A PROPOSAL FOR A DECISION-MAKING TOOL IN PROVIDER EVALUATION AND SELECTION BASED ON THE FUZZY APPROACH

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Abstract

In the area of supply chain management, selecting the right suppliers plays a key role in ensuring the smooth operation of the entire process. Traditional evaluation methods of the suppliers often rely on clear-cut metrics, failing to consider the complexity and uncertainty that often accompany these processes. In contrast, the fuzzy approach allows for the inclusion of a variety of criteria and assessments in the form of linguistic terms, what leads to a more comprehensive evaluation of potential suppliers.

The dynamic development of technology in recent years has become an important factor influencing the functioning of modern enterprises. Modern IT tools, artificial intelligence and data analysis enable companies to gain a competitive advantage by rationalizing and optimizing business and decision-making processes. Organizations have the opportunity to improve their activities, increase efficiency, identify new opportunities and respond faster to changing market conditions.

The paper introduces a multi-criteria provider evaluation model based on fuzzy logic, which will allow you to take into consideration different expert's opinions on various criteria, such as product/service quality, costs, on-time delivery, innovation, or communication ability. Presenting approach should help company in adapting to changing market requirements. In addition to the model, an application with an intuitive interface will be presented, which will allow users to conveniently use the tool and make good decisions in the process of selecting the best supplier.

The proposed methodology is a valuable resource for organizations, helping them use the potential of modern technologies to improve supply chain management and make strategic business decisions.

Keywords: Supply chain management, multi-criteria supplier selection, fuzzy numbers, fuzzy logic

1. INTRODUCTION

To ensure the effective and smooth operation of an enterprise, the key area is supply chain management and, more specifically, the issue of supplier selection. Cooperation with the right business partners gives a chance to increase the efficiency of the organization, increase competitiveness and minimize costs. To make the right decision during the evaluation and selection it is necessary to determine the factors by which suppliers will be verified. The most considered criteria are price, delivery, and quality [1, 2]. In addition to these, during the evaluation process, experts also pay attention to other aspects of cooperation with suppliers, making this issue a multi-criteria problem. The development of technology and artificial intelligence makes it possible to effectively consider various selection criteria.

The purpose of this paper is proposing a tool for an expert multi-criteria method of the supplier evaluation and selection in a resilient supply chain. After analyzing the used multi-criteria supplier evaluation methods, an application in MATLAB software was developed that use fuzzy sets theory to aggregate linguistic expert assessments in selected categories and generate supplier rating in linguistic, numerical and ranking form.

2. MULTI-CRITERIA SUPPORT FOR SUPPLIER SELECTION

Dynamic business changes and the multiplicity of factors affecting decisions on supplier selection force the use and development of tools to support multi-criteria evaluation.

Among others, the following methods are used to assist multi-criteria supplier evaluation:

- **Decision-Making Trial and Evaluation Laboratory (DEMATEL)** method. It is a decision analysis and evaluation method that helps understand the complex relationships between different variables in the context of decision-making. The method creates a graph of relationships between variables to better understand how they affect each other [3].
- **Analytic Hierarchy Process (AHP)** method. It is a structured approach to decision-making that helps solve the problem of choosing among multiple options that are rated in terms of multiple criteria. The AHP process involves comparing pairs of options in terms of their impact on the problem under consideration [4].
- **Analytic Network Process (ANP)**. It is an extension of the AHP method, as it allows the modeling of relationships between criteria in the form of a network of relationships. The method uses matrices of pairwise comparisons, so the effect of each criterion on every other criterion can be determined. Its advantage is flexibility and the ability to introduce new criteria into the analysis [5].
- **Genetic Algorithms (GA)**. This is an artificial intelligence technique inspired by evolutionary processes in nature. The algorithm searches the space of possible solutions through the creation of new generations by crossing u mutation of individuals from the previous generation. The condition for stopping the search is, for example, a set time or number of iterations [6].
- **Linear programming (LP)**. It is a mathematical method for solving optimization problems in which the goal is to find the best solution of the linear function. Linear programming problems involve maximizing or minimizing the objective function while maintaining linear constraints [7].
- **Fuzzy set theory (FST)**. This field deals with the representation of information that is not unambiguous or exact. Unlike classical set theory, where elements are either in or out of a set, in fuzzy set theory, elements can belong to a set on some level rather than fully. The concept of fuzzy sets is particularly useful in situations where the boundaries between belonging and not belonging to a set are unclear or subjective. Fuzzy set theory defines membership functions that determine the degree to which an element belongs to a set. The theory is widely used as a method to support multi-criteria decisions because it allows uncertainty and subjective judgments to be taken into account in the decision-making process. In result the decision-makers can make more rational choices that are consistent with their preferences [8].

