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ORIGINAL ARTICLE

Supplier evaluation and selection with QFD and FAHP in a pharmaceutical company

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Abstract In this paper, quality function deployment (QFD) approach is used for selecting the vendors in pharmaceutical company and the fuzzy analytic hierarchy process has been used to determine the importance of the "weights" in QFD. Determining the importance of the weights for the customer requirements is essential and crucial in QFD process. Using fuzzy approach can reflect the customer requirement more precisely and provides a decision tool that facilitates the vendor selection especially for a pharmaceutical company, since those companies face a very specific challenge: consumers do not have discretion over their choices; ethical drugs must be prescribed by physicians to be bought and used by final consumers.

Keywords Supplier's evaluation and selection · Multi-criteria decision making · Quality function deployment · Fuzzy analytical hierarchy process · Pharmaceutical industries

1 Introduction

Regarding the multiplicity of different suppliers in today's competitive industrial world, selection of a suitable supplier is crucially important. Current highly competitive markets forced companies to respond quickly and accurately to the needs of customers, to meet customer's satisfaction, and improve and develop their position in the market. Such pressures encourage companies to utilize implement concepts. In such circumstances, the role of suppliers and their supply chain management have a great importance, since a wrong decision may lead to higher industrial unit costs and consequently considerable damage of the supply chain relationship. In order to gain an acceptable profit, which is necessary for continued survival of the organization, selection of suitable suppliers is a multi-criteria problem with qualitative and quantitative factors that must be solved.

Also, these goals will elevate levels of customer satisfaction resulting in better profits if the mentioned goals and management principles were achieved. Supplier selection becomes more complex when groups and organizations participate in this process and the criteria in each group had different suppliers.

Finally, choosing a good supplier and proving requested quantities from each selected supplier must be managed. It has been proved that multi-criteria decision-making approach is better than considering one single approach which is only based on cost [1, 2].

Traditional methods only consider the cost without covering all aspects of a general and universal of supplier selection problem. But in multi-criteria decision-making methods, other criteria such as quality, flexibility, delivery, etc. are also taken into account. One of the issues in process of evaluation of supplier's selection criteria is that these indicators can be quantitative or qualitative performance [3–5].

In this research, the linguistic judgment of customer requirements is converted to the triangular fuzzy numbers. These triangular fuzzy numbers are used to build a pairwise comparison matrix for the analytic hierarchy process (AHP).

Considering the "voice" of customers as a vital element in making decision in any company, this paper develops and integrated approach, combining quality function deployment (QFD), fuzzy set theory, and AHP for supplier

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evaluation in pharmaceutical company. Since multiple evaluating criteria are proposed, and some of them are qualitative and uncertain, the fuzzy set theory is therefore incorporated into the traditional AHP to enable company customers to express their linguistic preferences and to transform those preferences into the quantitative form for comparison. Fuzzy AHP is responsible for the assignment of importance ratings and relationship weightings in the house of quality (HOQs) so that inconsistencies due to subjective judgments can be avoided. This research was organized in six divisions. In Section 1, the most important criteria are obtained from the buyer's expert team. In Section 2, some topics considered as strategic factors of supplier's selection are developed. In Section 3, materials and methods are discussed. In Section 4, the combination of fuzzy AHP and QFD is discussed with a case study of a pharmaceutical industry, which is employed to illustrate the application of the proposed method. Finally, the results of the fuzzy AHP and QFD as well as conclusions are presented in Sections 5 and 6.

2 Literature review

The contemporary supply evaluation is to maintain long-term partnership with suppliers and use fewer but reliable suppliers. Therefore, choosing the right suppliers involves not only scanning a series of price list, but also supplier selection depends on a wide range variety of factors comprising both quantitative and qualitative criteria.

There are at least three journal researches reviewing the literature regarding supplier evaluation and selection models by 2001 [4]. Ho et al. reviewed papers studying the supplier evaluation and selection problems from 2000 to 2008. As the addressed research declares, the most popular criterion to evaluate suppliers is quality, followed by delivery, price/cost, manufacturing capability, service, management, technology, research and development, finance, flexibility, reputation, relationship, risk, and safety and environment [6].

Karpak et al. [7] created a goal programming (GP) with three goals: cost, quality, and delivery to evaluate and select the suppliers. Narasimhan et al. [8] constructed a multi-objective programming with five criteria to select the optimal suppliers. They also used AHP to generate weightings. Muralidharan et al. [9] proposed a five-step AHP-based model to support decision makers in rating and selecting suppliers with nine evaluation criteria.

