Dependability Assessment of Supplier Performance based on the Fuzzy Sets Theory

Živan Živković, Djordje Nikolić, Ivan Mihajlović, Predrag Djordjević

University of Belgrade, Technical Faculty in Bor, Serbia
zzivkovic@tf.bor.ac.rs, djnikolic@tf.bor.ac.rs, ivanmihajlovic@tf.bor.ac.rs

Abstract: In the literature, considerable attention has been given to the role of suppliers, thus companies have been increasingly considering better supplier selection approaches in order to attain the competitive advantage in the demanding markets. The aim of this study is to provide an effective tool for decision makers (DMs) to help them with evaluation and prioritization of current suppliers. Moreover, the supplier prioritization is inherently multi-criteria decision-making problem (MCDM), with involved high degree of fuzziness. Hence, this paper introduces fuzzy decision-making model where dependability assessment of the suppliers could be done based on the fuzzy set theory and max-min composition. Furthermore, in order to determine supplier dependability, the typical influence indicators: Production facilities and capacities (PFC), Delivery (D) and Service (S), were analysed in an illustrative example, where proposed model used triangular fuzzy numbers (TFN) to establish linguistic description of these three indicators. At the practical level, the results and findings of this paper provide decision makers with a complete picture of those suppliers that have the highest dependability performance in their supplier network.

Keywords: Suppliers, fuzzy set theory, Suppliers evaluation

1 Introduction

In today's competitive market proper management of the supply chain management is the key to success of every company, where they should know that for a company to remain competitive it is crucial to work with its supply chain partners [1]. Therefore, supplier evaluation and selection is one of the most important components of supply chain, which influence the long-term commitments and performance of the company [2]. Thus, supplier selection problem has been the focus of numerous studies both theoretical and empirical [3,4].

According to the Meoini, the supplier (vendor) selection problem is an unstructured, complicated and multi-criteria decision problem [5]. There have

been many analytical models proposed for the supplier selection problem in the extant literature [6-10]. Although, earlier studies on supplier selection emphasized the traditional approach to supplier selection, which has been to select suppliers solely based on price, companies have learned that the sole emphasis on price as a single criterion for supplier selection is not efficient. Hence, they have turned into to a more comprehensive multi-criteria approach. Recently, these criteria have become increasingly complex as: environmental, social, political, and customer satisfaction concerns have been added to the traditional factors of quality, delivery, cost, and service.

The idea of this paper is to establish the model for supplier dependability assessment according to the fuzzy set theory utilization. Moreover, the fuzzy sets were used to analyse several influence indicators on supplier performance. Since, this research is still going on, in this phase authors have decided to present the results for only three indicators of supplier dependability. Thereby, the proposed fuzzy model was used to analyse production facilities and capacities, delivery and service (as partial indicators of supplier's performance), as well as for their integration into supplier dependability evaluation.

This paper is organized as follows: research design and determination of the influence factors are discussed in Section 2. In Section 3, a brief overview of fuzzy set theory and evaluation methodology are provided. Section 4 covers numerical example with aim to demonstrate the application of the proposed fuzzy model. Finally, in the Section 5 this paper concludes with results summary and suggestions for future research.

2 Conceptual framework

Conceptual model of this research is practically summarized in two phases:

1. Identification of supplier's dependability indicators,

2. Development of a research methodology that uses these influence indicators for evaluation and prioritization of the suppliers.

To indicate a set of influence indicators of supplier's performance dependability in supply chains, we surveyed supplier selection literature [5]. For example, even Dickson in 1966 found that seven factors, out of 23 analysed, were perceived as being the most important [11]. These seven factors, in descending order of importance, were: quality, delivery, performance history, warranties and claims policies, production facilities and capacity, price and technical capabilities. On the other hand, Webber with his associates identified six factors as being most used to make selection between suppliers, which varied somewhat from the previous

Dickson research, and they included: quality, delivery, price, facilities/capabilities, geographical location and technical capability [12].

Ordoobadi in his research concluded that factors considered in supplier selection are situation specific and each company should develop its own set of factors when facing with determing the appropriate supliers [13].

In this study three influece indicators of supplier dependability were used, and there are shown in Table 1. Based on the past literature and expert opinions [1], each indicator was considered through the sets of sub-indicators, that are also explain in the following Table 1.