2.1 Fuzzy set and fuzzy logic

In the literature, a fuzzy set A is defined as an ordered set of pairs:

$$A = \{(x, \mu_A(x)) \; ; \; x \in X\}, \tag{1}$$

where:

$\mu_A(x) \rightarrow [0,1]$ is the membership function of the fuzzy set A, X is finite universe of discourse. This function determines the membership value for each element in the set, indicating the degree to which the element belongs to the fuzzy set. The membership function can have the values [9]:

- $\mu_A(x) = 1$ – that means the full membership to fuzzy set A;
- $\mu_A(x) = 0$ – that means no membership to fuzzy set A;
- $0 < \mu_A(x) < 1$ – that means partial membership to fuzzy set A.

Fuzzy logic enables the representation of concepts that cannot be defined uniquely, making it more flexible than classical two-value logic and allowing a more accurate representation of reality. Its advantages include enabling more accurate modeling of reality and a more realistic approach to problems in which the boundaries between concepts are fuzzy. These features make fuzzy logic more „user-friendly“ and lead to faster decision-making. Decision-making process based on fuzzy logic depends on the fuzzy rules of the form IF ... AND / OR ... THEN, for example:

IF a is A1 AND b is B2 THEN c is C1

IF a is A2 OR b is B1 THEN c is C2,

where a, b, c are the linguistic variables and A1, A2, B1, B2, C1, C2 are the fuzzy subsets.

2.2 Fuzzy approach in supplier selection

Fuzzy sets theory is applied in many areas, one of them is supply chain management. In [10], a universal supplier selection model supporting the purchasing department was proposed. The main task in the proposed model is to determine the numerical score for different suppliers considering their respective performance in each criterion and then select the best supplier. The literature also includes developments of more advanced methods using fuzzy sets. An example is the fuzzy TOPSIS and fuzzy ELECTRE methods used in green supplier selection for internet company [11], or fuzzy AHP used to generate criteria weights for a sustainable global selection of suppliers [12]. In turn, paper [13] presents a sustainable selection of suppliers of components for the production of gears using fuzzy DEMATEL method. Another example of sustainable supplier selection, this time in an automotive company gives work [14] that uses the fuzzy data envelopment analysis method. In this work, a fuzzy point method is proposed for the evaluation of suppliers, in which the assessment is performed not by one but several experts.

3. TOOL FOR PROVIDER EVALUATION AND SELECTION

3.1 Fuzzy supplier evaluation model

The basis for the creation of a fuzzy model to evaluate suppliers is the adoption of input variables, i.e. the criteria by which potential providers are to be evaluated. **Table 1** presents the evaluation criteria along with the linguistic variables proposed to represent the attitude and opinion of the experts involved in the evaluation process. The parameters for the membership function are in the interval [0,1], which facilitates normalization for different criteria. Thus, results from different categories can be aggregated in a uniform way. Using the quality criterion as an example, the ratio of the number of products with acceptable quality to the number of defective products can be calculated. **Table 2** lists the categories into which a supplier can be classified.

Table 1 Input variables and their membership function parameters (source: own elaboration)

Criterion	Linguistic variable	Membership function parameters
Quality	poor	[0 0 0.25 0.45]
	average	[0.3 0.55 0.8]
	perfect	[0.65 0.85 1 1]
Price	high	[0 0 0.15 0.3]
	average	[0.25 0.5 0.75]
	low	[0.7 0.85 1 1]
Communication	minimal	[0 0 0.25 0.5]
	moderate	[0.35 0.55 0.75]
	effective	[0.6 0.8 1 1]

Innovation	little	[0 0 0.2 0.4]
	sufficient	[0.3 0.6 0.8]
	high	[0.75 0.9 1 1]
Timeliness	unacceptable	[0 0 0.2 0.4]
	moderate	[0.3 0.5 0.7]
	precise	[0.6 0.8 1 1]