Chen and Wang [10] developed an interactive selection model with the AHP to facilitate selecting suppliers for decision makers. AHP was only applied to generate the overall score for alternative suppliers based on the relative importance ratings. For the customer requirement, Chan [11] employed AHP to evaluate and select the best suppliers. The AHP hierarchy consists of six evaluating criteria and 20 sub-factors, in which the relative importance ratings were computed based on the customer requirements. Liu and Hai [12] used AHP to evaluate and select suppliers, alike to Chan [11], the authors did not use the AHP's pairwise comparison to resolve the relative importance ratings between the criteria and sub-factors. Instead, the authors applied ranking method, which allowed every manager to establish the order of criteria rather than the weights. Chan et al. [13] developed an AHP-based decision-making approach to solve the supplier selection problem. Potential suppliers were evaluated based on 14 criteria. A compassion analysis using Expert Choice software was performed to examine the response of alternatives when the relative importance rating of each criterion was changed.

A hierarchy model based on fuzzy set theory to deal with the supplier selection problem was presented by Chen et al. [14]. The linguistic values were used to assess the ratings and weights for the supplier evaluating factors. Kahraman et al. [1] applied a fuzzy AHP to select the best supplier in a Turkish manufacturing company. Decision makers could specify preferences about the importance of each evaluating criterion using linguistic variable.

Chan and Kumar [4] also used a fuzzy AHP for supplier selection as the case with Kahraman et al. [1]. In this approach, triangular fuzzy numbers and fuzzy synthetic extent analysis method were demonstrated to represent decision makers' comparison judgment and to decide the final priority of different criteria. Ghodsypour and O'Brien [15] formulated a mixed integer nonlinear programming model to solve the multi-criteria sourcing problem. The model was extended to determine the optimal allocation of products to suppliers so that the total annual purchasing cost could be minimized. Three restraints were considered in their model.

Bevilacqua et al. [16] presented the fuzzy-QFD approach to supplier selection. They obtained the "WHATs" from the company's requirements afterward the "HOWs" was found from the supplier consideration criteria. They use a fuzzy algorithm to arise a final decision based on the fuzzy suitability index. Chan and Kumar [4] suggested the global supplier development considering risk factors and using fuzzy extended AHP-based approach. They indicated the risk factors in their supplier selection model. Fuzzy extended AHP (fuzzy AHP) was applied to tackle this problem. Cost, quality, service performance, and supplier's profile with the risk factors were considered in their model. This paper can be considered as an extension in the literature; QFD method would be considered to solve the problem and we use FAHP to add the uncertainty condition and imprecise the QFD model.

3 Material and methods

3.1 Fuzzy set theory

The fuzzy set theory was defined by Zadeh [17] to cope with problems in the way that a source of vagueness is involved. A fuzzy set can be introduced mathematically by allocating a value to each possible individual in the universe of discourse in which each value is representing its grade of membership in the fuzzy set.

Fuzzy set theory indicates and handles unclear or imprecise judgments mathematically. The fuzzy set theory is designed to express the extraction of the primary possible result from a multiplicity of information which may be vague and imprecise. Fuzzy set theory deals with vague data as possibility distributions in terms of set memberships.

Once determined and defined, the sets of memberships can be effectively employed in logical reasoning. Triangular fuzzy numbers are one of the main components. According to the definition of Laarhoven and Pedrycz [18], a triangular fuzzy number (TFN) should possess some basic features as described in the next section.

3.2 Triangular fuzzy numbers

A fuzzy number is a special fuzzy set. The following expressions are $F = \{(x, \mu_F(x)),\ x \in R\}$, $R_1 = -\infty \prec x \prec +\infty$, and $\mu_F(x)$ which the last one is called membership function and possesses a continuous mapping from R_1 to the close interval of [0,1]. A triangular fuzzy number can be denoted as M=(l, m, u). The main operational laws for two triangular fuzzy numbers M_1 and M_2 are as follows [19]:

$$M_1 + M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{1}$$

$$M_1 \times M_2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \tag{2}$$

$$M_1{}^{-1} = \left[\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right], M_2{}^{-1} = \left[\frac{1}{u_2}, \frac{1}{m_2}, \frac{1}{l_2}\right] \tag{3}$$

To calculate the evaluation aspects and criteria, the measures are multiple and frequently structured into study framework, with qualitative assessment. Numerous aspects and criteria must be taken into account in structuring the hierarchical framework. This proposed hierarchy allows experts to identify options using linguistic expressions.

To effectively solve the study problems with a hierarchical structure, this research utilizes a set of fuzzy numbers in a straightforward method. The triangular fuzzy membership function (Table 1) can accommodate the qualitative data while the evaluators process the evaluation in linguistic information. The following sections present the application method for this study.

