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Modeling and development of fuzzy logic-based intelligent decision support system

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Abstract. The concept of fuzzy logic has been used to quantify the qualitative data in real-world decision-making problems. Evaluation and selection of supplier are the main problems where the decision depends on both quantitative and qualitative data. This paper proposes a fuzzy based modelling of an intelligent decision support system for a supplier selection problem. The proposed model is evaluated and validated using a case study in a chemical processing. The proposed system has been implemented in the case study organization to disclose the procedure and to identify the best supplier thorough the discussions.

Key-words: Decision Support Systems; Fuzzy Systems; Information Systems.

1. Introduction

Decision Support System (DSS) is an interactive computer-based system that supports decision-makers to utilize data as well as models to solve ill-structured, unstructured or semi-structured problems [1]. DSS is generally used for decision-making because of the intricacy and importance of decisions in real world problems. DSS aids in problem solving by allowing manipulation of data and models. The functions of DSS are based on models and algorithms and sometimes, it requires approximations of real problems [2]. Hence, to make clear decisions, a DSS which is working based on knowledge processing instead of model processing is required. In this paper, the development of an *Intelligent Decision Support System* (IDSS), which works based on the knowledge base, is discussed with a case study. An IDSS is a computer program that simulates the judgment and behavior of a human or an organization which possesses expert knowledge and experience in a particular field. Typically, such a system contains a knowledge base comprising accumulated experience and a set of rules for applying the knowledge base to each particular situation that is analyzed by the program. Sophisticated IDSS can be enhanced with the additions of knowledge base or the set of rules [3].

Sourcing decision is one of the major decisions in manufacturing, process and service sectors. Selection of supplier is one among the sourcing decision problems. Improper selection of supplier may lead to the purchase of inferior quality material with relatively higher cost. If the supplier fails to deliver the right materials at the right time and place, and at the right price, then the recipient organization will be failing in its obligations to satisfy the needs of its customers, and to stay in business. Besides, supplier selection is a problem dealt with multiple criteria which include both qualitative and quantitative factors.

In this paper, the modeling and development of IDSS for the evaluation and selection of supplier for a process industry are discussed. First, the evaluation criteria are identified from thorough literature review. Several researchers have done extensive studies related to supplier evaluation criteria. Dickson [4] carried out a survey in 300 business organizations to identify the factors that were influencing the supplier selection. As an outcome, 23 factors were identified as important factors for the supplier selection decision problem. David and Sunil [5] developed a supplier selection model for a distributor of engineering products by using survey technique. A thorough review of 74 literatures in various journals was done and identified cost, delivery, quality, production capability, geographical location, technical capability, reputation, financial position, performance history and warranty as the most contributed criteria for supplier selection [6]. Ho *et al.* [7] made an extensive review study on the literatures related to multi-criteria decision-making approaches for supplier evaluation and selection that appeared in the international journals from the year 2000 to 2008. For the supplier selection, various techniques such as mathematical programming (linear programming, integer programming and goal programming), *Data Envelopment Analysis* (DEA), *Analytical Hierarchy Process* (AHP), *Analytical Networking Process* (ANP), fuzzy set theory, and genetic algorithm are available in the literature. In most of the works, quality, delivery and price/cost are considered as the most influencing criteria for supplier evaluation and selection. Wetzstein, *et al.* [8] reviewed 246 papers that investigated supplier selection issues which were published between 1991 and 2017. Aouadni *et al.* [9] reviewed articles published in the supplier selection and order allocation domains between 2000 and 2017. As an outcome, they presented the gaps in the current research and the need for new research activities.

Various supplier evaluation techniques were used by the researchers. Saaty[10] introduced AHP, a multi criteria decision making approach which would be suitable to make decisions in situations when multiple and conflicting objectives / criteria are present. A prototype expert system was suggested to evaluate and select a potential supplier based on the strategic importance of the product involved as well as quantitative data and qualitative factors [11]. Kahraman *et al.* [12] proposed the *Fuzzy Analytical Hierarchy Process* (FAHP) to select the best supplier for a manufacturing firm. The focus was on the following criteria namely quality, delivery speed, capacity, reliability, maintainability, damage tolerance, handling, financial strength, management approach, technical ability, quality systems and service performance criteria. Zaim *et al.* [13] proposed FAHP for solving the problem of supplier selection by a case study in TV production suppliers. Haq and Kannan [14] compared AHP and FAHP based supplier selection models through a case study in a rubber tubes industry. FAHP approach for the selection of global supplier by considering both quantitative and qualitative decision factors involved in the current business scenario was presented by Felix *et al.* [15]. The triangular fuzzy numbers were used to transform the linguistic comparison of different decision criteria, sub-criteria and performance of the alternative suppliers. Galasso *et al.* [16] investigated the planning process of a production unit within a supply chain to satisfy the customer demand using mixed-integer linear programming model.

Razmi *et al.* [17] developed a fuzzy analytic network process model to evaluate the potential suppliers and select the best, using a numerical example. A decision support system was presented by Ceyda *et al.* [18] to select a suitable enterprise software by combining the qualitative and quantitative objectives for an electronics company. Fuzzy multi-criteria decision making procedure and a multi-objective programming model were used to make selection decision. An Expert *Decision Support System* (EDSS) using a fuzzy version of ELECTRE III method for ranking the alternatives based on the experts' knowledge was suggested by Gholam *et al.* [19]. This EDSS was applied to a vendor selection process in an Iranian oil industry. Ashraf [20] compared two decision making tools: fuzzy logic and AHP to support the decision of the selection of appropriate supplier. Khorasani and Bafruei [21] proposed a selection model for the best supplier of maize starch at a pharmacy company in Iran. FAHP was used to evaluate the supplier based on criteria such as price, quality, service and technical issues. Kilincci and Onal [22] developed FAHP supplier selection model for a washing machine company located in Turkey. Kumar *et al.* [23] developed a DSS for supplier selection based on fuzzy decision making techniques and the DSS was developed for a metal fabrication industry. Zhou *et al.* [24] developed a system for supplier selection and order allocation problem comprising a retailer and a set of candidate suppliers. Hosny *et al.* [25] developed a prototype program called ARO-META to take decision for housing developers under uncertain buyer behavior. Jeong *et al.* [26] identified the critical issues in supplier management and developed manufacturer-supplier relationship optimization model with variable supplier lead time, an inconsistent safety stock level, and a poor supplier evaluation process as the key constraints. Pitchipoo *et al.* [27] developed fuzzy based hybrid decision model for the evaluation and selection of supplier for an electroplating industry in India. A decision support system was developed with conventional techniques such as AHP & GRA with the limitation to adopt vague and imprecise data [28].