Table 2 Output variables and their membership function parameters (source: own elaboration)

Linguistic variable	**Membership function parameters**
top supplier	[0 0.1 0.4]
backup supplier	[0.3 0.6 0.8]
declined supplier	[0.75 0.9 1]

The fuzzy model and the application using it were created in MATLAB which allows the use of a ready-made environment for applying arithmetic and fuzzy logic. The designed model is illustrated in **Figure 1**. Expert knowledge of supplier evaluation has been implemented in the Rule Editor, which is a set of rules that condition the outcome of the model. In this model, all the rules were generated and then reviewed to verify and generalize some of them. The full list of rules (3^5=243) has been simplified to 115 items. An example of simplified rules are rules that contain the evaluated element at the lowest level, such as "Quality is poor" in combination with other lowest levels of criteria. All of them have been simplified to an exemplary form such as "If the Quality is poor, then the declined supplier ", i.e. the "extreme" cases of supplier evaluations have been simplified. The designed model is of Mamdani type and is based on a database of 115 rules.

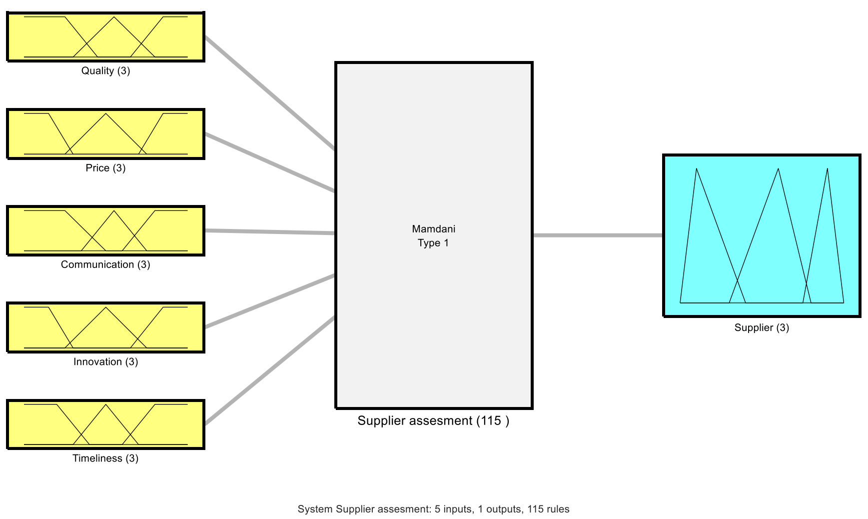

Figure 1 Main panel of Fuzzy Logic Designer (source: own elaboration)

3.2 Application based on fuzzy approach

The application interface presented in **Figure 2** is divided into two parts. In the left part there is an editing area where the user can enter data. There is also a button that starts the calculation and assessment process. In turn, on the right side there is a presentation area where the calculation results and short instructions on how to operate the application are displayed. Additionally, the user has access to a ranking that presents a summary of the best suppliers. This division into two functional parts facilitates the effective use of the application and ensures a clear distinction between the areas of operation.

The designed application allows the selection of ratings in the form of linguistic variables from drop-down lists (DropBox type) by three experts (Expert 1, Expert 2, Expert 3) for four suppliers (Supplier A, Supplier B, Supplier C, Supplier D), who are rated according to five criteria (Quality, Price, Communication, Innovation, Timeliness). During the rating process, each expert is asked to complete all available fields according to specific criteria. Each field contains three terms that allow you to evaluate a given criterion. There are several stages in the assessment process. In the first one, the ratings of each expert in all categories are obtained. In the described case, 4 suppliers were assessed according to 5 criteria, which gives 20 ratings generated by each expert. Then, the average values of the ratings for each supplier in individual criteria are calculated. The built-in functions of the MATLAB - Fuzarith were used for calculations. Fuzarith uses the continuous regions defined by the α-cuts of fuzzy sets A and B to compute the corresponding α-cut of the output fuzzy set C [15]. The following table (**Table 3**) shows how to compute the left and right boundaries of the output interval. Here:

$[A_L\ A_R]$ is the interval defined by the α-cut of fuzzy set A.