Table 1 TFN values (Tolga et al. [20])

Linguistic variable	Fuzzy number
Good (G)	(2,5/2,3)
Average (A)	(3/2,2,5/2)
Poor (P)	(1,3/2,2)
Very poor (VP)	(1/2,1,3/2)

3.3 Quality function deployment

The QFD is an implement to translate customer needs into prod product technical requirements of new products and services that have been developed from Japan in the late 1960s to early1970s [5]. The main concept of traditional QFD considered four relationship matrices that included product planning, parts planning, process planning, and production planning matrices, respectively [21]. Each translation used a matrix, also called HOQ, as shown in Fig. 1. In the first place, the product planning matrix is established. The customer requirements are to be translated to the second QFD as inputs for the development of product design requirements. Secondly, in the part planning matrix, important design requirements are linked to part component characteristics deployment. Additionally, the part component characteristics are also linked to manufacturing operations. In the production planning matrix, the process parameters and control limits are determined in the same way [22].

3.4 Fuzzy extended analytic hierarchy process

AHP has been widely used to address the multi-criterion decision-making problems. However, it has been generally criticized because of the use of a discrete scale of one to five which can handle the uncertainty and ambiguity [23]. The relative importance of different decision criteria in global supplier selection involves a high degree of subjective judgment and individual preferences.

The hierarchy of the decision variables is the subject of a pairwise comparison of the AHP. In conventional analytic hierarchy process, the pairwise comparison is established, using a nine-point scale which converts the human preferences between available alternatives as equally, moderately, strongly, very strongly, or extremely preferred [24].

Even though the discrete scale of AHP has the advantages of simplicity and ease of use, it is not sufficient to take into account the uncertainty associated with the mapping of one's perception to a number. The linguistic assessment of human opinion and judgments are vague and it is not logical to represent it in terms of exact numbers. It feels more

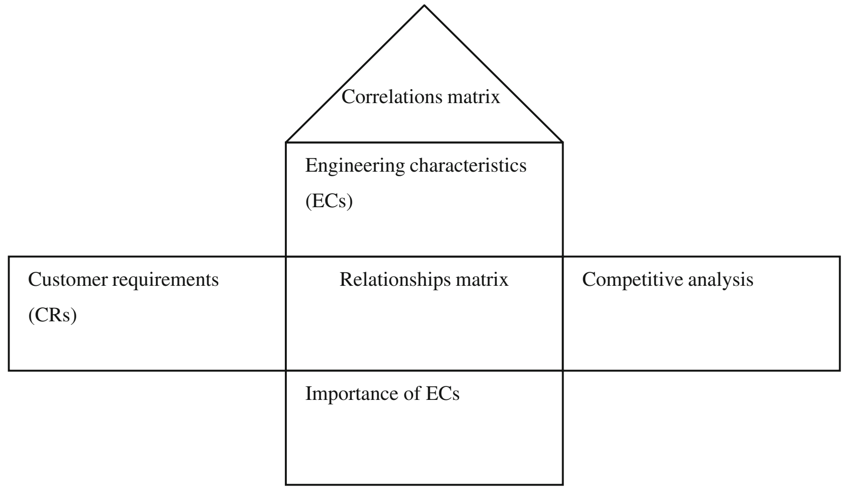


Fig. 1 House of quality

confident to give interval judgments than fixed value judgments.

Hence, triangular fuzzy numbers are used to decide the priority of one decision variable over other. Synthetic extent analysis method is used to decide the final priority weights based on triangular fuzzy numbers and so-called as fuzzy extended AHP (fuzzy AHP) [25].

Fuzzy set theory has proven advantages within vague, imprecise, and uncertain contexts and it resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It was specially designed to mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic to many decision problems [9, 14].

Fuzzy set theory implements classes and grouping of data with boundaries that are not sharply defined (i.e., fuzzy). Fuzzy set theory includes the fuzzy logic, fuzzy arithmetic, fuzzy mathematical programming, fuzzy graph theory, and fuzzy data analysis; usually the term fuzzy logic is used to describe all of these. The fuzzy AHP is the fuzzy extension of AHP to efficiently handle the fuzziness of the data involved in the decision of best global supplier. It is easier to understand and it can effectively handle both qualitative and quantitative data in the multi-attribute decision-making problems. In this approach, triangular fuzzy numbers are used for the preferences of one criterion over another, and then by using the extent analysis method, the synthetic extent value of the pairwise comparison is calculated. Based on this approach, the weight vectors are decided and normalized; thus, the normalized weight vectors will be determined. As a result, based on the different weights of criteria and attributes, the final priority weights of the alternative global suppliers are decided. The highest priority would be given to the supplier with highest weight [5, 13, 26, 27].