Babbar and Amin [29] proposed a novel *Fuzzy Quality Function Deployment* (QFD) model for determining the weights of the suppliers in beverages industry. The proposed model had two phases namely a two-stage QFD, and a stochastic multi-objective mathematical model. The stochastic approach helped to manage the uncertainty during the order allocation process. Trapezoidal fuzzy numbers were utilized to handle the vagueness in human thoughts. Morteza *et al.* [30] solved a complex multi-criteria decision-making problem to evaluate supply chain performance indicators using integrated QFD and grey relational analysis. The proposed decision system was applied in risk and uncertain conditions in an agriculture production systems project. A sensitivity analysis was performed to test and check the performance of the decision model. A decision support system for logistics service provider selection using fuzzy integrated MOORA technique for mining equipment manufacturing firm was proposed by Sarabi and Darestani [31]. Here, DSS with two decision-making methods such as *Fuzzy Best–Worst Method* (FBWM) and Multiple Objective Optimizations on the basis of Ratio Analysis plus full Multiplicative Form (MULTIMOORA) was used for ranking the alternatives using eight criteria. In [32], the authors used Fuzzy inference system for sustainable supplier selection. Initially, the essential sustainability criteria were recognized and their quantified sub criteria were given as inputs for FIS. Then, a modified FIS architecture was proposed to reduce the FIS rules. Finally, the *Sustainability Performance Index* (SPI) was determined for all suppliers.

The rest of the paper is organized as follows: Section 2 illustrates the framework of the IDSS, and Section 3 explains the development of models for supplier selection along with the case study. In Section 4, integration and validation of the IDSS are explained. Finally, Section 5 concludes the paper and outlines some future research directions.

2. Intelligent Decision Support System

The intention of developing IDSS for supplier evaluation and selection is to support the decision makers in order to achieve quick and accurate decisions. The IDSS is used to reduce the risk of the purchasing department. The absence of an adequate support system results in inefficient decisions and it may affect the profitability of the entire organization [33].

2.1. Proposed IDSS framework

IDSS is an interactive computer-based system which helps the decision makers to utilize the data and models to solve large and complex decision problems. The framework of the proposed IDSS is shown in Fig. 1. It consists of the following sub-systems: database management subsystem, model base and knowledge base management sub-system and user interface sub-system.

2.2. Database management sub-system (DBMS)

Various data relevant to the decision making process are stored in this sub-system. The user can add / retrieve the data from DBMS for model development in an accurate and precise manner.

A database is an integrated collection of data records, files, and other data related to the decision problem. It allows the organizations to conveniently develop databases for supplier selection through data extracted from the internal sources such as finance, production and procurement departments and external sources including journals, reference books, websites and materials from similar industries.

The proposed DBMS provides facilities for creation, controlling data access, enforcing data integrity, recovering the database after failures and restoring them from backup files, maintaining database security with updating and report generation options.

In this paper, the data categories can be defined as performance assessment criteria (quality of the supplied materials, delivery lead time and cost of the material) quality system assessment criteria (warranty given on the material by the supplier) and business factors (payment terms of the supplier). The theoretical information related to the organization such as organization structure, raw materials, products, processes and the details about the tools used for the evaluation of the suppliers are included as help menu of IDSS.

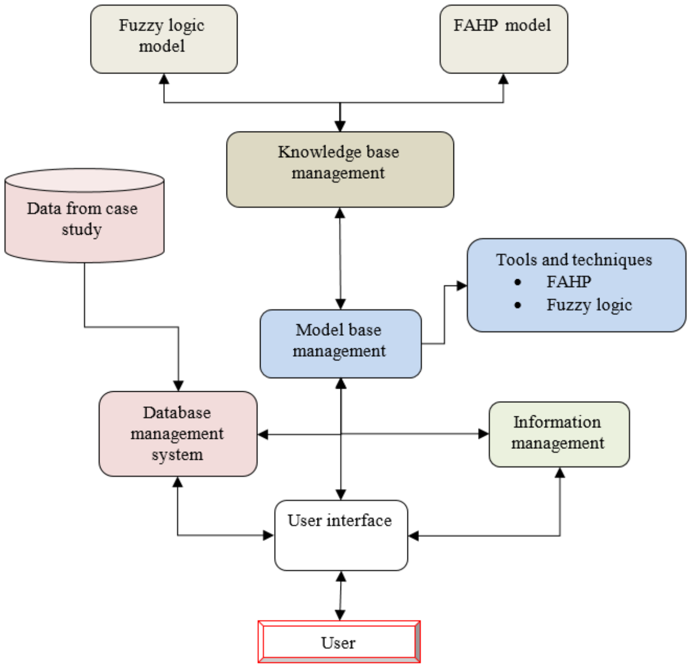

Fig. 1. Framework of the proposed intelligent decision support system for supplier selection (color online).

2.3. Model base and knowledge management sub-system (MB&KBMS)

This sub-system helps the decision makers to access a variety of models which are developed for this specific application to assist the decision makers in the decision-making process. This sub-system contains the supplier evaluation and selection models namely FL (the abbreviations comes from *Fuzzy Logic*) and FAHP models. These models mathematically represent various decision-making activities which are built using AHP and FL. The purpose of this sub-system is to transform data from the DBMS into information that is useful in decision making. The developed MB&KBMS has the components such as: model base, knowledge base, model directory, model execution, integration of models and command processor. The important functions of MB&KBMS allow the users to manipulate the models so that they can conduct experiments from what – if to goal seeking. They also store, retrieve and manage a wide variety of different types of models in an integrated manner.

2.4. User system interface and hardware

This sub-system interacts directly with a decision maker in the decision-making process in such a way that the user has choices and sequence of selection strategies. The IDSS requires a standard computer with input-output and data storage devices. The proposed IDSS can be used by the decision makers for the selection of suitable suppliers with appropriate evaluation strategies. The developed IDSS is tested and validated using the sample data collected from electroplating industry in Section 3.

3. Case Study

The developed IDSS is tested in the framework of the case study in an electroplating industry to select the best supplier for its raw materials. The case organization selected in this study involves nickel coating and chrome plating for auto components. Moreover, these types of industries are operating as small factories and workshops which are highly hazardous in nature. At present, the supplier selection is done based on the bidding technique. In this current practice, important criteria such as the quality and supply lead time are not considered. But these industries have to ensure that their product must meet the international standards and quality requirements to remain competent in the market. To achieve this, it is required that the supply of raw material or any other kind of necessary inputs should be selected appropriately. In this case study, the evaluation of suppliers has been carried out based on other criteria such as the performance assessment, manufacturing, quality system assessment and business factors.

3.1. Model 1: FL model

Fuzzy sets are more efficient in decision-making applications compared to classical (crisp) sets. In fact, fuzzy decision theory is suitable modeling uncertainty and ambiguity inherent in the preferences, goals and restrictions in decision making issues [34]. The fuzzy technique is used to solve complex problems using multiple criteria. A fuzzy set is a generalized set to which the objects belong with various degrees (grades) of memberships over the interval [0, 1]. Fuzzy systems involve processes that are too complex to be modeled by using conventional mathematical methods. In general, fuzziness describes objects or processes that are not amenable to precise definition or precise measurement. Thus, fuzzy processes can be defined as processes that are vaguely defined and they have some uncertainty in their description. A fuzzy set (subset) "A" on universal set "X" is defined by a membership function "μA" that represents the following mapping:

$$\mu A : X \to [0, 1]. \tag{1}$$

Here, the value of μA(X) is the value of membership or membership degree to the set A. The *membership function* (MF) allows to graphically represent a fuzzy set. An MF is basically a curve that defines how each point in the input space is mapped with a membership value (or degree of membership) between 0 and 1. The membership function has been classified as trapezoidal membership function, triangular membership function, 'Z' function, 'n' function, sigmoid membership function and single-valued or singleton membership function.