Indicator	Sub-indicator
1. Production facilities and capacities (PFC)	1. Process flexibility 2. Volume flexibility 3. Facilities for measurement, calibration and testing 4. Machine capacity and capability 5. Handling and packaging capability 6. Promotion of JIT concept 7. Training
2. Delivery (D)	1. Production lead time 2. Delivery reliability 3. Safety and security of components 4. Appropriateness of the packaging standards 5. Degree of product matching
3. Service (S)	1. After sales services 2. Spare parts availability 3. Technical support level 4. Sales representatives competencies

Table 1.

Influence indicators and sub-indicators of supplier dependability

3 Methodology framework

In assessing the dependability of supplier's performance based on the partial influence indicators, the fuzzy model has been proposed in this study. Furthermore, to establish assessment of supplier's dependability (SD), a fuzzy composition of defined indicators and their synthesis into one fuzzy value was performed.

In order to develop proposed research model based on the fuzzy set theory, it was required to define:

1. Linguistic variables and their description through a membership function,

2. Establish rules of the fuzzy composition and appropriate models of integration and defuzzification.

The main advantage of the concept of fuzzy sets is ability to addresses uncertain and ambiguous information. Hence, in this research scale with five linguistic variables (1-poor, 2-adequate, 3-average, 4-good, 5-excellent) was used to express uncertainty and vagueness in the structure of input data. In addition, fuzzy sets can be presented by membership function, which usually takes triangular or trapezoidal shape. Whereby, membership function is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. In figure 1, trapezoidal membership function is shown, which represents linguistic variables used in this study. Numeric values j=1,…,5 represent measurement units for supplier's dependability, as well as for the influence indicators of supplier dependability: production facilities and capacities (PFC), delivery (D) and service (S).
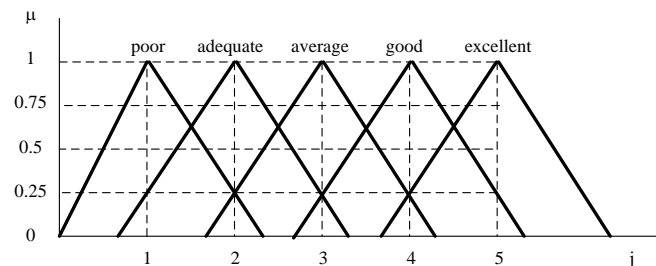

Figure 1
Fuzzy sets for linguistic variables

As a result, partial indicators of supplier's dependability can be expressed by following membership functions:

$$\mu_{PFC} = (\mu_{PFC}^1 .... \mu_{PFC}^5), \mu_D = (\mu_D^1 .... \mu_D^5), \mu_S = (\mu_S^1 .... \mu_S^5), \tag{1}$$

Furthermore, mathematical analysis was realized with aim to determine the level of supplier's dependability, where determination of relations and synthesis of partially considered indicators PFC, D, S was completed based on the max-min composition concept [14-16]. Additionally, it can be stated that all influence indicators (PCF, D, S) that cause dependability of supplier's performance (SD), have equal influence on SD, so max-min composition followed by Best fit method

[14], will be used in this study to simultaneously treats the partial indicators onto composition indicator.

The following methodology is proposed to obtain overall supplier's dependability:

Step 1. Determining the maximum number of combinations of membership functions for the considered fuzzy sets of influence indicators in model, where $C = j^3 = 5^3 = 125$. That means, each of these combinations represents one possible synthesis of supplier's dependability:

$$SD = \left\lfloor \mu_{PFC}^{j=1,\dots,5}, \mu_{D}^{j=1,\dots,5}, \mu_{S}^{j=1,\dots,5} \right\rfloor \text{ for all } c = 1,\dots,C \tag{2}$$

However, to obtain outcomes o based on the defined combination, only non-zero values are taken into account:

If $\quad \mu_{PFC,D,S}^{j=1,\dots,5} \neq 0$ it follows that $o = 1,\dots,O$, where $O \subseteq C$ $\qquad$ (3)

Step 2. Further, for each outcome its value Ω_c is then calculated by following formula:

$$\Omega_c = \frac{\left\lfloor \sum PFC, D, S^j \right\rfloor_c}{3} \tag{4}$$

where running variables in sum represent measurement values $j = 1,\dots,5$ for the influence indicators of supplier dependability: production facilities and capacities (PFC), delivery (D) and service (S).