4 Case study

4.1 Pharmaceutical industry discover

The pharmaceutical industry develops and produces drugs licensed for use as medications. Pharmaceutical companies offer medicines that treat many of the world's most serious and widespread diseases. Pharmaceutical companies can also deal in brand medications and generic. They have to consider a variety of laws and regulations regarding the patenting, testing, and marketing of drugs.

Medicine discovery is the process in which potential drugs are discovered or designed. In the past, most medicines have been discovered either by separating and extracting of the effective ingredient from traditional medicines.

Medicine development refers to all activities after a compound is recognized as a potential drug to found its suitability as a medication. Objectives of drug development are to determine suitable formulation and concentration, as well as to establish safety. The amount of capital required for the discovered drug development has made it a historical strength of the larger pharmaceutical companies.

4.2 Identifying customer requirements (WHATs) in the pharmaceutical industry

There are generally three fundamental characteristics required of products or services purchased from outside suppliers by the pharmacy company considered in this study:

1. Technical requirements, in terms of technical information, technical service, capacity of research and development, and supplier certificate
2. Commercial requirements, in terms of financial capacity, financial offer, discount, and quantity discount
3. Strategic requirements, in terms of organization's culture and strategy, industry's situation and reputation,

performance history, supplier information system, and transportation

Actually, the properties considered essential to a product or service purchased outside the company will vary case by case; sometimes, for instance, the after-sales service may be of little interest because this is often governed by separate contracts, but the above list nonetheless contains the significant attributes sought in the majority of purchases.

4.3 Identifying the principal supplier assessment criteria HOWs of the pharmaceutical industry

In a comparative session, our group of ten experts was presented with various criteria that had emerged from a careful review of the supplier selection literature and have the considerable experience of purchasing for pharmacy company. This analysis identified four criteria crucial to supplier assessment in our specific case. The following criteria (HOWs) were considered:

1. Cost
2. Supplier standing
3. Delivery time
4. Quality

4.4 Calculation of weight vectors for individual levels of a hierarchy of the customer requirements

The extent analysis method and the principles for the comparison of fuzzy numbers are employed to obtain estimates for the weight vectors for individual levels of a hierarchy of customer requirements [25]. The extent analysis method is utilized to consider the extent of an object to be satisfied for the goal, that is, satisfied extent. In the method, the "extent" is quantified using a fuzzy number. On the basis of the fuzzy values for the extent analysis of each object, a fuzzy synthetic degree value can be gained, which is defined as follows: If $X=\{x_1, x_2, \ldots, x_n\}$ assumed as an object set and $U=\{u_1, u_2, \ldots, u_m\}$ assumed as a goal set, then according to the extent analysis method, each object could be taken to perform extent analysis for each goal respectively. Therefore, m extent analysis values for each object could be obtained as follows:

$$M^1{}_{\mathrm{gi}},\ M^2{}_{\mathrm{gi}},\ \ldots, M^{\mathrm{m}}{}_{\mathrm{gi}}, i = 1,\ 2,\ \ldots,\ n.$$

Where all the $M^j{}_{\mathrm{gi}}$ ($j=1, 2, \ldots, m$) are triangular fuzzy numbers.

Therefore, the value of fuzzy synthetic degree with respect to the ith object is defined as:

$$S_k = \sum_{j=1}^{n} M_{kj} \otimes \left[\sum_{i=1}^{m} \sum_{j=1}^{n} M_{ij} \right]^{-1}. \tag{4}$$

Based on the above definition, the fuzzy synthetic degree values of all elements in the kth level can be calculated using Eq. (4) based on the fuzzy judgment matrix of the kth level;

$$S_I{}^K = \sum\nolimits_{j=1}^{n} a_{ij}{}^k \otimes \left(\sum\nolimits_{i=1}^{n} \sum\nolimits_{j=1}^{n} a_{ij}{}^k \right)^{-1} \tag{5}$$

$$i = 1, 2, \ldots, n$$

where $S_I{}^K j$ is the fuzzy synthetic degree values of element i is the kth level and $A^k=(a_{ij})^k{}_{nn}$ is the fuzzy judgment matrix of the kth level.

4.5 Construction of fuzzy judgment matrixes for the AHP

The hierarchy of attributes (customer requirements) is the subject of a pairwise comparison of the AHP. After constructing a hierarchy, decision makers are asked to compare the elements at a given level on a pairwise basis in order to estimate their relative importance in relation to the element at the immediately preceding level. In the conventional AHP, the pairwise comparison is made by using a ratio scale. A five-point scale is commonly used to show the participants' judgments or preference between options as equally, moderately, strongly, poor, or very poor. Even though the discrete scale of one to five has the advantages of simplicity and ease of use, it does not take into account the uncertainty associative with the mapping of one's perception (or judgment) to a number. However, it is also well recognized that human assessment on the relative importance of individual customer requirements is always subjective and vague. The linguistic terms that people use to express their feelings or judgments are unclear. Using objective, definite and precise numbers to represent linguistic assessments is, although widely adopted, not very reasonable [14, 23, 25].