Triangular membership functions enable fast solutions to the fuzzy optimization problems [35]. Hence, triangular MFs are used in this case study. In the triangular MF, a fuzzy set is fully determined by the triplet (a, b, c) of crisp numbers with $a < b < c$, whose MF is:

$$\mu(x) = \begin{cases} 0, & (x \le a)\ or\ (x \ge c), \\ \frac{x-a}{b-a} & if\ a\ < x \le b, \\ \frac{c-x}{c-b} & if\ b\ < x < c. \end{cases} \tag{2}$$

While developing the FL-based supplier evaluation and selection model, the following steps have to be considered as shown in Fig. 2. The proposed FL methodology used for the supplier selection comprises the following steps:

- State the objective: The objective is to select the best supplier using fuzzy logic.
- Identification of influencing criteria: In this study, for the development of FL model, the following criteria namely performance assessment, quality system assessment and business factors have been considered. The alternatives chosen in this case study are: supplier 1, supplier 2, supplier 3, supplier 4 and supplier 5.
- Fuzzification: It refers to the process of taking a crisp input value and transforming it into the degree required by the terms. The "fuzzified" values are determined by intersecting the input value into the fuzzy membership function. In the present study, triangular membership function has been used to define the fuzzy sets for the linguistic values of cost, lead time, quality, warranty and payment terms. Due to the fact that all input values are normalized, fuzzification input will be between 0 and 1. The required data used for the development of the model are presented in Table 1. The raw data are normalized and shown in Table 2.

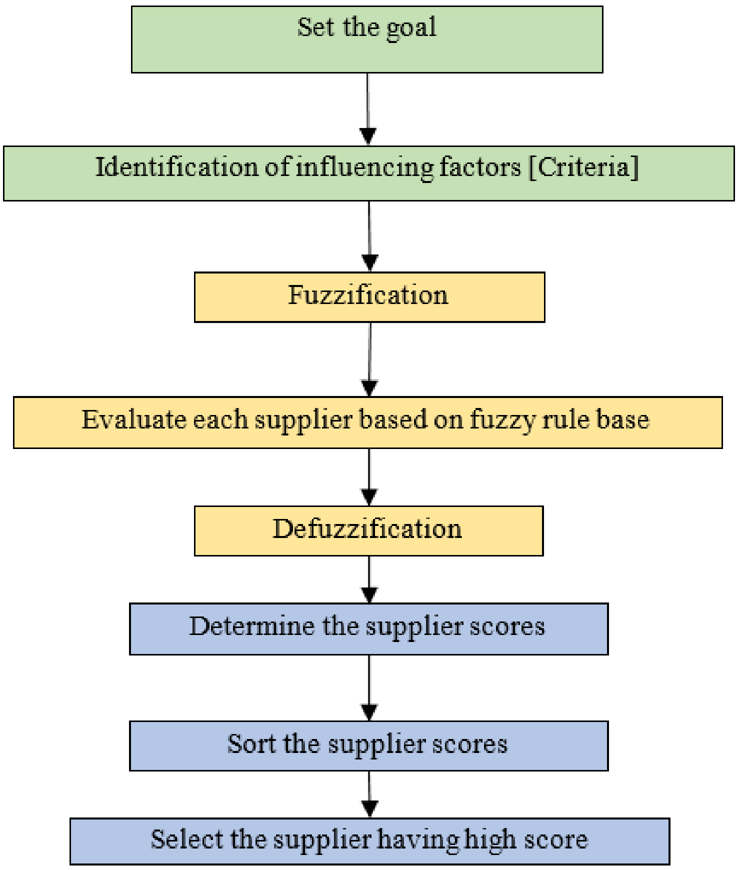

Fig. 2. Procedural steps used for supplier selection by FL algorithm (color online).

Table 1. Raw data used for the development of FL model

Suppliers	Cost (Rs)	Lead time (Days)	Quality (%)	Warranty (Days)	Payment terms (Days)
Supplier 1	2875	4	96	14	30
Supplier 2	2800	2	94	14	15
Supplier 3	2750	6	98	0	30
Supplier 4	2900	2	97	7	15
Supplier 5	2450	2	96	21	15

- The Fuzzy Logic Toolbox in Matlab is used for the development of FL model based on the number of input variables and the required output. Fig. 3 shows the structure of FL model that is used in this study. Fig. 4 shows the sample membership functions for the cost criterion.
- Fuzzy rule construction: Fuzzy logic system makes decisions and generates output values based on knowledge provided by the designer in the form of if–then rules. The rule base specifies qualitatively how the output parameter "overall rating" of the supplier proposal is determined for various instances of the input parameters of "cost", "lead time", "quality", "warranty", and "payment terms" and the output parameter is the selection of "best supplier". The fuzzy rules are generated by the concept according to expert's opinion.

Table 2. Normalized data

Suppliers	Cost	Lead Time	Quality	Warranty	Payment Terms
Supplier 1	0.209	0.250	0.200	0.250	0.286
Supplier 2	0.203	0.125	0.195	0.250	0.143
Supplier 3	0.200	0.375	0.204	0	0.286
Supplier 4	0.211	0.125	0.202	0.125	0.143
Supplier 5	0.178	0.125	0.199	0.375	0.143
Maximum	0.211	0.375	0.204	0.375	0.286
Minimum	0.178	0.125	0.195	0	0.143

- Evaluate each supplier based on fuzzy rule base: For rules generation, the following steps (decision maker's opinion) are used as rules of thumb:
  - In 'acceptance' category, quality, delivery time and cost must be of superior level and out of the remaining factors; any one factor can be of medium level.
  - In 'may be accepted' category, out of five factors other than quality and delivery time, any of the remaining three factors should be superior level.

If the above two conditions are not satisfied, then the supplier falls under rejection.

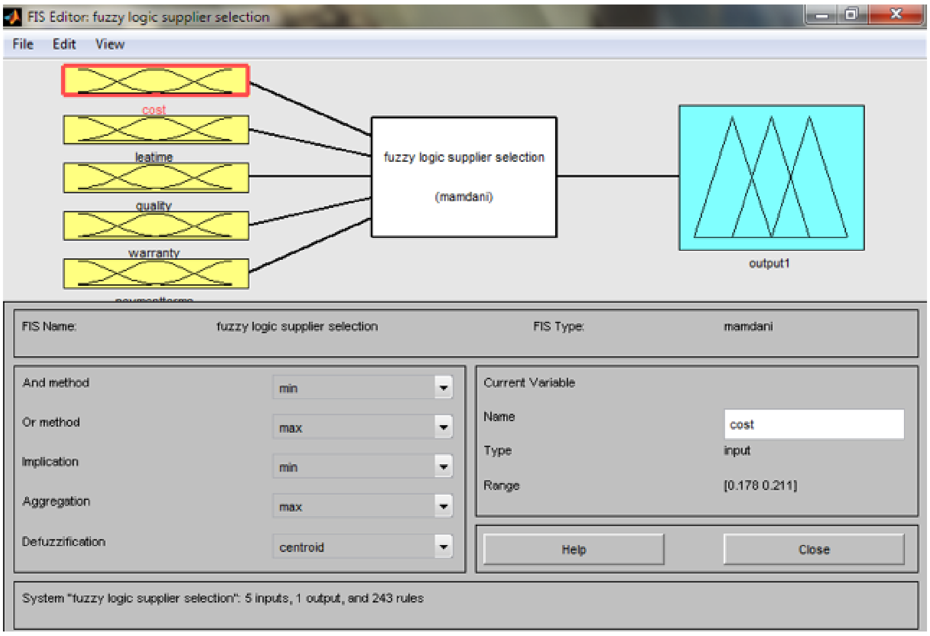

Fig. 3. Structure of FL model (color online).