Step 3. In the next step, for each obtained combination the minimum value of $\mu_{PFC,D,S}$ should be determined, where outcomes are grouped according to their Ω_c, ie. by the size of j ($j = 1,\dots,5$).

$$MIN_o = \min\{\mu_{PFC}^{j=1,\dots,5}, \mu_{D}^{j=1,\dots,5}, \mu_{S}^{j=1,\dots,5}\}, \text{ for all } o = 1,\dots, O \tag{5}$$

Step 4. For previously identified minimums of $\mu_{PFC,D,S}$ for each group and outcome, maximum should be found between these values. Where maximums should be obtain for the each value of j ($j = 1,\dots,5$) by using next formula:

$$MAX_j = \max\{MIN_o\}, \text{ for every } j \qquad\qquad\qquad \dots \tag{6}$$

As a result, dependability of supplier's performance (SD) is calculated:

$$\mu_{SD} = (MAX_{j=1},\dots,MAX_{j=5}) = (\mu_{SD}^1,\dots,\mu_{SD}^5) \tag{7}$$

Step 5. Additionally, the Best fit method is used to transform SD expression, obtained by formula 7, into a form that defines grade of membership to fuzzy sets presented in Figure 1[14]. This methodology calculates distance d between μ_{SD}, obtained by the previous steps, and each of the expressions (1-poor, 2-adequate, 3-average, 4-good, 5-excellent) according to the Figure 1. Hence, to represent the

degree to which SD is confirmed to each of fuzzy sets in Figure 1, next formula is used:

$$d_i(SD, H_i) = \sqrt{\sum_{j=1}^{5} (\mu_{SD}^j - \mu_{Hi}^j)^2} \qquad (8)$$

where: $i=1\ldots5$, H_i\{excellent, good, average, adequate, poor\}

and according to the Figure 1:
$$\mu_{excellent} = (0,0,0,0.25,1), \quad \mu_{good} = (0,0,0.25,1,0.25), \quad \mu_{average} = (0,0.25,1,0.25,0)$$

$$\mu_{adequate} = (0.25,1,0.25,0,0), \quad \mu_{poor} = (1,0.25,0,0,0). \qquad (9)$$

It could be concluded that the closer the SD is to the ith linguistic variable, smaller is d_i. Also, if distance d_i is equal to zero, SD should not be compared to other expressions [15].

Suppose d_{imin} ($i=1,\ldots,5$) is the smallest among the obtain distances for SD and let α_i ($i=1,\ldots,5$) represents the reciprocal of the relative distance, which is calculated as the ratio between corresponding distance d_i and d_{imin}, then α_i can be formulated as:

$$\alpha_i = \frac{1}{d_i / d_{imin}}, \qquad i = 1\ldots5 \qquad (10)$$

If $d_i=0$ it implies that $\alpha_i=1$ and others are equal to zero. Thereby, α_i can be normalized as follows:

$$\beta_i = \frac{\alpha_i}{\sum\limits_{i=1}^{5} \alpha_i}, \qquad i = 1\ldots5, \qquad \sum_{i=1}^{5} \beta_i = 1 \qquad (11)$$

Each β_i represents the extent to which SD belongs to the ith defined fuzzy sets expressions in Figure 1. Thus, β_i could be understood as a degree of the confidence that SD belongs to the ith SD expression. Finally, the expression for the dependability of supplier's performance could be obtained as [16]:

$$SD = \{(\beta_{i=1}, "poor"), (\beta_{i=2}, "adequate"), (\beta_{i=3}, "average"),$$
$$(\beta_{i=4}, "good"), (\beta_{i=5}, "excellent")\} \qquad (12)$$

Step 6. In the last step defuzzification is done. Where, defuzzification of obtained expressions for the dependability of supplier's performance SD is realized by center of mass point approach [17], according to following formula:

$$Z = \frac{\sum\limits_{i=1}^{5} \beta_i \cdot C_i}{\sum\limits_{i=1}^{5} \beta_i} \tag{13}$$

where C is numerical equivalent for linguistic variables (1-poor, 2-adequate, 3-average, 4-good, 5-excellent).