First advocated in 1965, fuzzy set theory [28] has become an important theory to deal with ambiguity in a system. In this paper, the widely adopted triangular fuzzy number technique [14] is used to represent a pairwise comparison of customer requirements [27].

In a pharmaceutical company, customer requirements have been divided into three groups, technical, commercial, and strategic requirements, for which they have some sub-criteria as well. Technical requirements have been divided into four sub-criteria which are technical information, technical services, capacity of research and development, and supplier certificate. Commercial requirements are divided into financial capacity, financial offer, discount, and quantity discount. Finally, strategic requirements have been subdivided into four categories including organization's culture and strategy, industry's situation and reputation, performance history, supplier information system, and transportation (Fig. 2).

4.6 Combination of quality function development and analytic hierarchy process in the pharmaceutical industry

Quality function deployment process aims to satisfy customer preferences. This technique helps companies to meet the necessary quality rather than taking action in response to customers' complaints—and to maintain a quality that the product should have in the first place. The quality function deployment matrix transforms the quality requirements into measurable criteria to evaluate suppliers' needs [22].

This matrix needs to achieve the overall customer demands which must be met by the suppliers' capabilities. Fuzzy AHP approach, with multiple criteria and a framework for problem solving and a systematic procedure, is to show what the elements of each issue are.

The advantages of using fuzzy AHP are its ability to offer solutions to non-deterministic and doubt-laden problems which is its prominent characteristic compared to other multi-criteria decision-making methods giving the highest degree of certainty to the user. To make this model, the following steps should be applied:

1. Supplier requirements
2. A single-system model would identify the suppliers' evaluation criteria. The "evaluation criteria" are directly derived from the "requirements" of the customer. In other words, in order to meet the needs by a supplier, what criteria should be considered? Identifying the characteristics of the product which is being purchased must have internal variables or WHATs criteria which identify and directly measure the requirements from which they are obtained.
3. The vertical vector of the requirements which indicate the "weight importance" is a relative indication of the importance of each requirement compared to the other. For this purpose, the fuzzy AHP has been utilized. At this stage, while using the judgments of the buyer expert team, a pairwise comparison is made between the various requirements which finally lead into the vertical vector of the requirements.
4. The HOQ matrix is determined and reached at by using the opinions of the buyer expert team. This matrix indicates as to what degree the evaluation criteria are affected by the related requirements.
5. The degree of importance of each of the evaluation criteria is reached at by the total sum of the multiplication of the weight importance of each requirement by the equivalent item from the HOQ.

$$W_j = \sum_{i=1}^{m} R_{ij} \otimes W_i \tag{6}$$

$j = 1, 2, \ldots, m$

$$R_{ij}{}^{*} = W_j + \sum_{k=j} \left(T_{kj} \otimes R_{kj}\right) \tag{7}$$

$J = 1, \ldots, m$

Then, the degree of importance of each criterion is normalized on a scale of 100 so that the importance weight of each criterion in the supplier selection model is arrived at.

$$W_{jN} = \left(\frac{R_{ij}}{\sum_{j=1}^{n} R^{*}{}_{ij}} \right) \times 100 \tag{8}$$

T_{kj} was shown in the roof part of the HOQ. The mentioned parameters are shown in Fig. 3. Furthermore, each element of $R_{ij}{}^{*}$ was de-fuzzified by dividing it by 3.