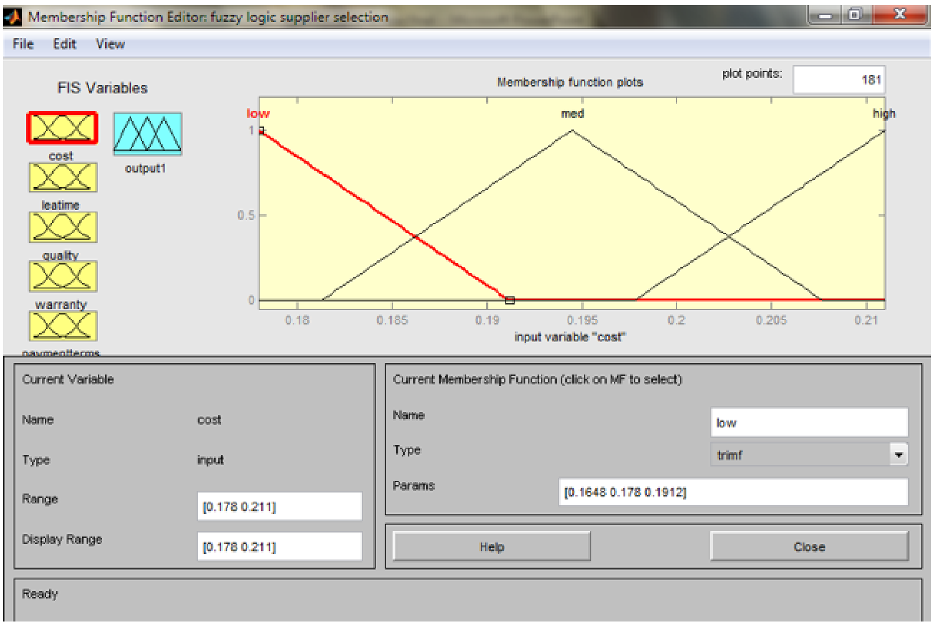

Fig. 4. Membership functions for cost (color online).

The fuzzy rules are generated using Mamdani system which is more suitable for engineering systems because its inputs and outputs are real-valued variables. The rule base of the proposed FL model has been defined in three steps; initially, total numbers of interactions between the input variables of the FL are defined. The numbers of rules are established based on the permutation with number of membership function and numbers of criteria.

The number of criteria is five and number of membership functions is three. The total number of rules will be 3^5 equal to 243 rules. The rules illustrate all states between criteria and their relationships. Finally, rules and membership functions are used to evaluate the output of the data. The snapshot of the rules screen is shown in Fig. 5.

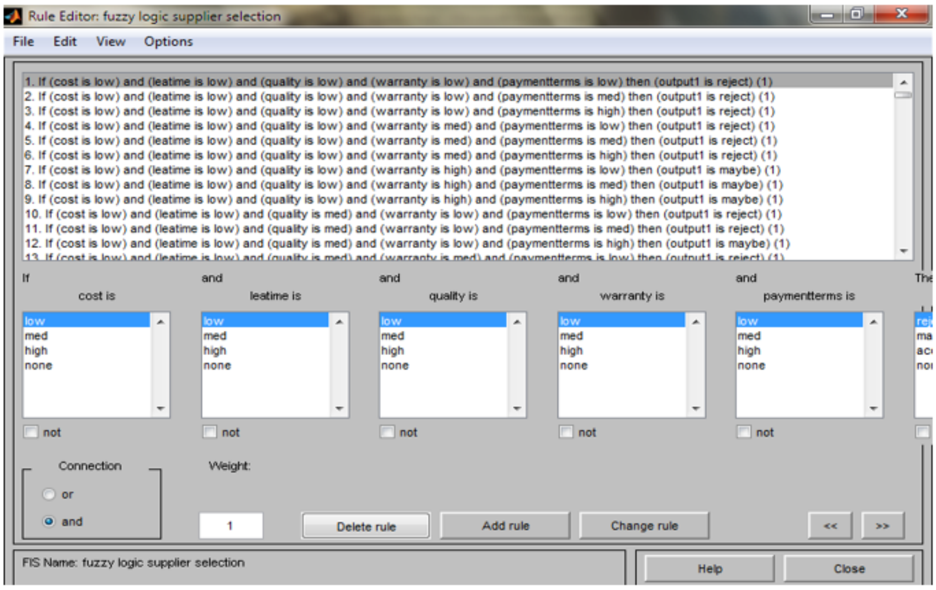

Fig. 5. Snapshot of the rules screen (color online).

- Defuzzification: If the values considered in the fuzzy sets are in terms of degree variation, then in the final output, the fuzzy values should be converted into crisp values by using any defuzzification method. In this case study, defuzzification is performed in terms of the center of gravity method with the help of Matlab. With the help of Fuzzy Logic Toolbox of Matlab, the overall ratings for all suppliers are obtained by using the proposed FL model. The final score is calculated through defuzzification. The system finally ranks all the suppliers according to their final scores and displays them in descending order. Fig. 6 shows the sample rule viewer of supplier 1.

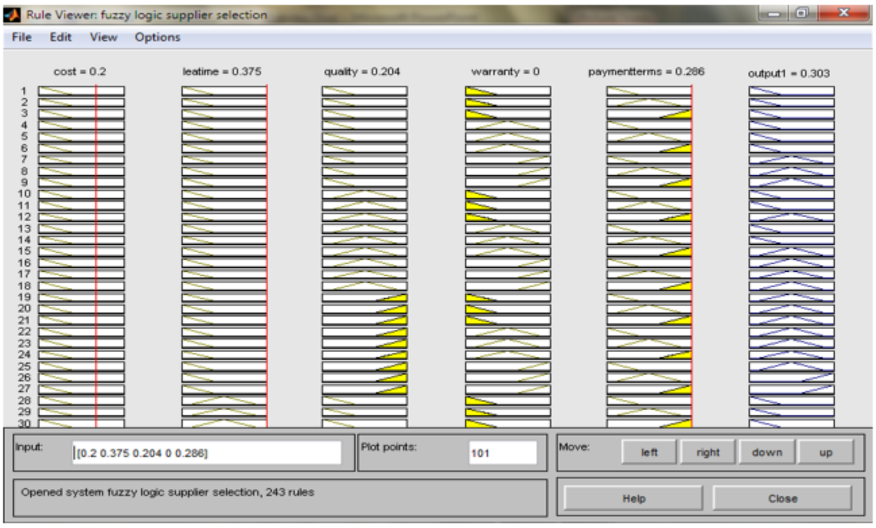

Fig. 6. Sample rule viewer for supplier 1 (color online).