4 An illustrative example

As an illustrative example of evaluation of supplier dependability, comparative analysis of three suppliers is performed for company XYZ. This company is faced with a task of making analysis of its current suppliers, based on their past performance and cooperation.

The application of the proposed model in this study was initiated by collection of expert's judgements and estimations. Five experts (analysts) were interviewed and their task was to fill the questionnaires regarding influence sub-factors, presented in Table1. Further, the obtained ratings were then averaged and rounded within each factor, in order to get discrete rates (1-poor, 2-adequate, 3-average, 4-good, 5-excellent) for considered influence indicators of supplier's dependability (production facilities and capacities (PFC), delivery (D) and service (S)). Hence, the results of experts evaluation of PFC, D, S are summarized in Table 2.

	Linguistic variables								
	Supplier 1			Supplier 2			Supplier 3		
Expert	**PFC**	**D**	**S**	**PFC**	**D**	**S**	**PFC**	**D**	**S**
Expert 1	*adequate*	*poor*	*poor*	*average*	*excellent*	*good*	*good*	*excellent*	*excellent*
Expert 2	*average*	*average*	*average*	*good*	*good*	*good*	*good*	*excellent*	*excellent*
Expert 3	*good*	*good*	*good*	*average*	*good*	*good*	*good*	*good*	*good*
Expert 4	*good*	*good*	*good*	*good*	*good*	*good*	*average*	*good*	*good*
Expert 5	*average*	*good*	*average*	*good*	*excellent*	*excellent*	*good*	*excellent*	*excellent*

Table 2.
Expert's evaluation of influence indicators PFC, D, S

First, the dependability of the first supplier's performance is calculated.

Based on the given rates of five experts it can be concluded that production facilities and capacities (PFC) was evaluated as good by two experts (2/5=0.4), as average by two experts (0.4), and as adequate by one expert (0.2). Thereby, the assessment of PFC is obtained in the form:

$$PFC_1 = (0/poor, 0.2/adequate, 0.4/average, 0.4/good, 0/excellent) \qquad (14)$$

Same, the assessments for D_1 and S_1 are obtained:

$$D_1 = (0.2/poor, 0/adequate, 0.2/average, 0.6/good, 0/excellent) \qquad (15)$$

$$S_1 = (0.2/poor, 0/adequate, 0.4/average, 0.4/good, 0/excellent) \qquad (16)$$

Further, these assessments are then mapped on fuzzy sets in the Figure 1 in order to obtain fuzzy membership function of each influence indicator based on the five linguistic variables j (j=1,...,5). In Table 3 (last row) result of fuzzy membership function for PFC_1 was obtained, where each of expression in (9) is weighted by values from assessments in (14), for each linguistic variable respectively.

	1	**2**	**3**	**4**	**5**
poor×0	1×0	0.25×0	0×0	0×0	0×0
adequate×0.2	0.25×0.2	1×0.2	0.25×0.2	0×0.2	0×0.2
average×0.4	0×0.4	0.25×0.4	1×0.4	0.25×0.4	0×0.4
good×0.4	0×0.4	0×0.4	0.25×0.4	1×0.4	0.25×0.4
excellent×0	0×0	0×0	0×0	0.25×0	1×0
ΣPFC	**0.05**	**0.30**	**0.55**	**0.50**	**0.10**

Table 3.

Calculation of specific values of fuzzy sets for PFC

From the previous Table 3, it follows that:

$$\mu_{PFC1} = (0.05, 0.3, 0.55, 0.5, 0.1) \qquad (17)$$

Also, based on the assessments in (15) and (16) for the first supplier, specific fuzzy form for D_1 and S_1, are calculated as:

$$\mu_{D1} = (0.2, 0.1, 035, 0.65, 015) \qquad (18)$$

$$\mu_{S1} = (0.2, 0.15, 05, 0.5, 0.1) \qquad (19)$$

These fuzzificated assessments (17), (18) and (19) are then used in the max-min composition in order to be synthesized into assessment of SD_1. Following the proposed methodology steps in this research, a number of possible combination with the values of membership functions in fuzzificated assessments (17), (18) and (19) different from zero, are only taken in analysis. In case of the first supplier's SD_1 it is possible to make 125 combinations, since all values in fuzzificated assessments (17), (18) and (19) are different from zero, hence $C=5^3=125$. Further, the first outcome out of 125 outcomes in Table 4 would be for combination 1-1-1,

which means that $SD_1=(0.05,0.2,0.2)$, where based on the formula (4) outcome value is $\Omega_{1-1-1}=(1+1+1)/3$, as well as the minimum for this outcome value according to the formula (5) is 0.05. Other combinations, outcome values and their corresponding minimums are shown in Table 4.