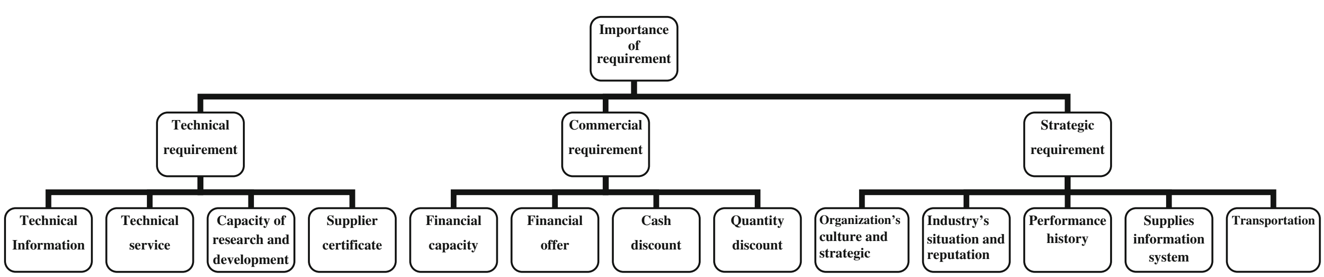
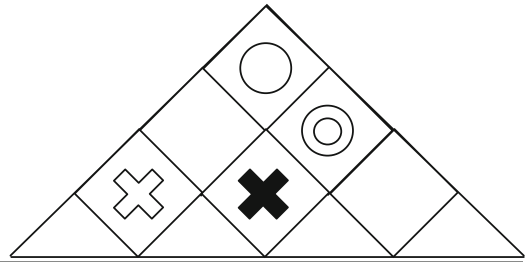


Fig. 2 A hierarchy structure of customer requirements in a pharmacy company



	Y's (What's)(Customer Requirements)	X's (How's) Criteria	Cost	Supplier Standing	Delivery Time	Quality
Technical Requirements		Importance	6.3	4.5	4.2	8.1
	Technical Information	0.402	7.8	5.4	6	3.5
	Technical Service	0.238	3.6	5.7	2.7	1.2
	Capacity of Research and development	0.0285	5.7	5.7	5.7	3.1
	Supplier Certificate	0.095	3.9	6.1	7.2	6.5
Commercial Requirements		Importance	5.4	3.0	3.1	6.7
	Financial Capacity	0.030	3.4	2.7	1.4	1
	Financial Offer	0.026	3.6	1.9	3.3	2.4
	Discount	0.025	6.4	6	3	1.2
	quantity discount	0.002	2.3	7.3	2.6	1.4
Strategic Requirements		Importance	7.2	3.9	3.0	7.0
	Organization's culture and Strategic	0.005	2.4	5.8	3.3	2.9
	Industry's Situation and reputation	0.039	2.9	3	1.9	4.9
	Performance History	0.032	1.7	3	1.6	2.4
	Supplier Information System	0.019	5.8	5.2	1.7	1.6
	Transportation	0.007	2.8	2.6	5.4	2.2
	R_{ij}		32.7	21.5	17.7	22.6
	R_{ij}^*		49.9	43.9	18.7	66.5
	Normalize $R_{ij}^*(Nr_{ij}^*)$ [a]		27.9	24.5	10.5	37.1
	Relative Weight (Priority) [b]		27.90%	24.50%	10.48%	37.12%

a Total equals 100

b Total equals 1

Fig 3 House of quality–fuzzy AHP in the pharmaceutical case study

Suppose $M\,(a, b, c)$ is a TFN; then, the de-fuzzified value is computed as: $(a+b+c)/3$

W_i=priority weight of WHATs

R_{ij}=the relationship between the ith WHAT and the jth HOW

R_{ij}^*=priority weight of a HOWs

R_{kj}=the relative importance of the kth HOW

T_{kj}=The degree of correlation between the kth and jth HOWs

6. The model for the supplier selection is constructed by preparing a list of supplier selection criteria along with the related degrees of importance which are obtained from the formula 8.
7. The buyers' "supplier evaluation team" will utilize the fuzzy AHP to carry out the pairwise supplier comparison to reach the final ranking for every criteria for each supplier.

4.7 Giving weight to the customer requirements (WHATs) with fuzzy AHP

The required data were obtained from the questionnaires which were filled up by the buyers' expert team. The data were analyzed with the fuzzy AHP with an extent analysis approach [25]. Each matrix corresponds to every matrix house with one factor from the row and one factor from the column. After pairwise comparison with two factors, the related results will be printed according to the triangular fuzzy numbers in the respective house. Before carrying out this approach, it is very important to determine whether each row or column exactly compares to the corresponding items.

In this paper, the rows are compared with the columns. The result of the calculations, for each matrix comparison using fuzzy AHP methods and pairwise comparison, is shown in Table 1, presented by Tolga et al. [20].

Table 2 Matrix for pairwise comparison for supplier selection based on cost criteria

Matrix 1	S_1	S_2	S_3	S_4	S_5
S_1	1	(1/2,1,3/2)	(1/2,1,3/2)	(1/2,1,3/2)	(1/2,1,3/2)
S_2		1	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)
S_3			1	(1/2,1,3/2)	(3/2,2,5/2)
S_4				1	(2,5/2,3)
S_5					1

4.8 Developing the matrix of correlations between the supplier assessment criteria HOWs of the house of quality

The correlations of the supplier assessment criteria HOWs are comprised of the "roof" of the HOQ (Fig. 3). This step in the construction of the HOQ enables the team members to keep recording of pairs of HOWs or comparing the supplier assessment criteria. Potential difficult relationships, that consequently imply measures, are inconsistent with each other. This matrix contains positive and negative correlations between pairs of HOWs using the same symbols as Hines et al. [29]. The completed fuzzy-HOQ is illustrated below (Fig. 3).