- Select the supplier with high score: The determined fuzzy scores for each supplier are given in Table 3. From this, the supplier with higher fuzzy score is selected as the best supplier. In this case study, supplier 5 is selected as the best supplier. In Fig. 7 the fuzzy score for all suppliers is shown.

Table 3. Ranking of suppliers based on fuzzy scores

Suppliers	FUZZY SCORE	RANK
Supplier 1	0.303	2
Supplier 2	0.147	5
Supplier 3	0.157	4
Supplier 4	0.161	3
Supplier 5	0.5	1

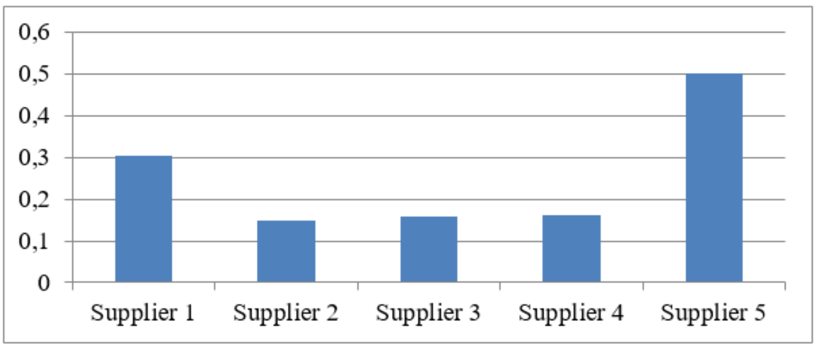

Fig. 7. Fuzzy supplier score (color online).

3.2. Model 2: FAHP approach

FAHP approach is the fuzzy extension of AHP [36]. AHP is one of the most widely utilized methodologies to solve multi-criteria decision-making problem. AHP methodology decomposes a problem and performs pairwise comparison of all elements. and compares criteria or alternatives with respect to a criterion in a natural, pairwise mode. The FAHP algorithm is presented in Fig. 8 focusing on supplier selection.

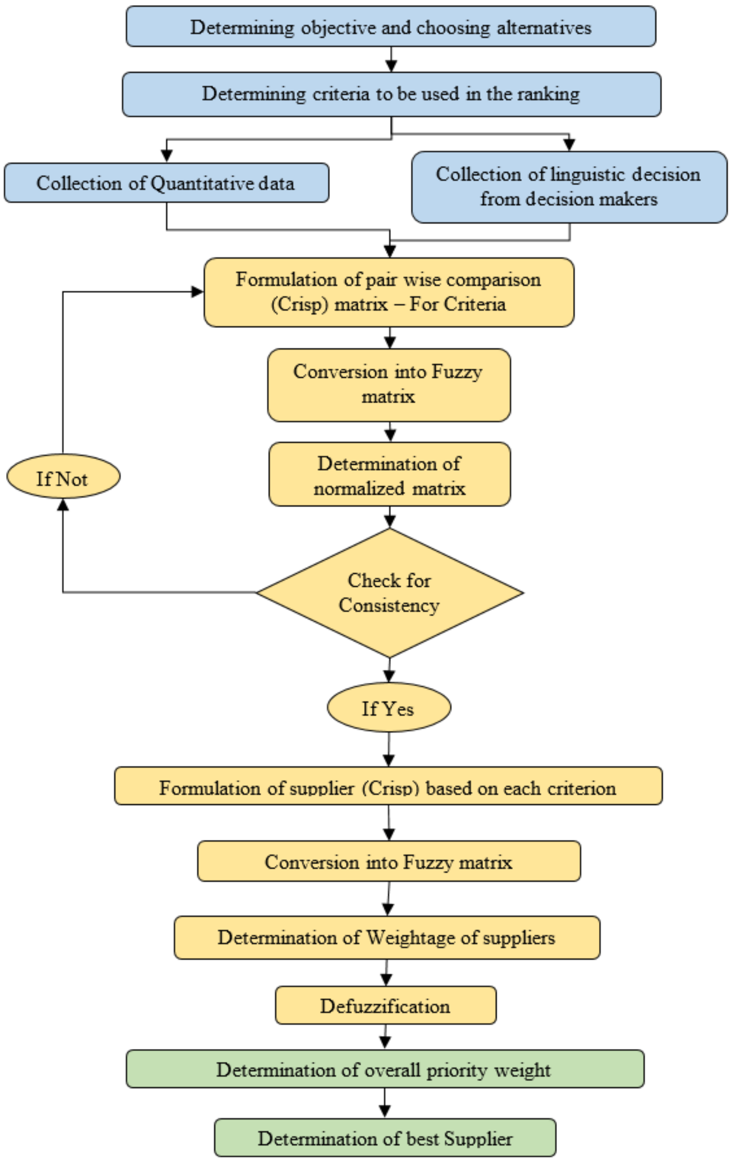

Fig. 8. Fuzzy AHP algorithm for supplier selection (color online).

The FAHP process starts with the collection of both quantitative and qualitative data and the linguistic decision from the decision makers. The FAHP model has been developed by considering the evaluation by using the same criteria. After the data are collected, the comparisons of criteria are obtained from the decision makers based on Satty's [10] nine-point scale of relative importance, and it is shown in Table 4. The criteria matrix which is formed using (3) is shown in Table 5. The crisp matrix is converted into fuzzy matrix using triangular fuzzy numbers as recommended by Alias *et al.* [37].

Table 4. Equivalent triangular fuzzy number for Saaty's nine point scale [10]

Verbal judgement or preference	Saaty's sscale of relative importance	Triangularfuzzy numbers
Extremely preferred	9	9,9,9
Very strongly to extremely preferred	8	7,8,9
Very strongly preferred	7	6,7,8
Strongly to very strongly preferred	6	5,6,7
Strongly preferred	5	4,5,6
Moderately to strongly preferred	4	3,4,5
Moderately preferred	3	2,3,4
Equally to moderately preferred	2	1,2,3
Equally preferred	1	1,1,1

The equivalent triangular fuzzy number shown in Table 4 is used for Saaty's nine-point scale. By using this, the criteria matrix is converted into fuzzy criteria matrix and it is shown in Table ST-1. The fuzzy criteria matrix is normalized using (4) and it is shown in Table ST-2.

First, each criterion is compared with others and the original matrix / criteria matrix which is given by matrix X_{att} is formed:

$$X_{att} = [a_{ij}];\ 1 \leq i,\, j \leq n\ = \begin{bmatrix} 1 & a_{12} \ldots\ldots\ldots a_{1n} \\ \frac{1}{a_{12}} & a_{12} \ldots\ldots\ldots a_{2n} \\ \ldots & \ldots\ldots\ldots\ldots\ldots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} \ldots\ldots\ldots 1 \end{bmatrix}, \tag{3}$$

where a_{ij} – parameters of pair-wise comparison of i^{th} and j^{th} criteria, and n – the number of criteria. The cell values in the criteria matrix are next converted into fuzzy values using Table 4 and the notation $Fuzzy\ Value\ of\ \ (a_{ij}) = \widetilde{a_{ij}} = (a_{ij}^L,\ a_{ij}^M,\ a_{ij}^U\ )$, where: a_{ij}^L – lower value in fuzzy triangular number corresponding to the crisp value, a_{ij}^M – middle value in fuzzy triangular number corresponding to the crisp value, and a_{ij}^U – upper value in fuzzy triangular number corresponding to the crisp value.