	Combination				μ			MIN				
No.	PFC	D	S	Ω	PFC	D	S	1	2	3	4	5
1.	1	1	1	1	0.050	0.200	0.200	0.05	0	0	0	0
2.	1	1	2	1	0.050	0.200	0.150	0.05	0	0	0	0
3.	1	1	3	2	0.050	0.200	0.500	0	0.05	0	0	0
.	.	.	.	.	.	.	.	.	.	.	.	.
124.	5	5	4	5	0.100	0.150	0.500	0	0	0	0	0.1
125.	5	5	5	5	0.100	0.150	0.100	0	0	0	0	0.1
				MAX				0.2	0.2	0.5	0.5	0.1

Table 4.
Structure of the max-min synthesis of the first supllier's SD

Finally, membership function of the first supplier's SD_1 is obtained from the last row in Table 4, as follows:

$$\mu_{SD1} = (0.2, 0.2, 05, 0.5, 0.1) \tag{20}$$

Based on the Step 5 in proposed methodology, Best fit method is further applied with aim to gives final assessment of SD for the first supplier.

Hence, distances *di* for the first supplier assessment, are calculated as:

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$$d_1(SD, poor) = \sqrt{\sum_{j=1}^{5}(\mu_{SD}^j - \mu_{poor}^j)^2} =$$

$$= \sqrt{(0.2-1)^2 + (0.2-0.25)^2 + (0.5-0)^2 + (0.5-0)^2 + (0.1-0)^2} = 1.074$$

$$d_2(SD, adequate) = \sqrt{\sum_{j=1}^{5}(\mu_{SD}^j - \mu_{adequate}^j)^2} =$$

$$= \sqrt{(0.2-0.25)^2 + (0.2-1)^2 + (0.5-0.25)^2 + (0.5-0)^2 + (0.1-0)^2} = 0.982$$

$$d_3(SD, average) = \sqrt{\sum_{j=1}^{5}(\mu_{SD}^j - \mu_{average}^j)^2} =$$

$$= \sqrt{(0.2-0)^2 + (0.2-0.25)^2 + (0.5-1)^2 + (0.5-0.25)^2 + (0.1-0)^2} = 0.604$$

$$d_4(SD, good) = \sqrt{\sum_{j=1}^{5}(\mu_{SD}^j - \mu_{good}^j)^2} =$$

$$= \sqrt{(0.2-0)^2 + (0.2-0)^2 + (0.5-0.25)^2 + (0.5-1)^2 + (0.1-0.25)^2} = 0.644$$

$$d_5(SD, excellent) = \sqrt{\sum_{j=1}^{5}(\mu_{SD}^j - \mu_{excellent}^j)^2} =$$

$$= \sqrt{(0.2-0)^2 + (0.2-0.0)^2 + (0.5-0)^2 + (0.5-0.25)^2 + (0.1-1)^2} = 1.097$$

(21)

where $d_{imin} = d_3 = 0.604$. Thereby, the reciprocals of the relative distances are then, based on the formula (10), as follows:

$$\alpha_1 = \frac{1}{d_1/d_{min}} = 0.563, \alpha_2 = \frac{1}{d_2/d_{min}} = 0.615, \alpha_3 = \frac{1}{d_3/d_{min}} = 1,$$

$$\alpha_4 = \frac{1}{d_4/d_{min}} = 0.938, \alpha_5 = \frac{1}{d_5/d_{min}} = 0.551$$

(22)

and corresponding normalized values based on the formula (11) are then:

$$\beta_1 = \frac{\alpha_1}{\sum_{i=1}^{5}\alpha_i} = 0.153, \beta_2 = \frac{\alpha_2}{\sum_{i=1}^{5}\alpha_i} = 0.168, \beta_3 = \frac{\alpha_3}{\sum_{i=1}^{5}\alpha_i} = 0.273,$$

$$\beta_4 = \frac{\alpha_4}{\sum_{i=1}^{5}\alpha_i} = 0.256, \beta_5 = \frac{\alpha_5}{\sum_{i=1}^{5}\alpha_i} = 0.150$$