4.9 Determining the "HOW"–"WHAT" correlation scores and giving weight to the supplier assessment criteria HOWs

Each decision maker was asked to express an opinion, using one of the five linguistic variables, on the impact of each supplier assessment criteria HOW. On each customer requirement WHAT, the opinions expressed by the ten decision makers, was calculated by fuzzy AHP.

Here again, triangular fuzzy numbers were used to quantify the linguistic variables and cases, and the crisp numbers were obtained by each decision maker from the "HOW–WHAT" matrix.

The degree of importance of each supplier has been obtained from the formula 9.

$$S_j = \sum_{j=1}^{n} W_{jN} \otimes e_{ij} \quad (9)$$

Table 3 Matrix for pairwise comparison for supplier selection based on delivery time criteria

Matrix 2	S_1	S_2	S_3	S_4	S_5
S_1	1	(1,3/2,2)	(1,3/2,2)	(1,3/2,2)	(1,3/2,2)
S_2		1	(3/2,2,5/2)	(3/2,2,5/2)	(1,3/2,2)
S_3			1	(2,5/2,3)	(3/2,2,5/2)
S_4				1	(2,5/2,3)
S_5					1

Table 4 Matrix for pairwise comparison for supplier selection based on supplier standing criteria

Matrix 3	S_1	S_2	S_3	S_3	S_5
S_1	1	(1,3/2,2)	(1,3/2,2)	(1/2,1,3/2)	(1,3/2,2)
S_2		1	(1,3/2,2)	(1/2,1,3/2)	(3/2,2,5/2)
S_3			1	(1/2,1,3/2)	(2,5/2,3)
S_3				1	(2,5/2,3)
S_5					1

W_{jN}=normalized degree of importance of jth criteria, obtained from formula 8

e_{ij}=evaluation score of jth supplier's criteria in ith criteria, calculated using fuzzy AHP

4.10 Determining the impact of each potential supplier on the considered attributes

Having completed the weighing of each attribute, all we have to do is to assess each supplier vis-a-vis the attribute in question and combine the said assessments with the weight of each attribute in order to establish a final ranking. Tables 2, 3, 4, and 5 show the opinions of the buyers' expert team about the various suppliers in relation to each attribute in the questionnaire. Eeach member of the expert team is asked to fill out the questionnaire matrix form to enable the supplier ranking determination.

4.11 Supplier ranking

There are five suppliers who have participated in this survey. The related data have been provided in each supplier selection matrix by the questionnaire. The tabulated results 2 to 5 are presented in the form of geometric data mean and consistency of each matrix were confirmed by using SPSS software. After the pairwise comparisons for each criterion were carried out with fuzzy AHP and the QFD model was done by Excel software, the suppliers are ranked and finally the best one is selected.

Table 5 Matrix for pairwise comparison for supplier selection based on quality criteria

Matrix 4	S_1	S_2	S_3	S_3	S_5
S_1	1	(1/2,1,3/2)	(1/2,1,3/2)	(1/2,1,3/2)	(1/2,1,3/2)
S_2		1	(1,3/2,2)	(1/2,1,3/2)	(1,3/2,2)
S_3			1	(3/2,2,5/2)	(1,3/2,2)
S_3				1	(2,5/2,3)
S_5					1

Table 6 Results of the fuzzy AHP–QFD model with Excel software

	Cost	Supplier standing	Delivery time	Quality	Result	Rank
Importance	27.90	24.50	10.47	37.12		
Supplier 1	0.16	0.23	0.27	0.18	19.57	4
Supplier 2	0.24	0.22	0.28	0.25	24.20[a]	1[a]
Supplier 3	0.16	0.22	0.25	0.24	21.5	2
Supplier 4	0.19	0.24	0.17	0.2	20.78	3
Supplier 5	0.24	0.09	0.03	0.1	13.93	5

[a]Selected supplier

5 Discussion

It becomes obvious, in fact, that the company's ultimate aim is to have access to suppliers that ensure a certain quality standard, in terms of their characteristics of the purchased products or services [6].

In this paper, an integrated "fuzzy AHP–QFD" approach was proposed to evaluate and select suppliers. The fuzzy AHP method was used for determining the weight of the supplier's requirements. The use of fuzzy logic enables the decision makers to eliminate problems stemming from the subjective and unclear nature of data; therefore, data can be formally treated.