By using these fuzzy values, the following fuzzy criteria matrix can be formulated:

$$\widetilde{A} = [\widetilde{a_{ij}}]\,, \widetilde{a_{ij}} = \begin{cases} 1 & i = j \\ 1/\widetilde{a_{ij}} = (\frac{1}{a_{ij}^U},\ \frac{1}{a_{ij}^M},\ \frac{1}{a_{ij}^L}) & i \neq j \end{cases}. \tag{4}$$

The fuzzy criteria matrix is presented in Table ST-1.

Then this fuzzy criteria matrix is normalized to reduce the data range by dividing the individual elements by the column total. The normalized values are shown in Table ST – 2.

Table 5. Criteria matrix

	Cost (C)	Quality (Q)	Deliverytime (D)	Warranty (W)	Paymentterms (PT)
Cost	1	0.200	0.333	3	5
Quality	5	1	3	7	8
Delivery time	3	0.333	1	5	7
Warranty	0.333	0.143	0.200	1	3
Payment terms	0.200	0.125	0.143	0.333	1
Total	9.5333	1.801	4.676	16.333	24

After the normalization, the weights are determined by converting fuzzy numbers into crisp values by using defuzzification technique. The defuzzification has the capability to reduce a fuzzy to a crisp single-valued quantity. Sadia Husain *et al.* [38] have done extensive comparative analysis among the defuzzification approaches and concluded that centroid method performs well compared to others. As a result, centroid method has been used for defuzzification in this case study and its application is briefly described as follows. Let us assume the normalized value for $(a_{ij}^L,\ a_{ij}^M,\ a_{ij}^U) = (b_{ij}^L,\ b_{ij}^M,\ b_{ij}^U) = \widetilde{b_{ij}}$. Let $\mu_{ij} = \frac{b_{ij}^L + b_{ij}^M + b_{ij}^U}{3}$, where $i = 1 \ldots n,\ j = 1 \ldots n$, and n – number of criteria. The centroid method produces the following weights for all ‘n’ criteria:

$$W_i = \frac{\sum_{j=1}^{n} (b_{ij}^L + \ b_{ij}^M + \ b_{ij}^U) * \mu_{ij}}{3 * \sum_{j=\mathbf{1}}^{n} \mu_{ij}},\ i = 1 \ldots n. \tag{5}$$

The weight determination for cost $i = 1$ is given below as an example. The average values for all criteria (Cost, Quality, Delivery time, Warranty and Payment terms) are 0.107, 0.111, 0.081, 0.180 and 0.208, respectively (determined from Table ST – 2):

$$\begin{aligned} W_{cost} &= \frac{((0.129 + 0.105 + 0.088) * 0.107) + ((0.121 + 0.111 + 0.101) * 0.111)}{3 * (0.107 + 0.111 + 0.081 + 0.180 + 0.208)} + \\ &+ \frac{((0.128 + 0.071 + 0.045) * 0.081 + ((0.148 + 0.184 + 0.208) * 0.180)}{3 * (0.107 + 0.111 + 0.081 + 0.180 + 0.208)} + \\ &+ \frac{(0.2 + 0.208 + 0.214) * 0.208)}{3 * (0.107 + 0.111 + 0.081 + 0.180 + 0.208)} \\ &= 0.154 \end{aligned} \tag{6}$$

Similarly, the weights for other criteria are computed.

Since the pairwise comparison is made by human judgement, the consistency of model must be checked. For this Consistency Ratio (CR) is used. It is the ratio CR between *Consistency Index* (CI) and *Random indices* (RI):

$$CR = \frac{CI}{RI}, \tag{7}$$

where:

$$CI = \frac{\lambda_{max} - n}{n - 1}, \tag{8}$$

$$\lambda_{max} = \max(B, n),\ B = \left(\frac{\frac{A_1}{w_1} + \frac{A_2}{w_2} + \frac{A_3}{w_3} + \ldots + \frac{A_n}{w_n}}{n}\right), \tag{9}$$

where: m – number of criteria, and $A1, A2, \ldots, Am$ are calculated using

$$[X_{att}] \cdot [W_{att}] = [A], \tag{10}$$

which is equivalent to

$$\begin{bmatrix} 1 & a_{12} \ldots\ldots\ldots a_{1n} \\ \frac{1}{a_{12}} & a_{12} \ldots\ldots\ldots a_{2n} \\ \ldots & \ldots\ldots\ldots\ldots\ldots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} \ldots\ldots\ldots 1 \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \vdots \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} A_1 \\ A_2 \\ A_3 \\ \vdots \\ \vdots \\ A_n \end{bmatrix}. \tag{11}$$

If $CR < 1$, then the model can be accepted and proceed further [10].

Random indices (RI) for various matrix sizes are shown in Table ST-3 [39]. If $CR < 0.10$, then the decision maker's pairwise comparison matrix is acceptable [38]. The Consistency Ratio for this proposed FAHP model is calculated using (7) and it is found as 0.087 which is less than 0.1. Subsequently, this model is acceptable. After checking the consistency, the suppliers (S1, S2, S3, S4 and S5) are compared with each other based on all the selected criteria which are shown in Table ST-4. Then, these fuzzy matrixes are normalized and shown in Table ST-5. Finally, the overall priority matrix or overall matrix (O) is calculated as follows:

$$O = C \cdot W_{Att} = \begin{bmatrix} x_{11}x_{12}x_{13} & \ldots\ldots\ldots x_{1n} \\ x_{21}x_{22}x_{23} & \ldots\ldots\ldots x_{2n} \\ \ldots\ldots\ldots\ldots & \ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots & \ldots\ldots\ldots\ldots \\ x_{m1}x_{m2}x_{m3} & \ldots\ldots\ldots x_{mn} \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \vdots \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} O_1 \\ O_2 \\ O_3 \\ \vdots \\ \vdots \\ O_n \end{bmatrix}, \tag{12}$$

and it is depicted in Table 6, where m – number of alternatives, x_{ij} – weight of criterion j for alternative i, W_j – weight of criterion j, and o_i – overall priority for alternative i. From the overall matrix, the higher priority will be selected as the best alternative.