$[B_L\ B_R]$ is the interval defined by the α-cut of fuzzy set B.

$[C_L\ C_R]$ is the interval defined by the α-cut of fuzzy set C.

Table 3 Mathematical operations on fuzzy sets [15]

Interval Arithmetic Operator	**Definition**
Addition: $C = A+B$	$C_L = A_L + B_L$ $C_R = A_R + B_R$
Subtraction: $C = A\text{-}B$	$C_L = A_L - B_R$ $C_R = A_R - B_L$
Multiplication: $C = A*B$	$C_L = \min(A_L \cdot B_L, A_L \cdot B_R, A_R \cdot B_L, A_R \cdot B_R)$ $C_R = \max(A_L \cdot B_L, A_L \cdot B_R, A_R \cdot B_L, A_R \cdot B_R)$
Division: $C = A/B$	$C_L = \min\left(\frac{A_L}{B_L}, \frac{A_L}{B_R}, \frac{A_R}{B_L}, \frac{A_R}{B_R}\right)$ $C_R = \max\left(\frac{A_L}{B_L}, \frac{A_L}{B_R}, \frac{A_R}{B_L}, \frac{A_R}{B_R}\right)$

In the next step, a knowledge base defined in the form of an if...then rule is used. An example rule is:

If Quality is perfect and Price is average and Communication is moderate and Innovation is high and Timeliness is moderate then top supplier

Depending on the value of the input data, appropriate rules are used in the inference process, the activation of which allows the determination of the fuzzy form of the result. The next stage is the fuzzy value defuzzification process, during which the fuzzy result is transformed into a sharp numerical value. The "defuzz" MATLAB function and the centroid method were used for this purpose. The centroid method as a defuzzification method in fuzzy logic determines the weighted average of fuzzy values based on the degrees of membership. In presented example we can see expert opinion regarding the level of suppliers' compliance with the criteria as well as the crisp numerical and linguistics ratings for each supplier. There also is the visual prompt which of the supplier achieved the best result.