The first steps in this direction are to determine the requirements of the pharmaceutical companies which, by using the previous purchases and experience, are obtained from brainstorming meetings comprising of the shareholders and the company's experts. The resulting requirements are categorized into three groups: technical, commercial, and strategic requirements.

To determine the degree of importance of the each buyer's requirement elements, which was selected by the brainstorming of the buyer expert team, questionnaires have been provided. After completion of the questionnaires by the expert team, then geometric mean was used for calculating the data. Then, the pairwise comparison of these obtained data is used in Excel software. Weight priorities of the customer requirements are calculated by the programming in Visual Basic function of Excel. A case study was presented to illustrate the proposed approach. Data processing indicates that technical information possesses the highest importance, followed by service and technical services. Then, strategy and organization culture are important, respectively.

Supplier's certificate has much influence on supplier selection also industry's situation and reputation, performance history, financial offer, and financial capacity have similar influence. The other supplier requirements (WHATs), based on the degree of importance, are located after that. Constructing an HOQ enables to pinpoint how well each supplier characteristic succeeds in meeting the requirements established for the product being purchased outside the company; having done so, drawing up a supplier ranking list, was applied [30]. The proposed method tries to aggregate the decision makers' opinions in a different way of the others supplier selection methods, in order to satisfy the supplier selection.

Also, the construction of the roof of the HOQ, studying the correlations between pairs of HOW, helped the decision makers to define the judgments about the suppliers and to interpret the final ranking. The obtained result from the new mentioned model of supplier selection shows that supplier 2 is the most important supplier, followed by supplier 3 and then by supplier 4 and supplier 1, and that Supplier 5 is the least important one (Table 6). More clearly, to cope well with building the HOQs, relationships, and correlations, W_i, relative importance (R_{ij}), and priority weights (R_{ij}^{*}) of criteria (HOWs) were all defined. The normalized ratings are obtained for the crisp case by dividing all the ratings by their maximum value.

6 Conclusions

This paper developed an integrated multiple criteria fuzzy decision-making approach to measure the performance of alternative suppliers. A case study was given to demonstrate how it works. In the approach, QFD was used to translate the customer requirement.

Fuzzy AHP was used to determine both importance ratings and relationship weightings in HOQs consistently. The major advantage of this integrated approach is that the evaluating factors are of interest to the customers. This ensures that the selected supplier will achieve the business objectives and satisfy the customers most. Another advantage is that the approach can guarantee the benchmarking to be consistent and reliable.

In this study, fuzzy AHP method is used to determine the weight of the customer requirements. Customer requirements (WHATs) linguistic and subjective evaluations take place in questionnaire form. Each linguistic variable has its own numerical value in the predefined scale. In classical AHP, these numerical values are exact numbers, whereas in fuzzy AHP method, they are intervals between two numbers. Linguistic values can change from person to person. In these situations, taking the fuzziness into account will provide less risky decisions.

Although the ability of decision making is improved by using the fuzzy AHP, but the evaluation of the buyer expert team judgment consistency is more difficult than the crisp expert team judgment of the buyer. In this study, in order to evaluate the consistency of the matrices, first, the fuzzy numbers were transformed into crisp scales and then, by using the consistency definitions in AHP, which is generally acceptable, the evaluation of the acceptance of the results was carried out.

Determination and evaluation of the criteria for supplier selection in pharmaceutical company can be affected by the characteristics of the Standard Organization and Medical Department of the Ministry of Health so based on the experience of the expert team, they have been selected. If a multi-criteria decision-making method with linguistic evaluations is selected for supplier selection, the fuzzy AHP or similar methods concerning fuzzy conditions can be utilized.

The QFD multi-attribute decisional method, designed to support the development of products conforming to the customer's needs and requirements, was applied to the problem of supplier selection for a pharmaceutical company. In this general picture, the QFD—and the HOQ in particular—has demonstrated its potential as key tools for reconciling conventional needs (which remain important) with assessment criteria of the suppliers' attributes. Therefore, with the combination of fuzzy AHP with the QFD methods, suppliers are ranked based on the final requirements of the organization that they are measured with some criteria such as quality, supplier standing, delivery time, and cost in a pharmaceutical company.

An extension to this paper can be combining this model with GP model the purchase can be divided between a numbers of suppliers in a way to maximize the worth of the purchase with the minimum of costs. Future researches can also consider utilizing other ranking methods instead of the fuzzy AHP, such as fuzzy TOPSIS, to prioritize the company requirements and compute their priority weights. Moreover, W_i, i.e., WHATs priority weights, obtained from different ranking methods, can be compared.

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