	1	5	2						
Harmful environmental impacts		1	1	4	3	5	2	1	5	2	4	4	1						
CC_j^*		0.8079	0.9119	0.2574	0.7069	0.1028	0.6312	0.8096	1.095	7.64	2.31	8.087	7.775						
Final score		7.61	7.24	2.56	1.72	0.99	3.82	3.85	1.32	6.29	2.51	4.54	5.1						
Final ranking		1	2	8	10	12	7	6	11	3	;;;9	5	4						

5. Conclusions

Studies show a direct correlation between customer satisfaction and superior financial and competitive position of the company because understanding and meeting customers' satisfaction is one of the key tenets in the market response for manufacturers, as the dissatisfaction of customers may compromise the company revenues. In this study, attempts have been made to propose a method to incorporate side factors such as cost, ease of implementation and harmful environment impacts and other factors in the analysis of house of quality. In today's competitive economy, only organizations that can design products and services beyond customers' needs would be successful. Quality function deployment, as a practical technique, which deals with the relationship between customer needs and design and production of the product, is an instrument for classifying and analyzing customers' voice so that the overall feedbacks can be used in the design of products and services. A review of studies in the field of quality function deployment has shown that ranking of technical specifications in house of quality was usually based on the impact of each factor in meeting the demands of customers, whereas there are other criteria such as cost, time, technical difficulty, and market opportunities that should be considered in the ranking of the technical specifications. These factors, given the limited resources of each organization, the level of extensibility and manufacturing capabilities of technical specifications of products, play an important role in decision makings of managers in incorporating the views of customers. Moreover, this study compensates for the weaknesses of other models such as the one proposed by Ramanathan and Feng (2008) using TOPSIS technique, acting as an excellent model for decision making of managers.

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