Table 6. Final FAHP score of suppliers

Suppliers	Cost	Quality	Delivery	Warranty	Payment Terms	Final Score
Supplier 1	0.014	0.071	0.033	0.017	0.013	0.302
Supplier 2	0.024	0.028	0.081	0.017	0.003	0.153
Supplier 3	0.034	0.241	0.010	0.004	0.013	0.147
Supplier 4	0.007	0.137	0.081	0.010	0.003	0.238
Supplier 5	0.093	0.071	0.081	0.081	0.013	0.305

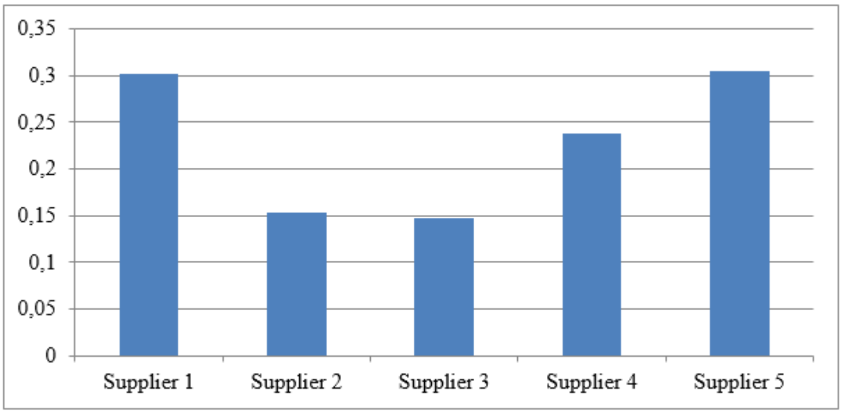

Fig. 9. Illustrates the overall score obtained using FAHP. From this FAHP model, supplier 5 who has higher score is selected as the best supplier (color online).

4. Systems Integration and Validation

The integration of subsystems in an IDSS has four fundamental dimensions: input, output, knowledge system and problem-processing system [40]. Integration technology supports the transfer of data across different subsystems. This process includes file transfer protocols, document protocols, and remote procedure calls. Integration architecture has configured all the subsystem designs to assure easy and secured data sharing across subsystems. User integration enables a system user to concentrate on the tasks to be accomplished and not on the specific details of the technological system being integrated. The integration can be done based on vertical integration, star integration and horizontal integration. In vertical integration, the subsystems are integrated based on their functionalities. If the subsystems are interconnected with each of the remaining subsystems, the star integration should be used. If a specialized subsystem is dedicated to communicate with other subsystems, then the horizontal integration is followed [41]. In this proposed IDSS, all subsystems should be interconnected to perform the decision-making process. Hence, star integration technique is used in IDSS.

To prove the system's efficiency and practical application, the knowledge based IDSS has been built for supplier selection and evaluation. During the implementation, confirmation testing and validation have been properly carried out. The validation can be done based on three main principles: formal validation, prescriptive validation and qualitative-based validation [41]. Confirmation testing is the process of checking the developed IDSS for its completeness and perfection. Various confirmation tests such as interface integrity test, information content test and performance test are conducted to determine the integrity of the individual subsystems and their functions. In the present work, the developed IDSS has been validated by the feedback from the decision makers (qualitative-based validation) in the organization where the case study has been conducted as well as the industrial experts who are in similar kind of industries and the subject experts from academic institutions. Besides, prescriptive validation is also performed under research constraints such as cost and time.

5. Conclusion

An intelligent decision support system for selecting the best supplier has been presented in this paper. The selection process is based on the theory of fuzzy sets and the combination of fuzzy sets and AHP. The intention is to create a methodology for handling qualitative and quantitative criteria under uncertainty. The applicability of these methods is illustrated through a case study of a supplier selection problem in a chemical processing industry. In this work, the model base and knowledge base systems are developed with the help of MS-Excel and MATLAB on a computer with Intel core 3.10 GHZ processor with 3 GB of RAM. The user interface of the IDSS has been developed with the help of Visual Basic as front-end tool. The proposed IDSS allows the purchasing officials to formulate the right sourcing decisions. This IDSS replaces the conventional methods employed by human decision makers with a systematic as well as consistent knowledge-based approach. This IDSS could be integrated with other systems of the organization to provide more features and flexibility to the decision makers. This approach can be extended to other corporate environments by considering the appropriate criteria.

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Supplementary Material:

Table 1. ST-1 Fuzzy criteria matrix: Original matrix

	C			Q			D			W			PT		
C	1	1	1	1/4	1/5	1/6	1/2	1/3	1/4	2	3	4	4	5	6
Q	4	5	6	1	1	1	2	3	4	6	7	8	7	8	9
D	2	3	4	1/2	1/3	1/4	1	1	1	4	5	6	6	7	8
W	1/2	1/3	1/4	1/6	1/7	1/8	1/4	1/5	1/6	1	1	1	2	3	4
PT	1/4	1/5	1/6	1/7	1/8	1/9	1/6	1/7	1/8	1/2	1/3	1/4	1	1	1
Total	7.75	9.53	11.4	2.06	1.80	1.65	3.91	4.6	5.5	13.5	16.33	19.25	20	24	28

Table 2. ST-2 Fuzzy adjusted matrix: Normalized matrix

		C			Q			D			W			PT			Score	
C	0.129	0.105	0.088	0.121	0.111	0.101	0.128	0.071	0.045	0.148	0.184	0.208	0.200	0.208	0.214	0.318	2.061	0.154
Q	0.516	0.524	0.526	0.486	0.555	0.605	0.511	0.642	0.722	0.444	0.429	0.416	0.350	0.333	0.321	3.781	7.379	0.512
D	0.258	0.315	0.350	0.243	0.185	0.151	0.255	0.214	0.180	0.296	0.306	0.312	0.300	0.292	0.286	1.072	3.943	0.272
W	0.065	0.035	0.022	0.081	0.079	0.076	0.064	0.043	0.030	0.074	0.061	0.052	0.100	0.125	0.143	0.0865	1.049	0.082
PT	0.032	0.021	0.015	0.069	0.069	0.067	0.043	0.031	0.023	0.037	0.020	0.013	0.050	0.042	0.036	0.026	0.567	0.045

Table 3. ST-2 Fuzzy adjusted matrix: Normalized matrix

m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.33	1.39	1.45	1.49	1.51	1.54	1.56	1.57	1.58