(23)

Finally, assessment of dependability of the first supplier's performance is obtained in form (12):

$$SD_1 = \{(\beta_{i=1}, "poor"), (\beta_{i=2}, "adequate"), (\beta_{i=3}, "average"),$$
$$(\beta_{i=4}, "good"), (\beta_{i=5}, "excellent")\} = \{(0.153, "poor"), (0.168, "adequate"), \quad (24)$$
$$(0.273, "average"), (0.256, "good"), (0.150, "excellent")\}$$

In the same way, in this study we have assessed SD of other two suppliers:

$$SD_2 = \{(0.112, "poor"), (0.114, "adequate"),$$
$$(0.144, "average"), (0.438, "good"), (0.192, "excellent")\}$$
$$\quad (25)$$
$$SD_3 = \{(0.120, "poor"), (0.119, "adequate"),$$
$$(0.136, "average"), (0.250, "good"), (0.375, "excellent")\}$$

At the end, if these SD assessments of considered suppliers are defuzzificated by center of mass point approach and formula (13), we can obtain the crisp values of SD's as:

$$Z_{SD1} = \frac{\sum_{i=1}^{5} \beta_i \cdot C_i}{\sum_{i=1}^{5} \beta_i} = \frac{0.153 \cdot 1 + 0.168 \cdot 2 + 0.273 \cdot 3 + 0.256 \cdot 4 + 0.150 \cdot 5}{0.153 + 0.168 + 0.273 + 0.256 + 0.150} = 3.082 \quad (26)$$

$$Z_{SD2} = 3.483 \qquad Z_{SD3} = 3.642$$

From obtain results it can be concluded that the first supplier's dependability is mostly estimated as average in extent of 27.3%, the second supplier is in great extent assessed as good (43.8%), and the third supplier is in great extent assessed as excellent (37.5%). Therefore, it could be stated that third supplier has highest assessed dependability in comparison with other two suppliers. What more, calculated Z values (defuzzifiacted-crisp values) also confirm and complete this conclusion, which can be also seen based on the illustration in Figure 2.
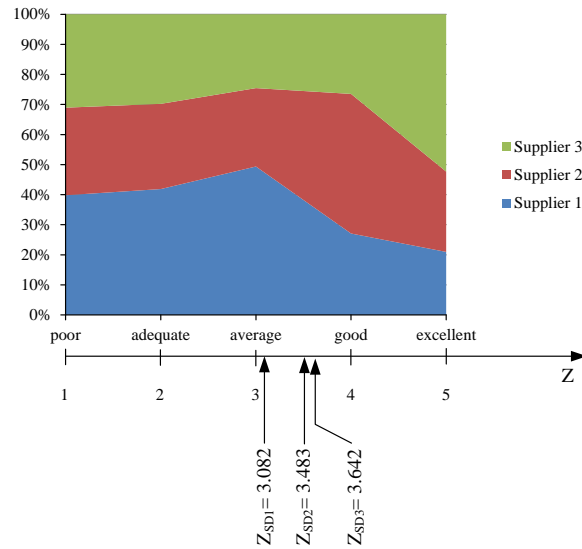
Figure 2
Results of suppliers dependability assessments

Conclusions

In this study, fuzzy evaluation model has been introduced to help decision makers with their decisions regarding rating and prioritization of the suppliers in their organization. Therefore, the proposed methodology could be very useful to the current state of knowledge, since it initiates new unconventional approach to the supplier selection problem.

The results of illustrative example that have been presented in this study, confirmed applicability of the proposed model. Moreover, the advantages of this fuzzy logic approach are clearly explained and implemented. Where, the most of the issues regarding decision-making process are covered, starting with the elimination of imprecision and uncertainty in expert judgments by using linguistic rates (qualitative phase), and then followed by effective quantitative decision-making analysis such are max-min synthesis and the Best-fit method, in order to obtain the priority list of considered suppliers.

As it was stated, this paper gives the preliminary results of the author's research that is still in progress, and which is dealing with the supplier selection problem. This research continues with a focus on development of upgraded methodology, where additional influence factors will be added in the current fuzzy model, as

well as the importance of these indicators will be investigated and implemented in a future model.

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