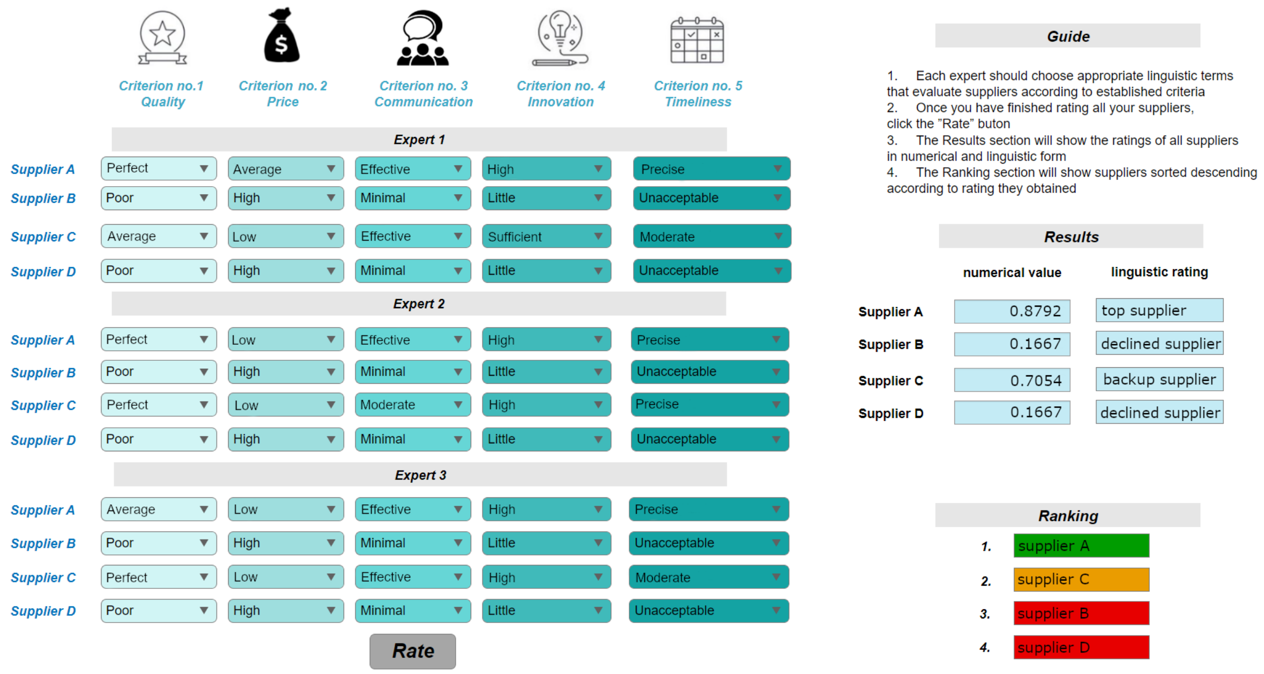

Figure 2 Application interface for supplier evaluation (source: own elaboration)

4. CONCLUSION

The selection and evaluation of suppliers is an extremely important task in an enterprise, which directly affects its position on the market and success in achieving strategic goals. The designed tool allows the company to make more effective decisions regarding the selection and evaluation of a supplier. The application aggregates subjective ratings of suppliers and eliminates the need to precisely enter unambiguous values, which is particularly important in situations where the data is uncertain or subject to a certain degree of subjectivity. This method of evaluating suppliers avoids the influence of the evaluators' personal preferences on the decision-making process.

REFERENCES

[1] WEBER Ch. A., CURRENT J. R. and Benton W. C. Vendor selection criteria and methods *European Journal of Operational Research.* 1991, vol. 50.

[2] DICKSON G. W. An Analysis of Vendor Selection Systems and Decisions. *Journal of Purchasing*. 1966, vol. 2, no. 1.

[3] SHUKLA N., PAUL S., TRIANNI A. Sustainable Supply Chain Management and Multi-Criteria Decision-Making Methods: A Systematic Review. *Sustainability*. 2021. vol. 13.

[4] TUŁECKI A., KRÓL S. Modele decyzyjne z wykorzystaniem metody Analytic Hierarchy Process (AHP) w obszarze transportu. *Problemy Eksploatacji*. 2007, vol. 2.

[5] SARKIS J., TALLURI, S. A model for strategic supplier selection. *Journal of Supply Chain Management.* 2002, vol. 38.

[6] TALLURI S., NARASIMHAN R. A Note on "A Methodology for Supply Base Optimization". *IEEE Transactions on Engineering Management*. 2005, vol. 52, no. 1.

[7] ROJEK K. Algorytmy genetyczne w logistyce zaopatrzenia. *Autobusy: technika, eksploatacja, systemy transportowe*. 2017, vol. 6.

[8] CHEN-TUNG Ch., CHING-TORNG L., SUE-FN H. A fuzzy approach for supplier evaluation and selection in supply chain management. *Int. J. Production Economics.* 2005, vol. 102.

[9] FELIKS J., MAJEWSKA K., MIKA K. The proposal of using fuzzy model for the warehouse management. In: *Proceedings Carpathian Logistics Congress*, 2016.

[10] HASAN M. M., SHOHAG M. A., AZEEM A., PAUL S. Multiple criteria supplier selection: A fuzzy approach. *International Journal of Logistics Systems and Management*. 2015, vol. 20, no. 4.

[11] ORJI I., Wei S. A decision support tool for sustainable supplier selection in manufacturing firms. *Journal of Industrial Engineering and Management*. 2014, vol. 7, no. 5.

[12] GUOHUA Q., ZHIJIE Z., WEIHUA Q, ZESHUI X. Green Supplier Selection Based on Green Practices Evaluated Using Fuzzy Approaches of TOPSIS and ELECTRE with a Case Study in a Chinese Internet Company. *Int. J. Environ. Res. Public Health*. 2020, vol. 17, no. 9.

[13] AWASTHI A., GOVINDAN K., GOLD S. Multi-tier sustainable global supplier selection using a fuzzy AHP-VIKOR based approach. *International Journal of Production Economics*. 2018, vol. 195.

[14] AMINDOUST A., AHMED S., SAGHAFINIA A., BAHREININEJAD A. Sustainable supplier selection: A ranking model based on fuzzy inference system. *Applied Soft Computing*. 2012, vol. 12, no. 6.

[15] MATLAB Help Center R2022b The MathWorks, Inc.