Table 4. ST-4 Fuzzy supplier matrix

		S1			S2			S3			S4			S5		
Cost	S1	1	1	1	1/3	1/4	1/5	1/4	1/5	1/6	2	3	4	1/7	1/8	1/9
	S 2	3	4	5	1	1	1	1/2	1/3	1/4	3	4	5	1/6	1/7	1/8
	S 3	4	5	6	2	3	4	1	1	1	4	5	6	1/5	1/6	1/7
	S 4	1/2	1/3	1/4	1/3	1/4	1/5	1/4	1/5	1/6	1	1	1	1/9	1/9	1/9
	S 5	7	8	9	6	7	8	5	6	7	9	9	9	1	1	1
	Net	15.500	18.333	21.250	9.667	11.500	13.400	7.000	7.733	8.583	19.000	22.000	25.000	1.621	1.546	1.490
Quality	S 1	1	1	1	3	4	5	1/3	1/4	1/5	1/2	1/3	1/4	1	1	1
	S 2	1/3	1/4	1/5	1	1	1	1/5	1/6	1/7	1/4	1/5	1/6	1/3	1/4	1/5
	S 3	3	4	5	5	6	7	1	1	1	2	3	4	3	4	5
	S 4	2	3	4	4	5	6	1/2	1/3	1/4	1	1	1	2	3	4
	S 5	1	1	1	3	4	5	1/3	1/4	1/5	1/2	1/3	1/4	1	1	1
	Net	7.333	9.250	11.200	16.000	20.000	24.000	2.367	2.000	1.793	4.250	4.867	5.667	7.333	9.250	11.200
Delivery	S 1	1	1	1	1/5	1/6	1/7	5	6	7	1/5	1/6	1/7	1/5	1/6	1/7
	S 2	5	6	7	1	1	1	7	8	9	1	1	1	1	1	1
	S 3	1/5	1/6	1/7	1/7	1/8	1/9	1	1	1	1/7	1/8	1/9	1/7	1/8	1/9
	S 4	5	6	7	1	1	1	7	8	9	1	1	1	1	1	1
	S 5	5	6	7	1	1	1	7	8	9	1	1	1	1	1	1
	Net	16.200	19.167	22.143	3.343	3.292	3.254	27.000	31.000	35.000	3.343	3.292	3.254	3.343	3.292	3.254
Warranty	S 1	1	1	1	1	1	1	5	6	7	4	5	6	1/4	1/5	1/6
	S 2	1	1	1	1	1	1	5	6	7	4	5	6	1/4	1/5	1/6
	S 3	1/5	1/6	1/7	1/5	1/6	1/7	1	1	1	1/4	1/5	1/6	1/7	1/8	1/9
	S 4	1/4	1/5	1/6	1/4	1/5	1/6	4	5	6	1	1	1	1/5	1/6	1/7
	S 5	4	5	6	4	5	6	7	8	9	5	6	7	1	1	1
	Net	6.450	7.367	8.310	6.450	7.367	8.310	22.000	26.000	30.000	14.250	17.200	20.167	1.843	1.692	1.587
Payment Terms	S 1	1	1	1	4	5	6	1	1	1	4	5	6	1	1	1
	S 2	1/4	1/5	1/6	1	1	1	1/4	1/5	1/6	1	1	1	1/4	1/5	1/6
	S 3	1	1	1	4	5	6	1	1	1	4	5	6	1	1	1
	S 4	1/4	1/5	1/6	1	1	1	1/4	1/5	1/6	1	1	1	1/4	1/5	1/6
	S 5	1	1	1	4	5	6	1	1	1	4	5	6	1	1	1
	Net	3.500	3.400	3.333	14.000	17.000	20.000	3.500	3.400	3.333	14.000	17.000	20.000	3.500	3.400	3.333

Table 5. ST-5 Fuzzy adjusted supplier matrix

		S1			S2			S3			S4			S5			Score		
Cost	S 1	0.065	0.055	0.047	0.034	0.022	0.015	0.036	0.026	0.019	0.105	0.136	0.160	0.088	0.081	0.075	0.087	0.963	0.090
	S 2	0.194	0.218	0.235	0.103	0.087	0.075	0.071	0.043	0.029	0.158	0.182	0.200	0.103	0.092	0.084	0.293	1.875	0.156
	S 3	0.258	0.273	0.282	0.207	0.261	0.299	0.143	0.129	0.117	0.211	0.227	0.240	0.123	0.108	0.096	0.655	2.973	0.220
	S 4	0.032	0.018	0.012	0.034	0.022	0.015	0.036	0.026	0.019	0.053	0.045	0.040	0.069	0.072	0.075	0.027	0.567	0.047
	S 5	0.452	0.436	0.424	0.621	0.609	0.597	0.714	0.776	0.816	0.474	0.409	0.360	0.617	0.647	0.671	5.220	8.621	0.606
Quality	S 1	0.136	0.108	0.089	0.188	0.200	0.208	0.141	0.125	0.112	0.118	0.068	0.044	0.136	0.108	0.089	0.258	1.871	0.138
	S 2	0.045	0.027	0.018	0.063	0.050	0.042	0.085	0.083	0.080	0.059	0.041	0.029	0.045	0.027	0.018	0.039	0.712	0.055
	S 3	0.409	0.432	0.446	0.313	0.300	0.292	0.423	0.500	0.558	0.471	0.616	0.706	0.409	0.432	0.446	3.180	6.753	0.471
	S 4	0.273	0.324	0.357	0.250	0.250	0.250	0.211	0.167	0.139	0.235	0.205	0.176	0.273	0.324	0.357	1.010	3.793	0.266
	S 5	0.136	0.108	0.089	0.188	0.200	0.208	0.141	0.125	0.112	0.118	0.068	0.044	0.136	0.108	0.089	0.258	1.871	0.138
Delivery	S1	0.062	0.052	0.052	0.060	0.051	0.044	0.185	0.194	0.200	0.060	0.051	0.044	0.060	0.051	0.044	0.144	1.200	0.120
	S2	0.309	0.313	0.316	0.299	0.304	0.307	0.259	0.258	0.257	0.299	0.304	0.307	0.299	0.304	0.307	1.322	4.443	0.297
	S 3	0.012	0.009	0.006	0.043	0.038	0.034	0.037	0.032	0.029	0.043	0.038	0.034	0.043	0.038	0.034	0.017	0.470	0.035
	S 4	0.309	0.313	0.316	0.299	0.304	0.307	0.259	0.258	0.257	0.299	0.304	0.307	0.299	0.304	0.307	1.322	4.443	0.297
	S 5	0.309	0.313	0.316	0.299	0.304	0.307	0.259	0.258	0.257	0.299	0.304	0.307	0.299	0.304	0.307	1.322	4.443	0.297
Warranty	S 1	0.155	0.136	0.120	0.155	0.136	0.120	0.227	0.231	0.233	0.281	0.291	0.298	0.136	0.118	0.105	0.567	2.741	0.207
	S 2	0.155	0.136	0.120	0.155	0.136	0.120	0.227	0.231	0.233	0.281	0.291	0.298	0.136	0.118	0.105	0.567	2.741	0.207
	S 3	0.031	0.023	0.017	0.031	0.023	0.017	0.045	0.038	0.033	0.018	0.012	0.008	0.078	0.074	0.070	0.025	0.518	0.048
	S 4	0.039	0.027	0.020	0.039	0.027	0.020	0.182	0.192	0.200	0.070	0.058	0.050	0.109	0.099	0.090	0.155	1.221	0.127
	S 5	0.620	0.679	0.722	0.620	0.679	0.722	0.318	0.308	0.300	0.351	0.349	0.347	0.543	0.591	0.630	4.411	7.778	0.567
Payment Terms	S 1	0.286	0.294	0.300	0.286	0.294	0.300	0.286	0.294	0.300	0.286	0.294	0.300	0.286	0.294	0.300	1.290	4.399	0.293
	S 2	0.071	0.059	0.050	0.071	0.059	0.050	0.071	0.059	0.050	0.071	0.059	0.050	0.071	0.059	0.050	0.054	0.901	0.060
	S 3	0.286	0.294	0.300	0.286	0.294	0.300	0.286	0.294	0.300	0.286	0.294	0.300	0.286	0.294	0.300	1.290	4.399	0.293
	S 4	0.071	0.059	0.050	0.071	0.059	0.050	0.071	0.059	0.050	0.071	0.059	0.050	0.071	0.059	0.050	0.054	0.901	0.060
	S 5	0.286	0.294	0.300	0.286	0.294	0.300	0.286	0.294	0.300	0.286	0.294	0.300	0.286	0.294	0.300	1.290	4.399	0.293