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DEFINING THE INPUT VALUES IN FIRST HOUSE OF QUALITY OF QFD METHOD USING FUZZY AHP METHOD

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Abstract: In this paper a problem of realization of customer demands in the design of cars B and C class was considered, the importance of using defined demands by using Fuzzy AHP (Analytic Hierarchy Process) method was respectively assessed. After defining characteristics, which should be provided in order to meet demands, the strength of the relation between each demand and each characteristic was assessed. Based on the relation between demands and characteristics, the first house of quality of QFD (Quality Function Deployment) method was formed, which refers to which of the products is considered better or worse, respecting each demand separately. In this way, the first house of quality of QFD method was upgraded by the application of Fuzzy AHP in decision making and assessing the importance of user demands.

Key words: B class car, C class car, customer demands, Fuzzy AHP, QFD

1 INTRODUCTION

The development of the automotive industry created a need for the production of cars of different purposes and characteristics. For example, today there are sports cars, military, ATVs, family cars, city cars, and many other types of cars, which may form on the basis of various parameters and classification. The topic of this paper is to extend and improve the first house of quality of method which was defined as quality planning geared towards customer demands QFD (*Quality Function Deployment*) method [1]. The method was applied for the first time in Mitsubishi Kobe in 1972., its greatest success achieved in the company of Toyota. The basic goal of QFD method is the creation of a new, or advancement of an existing product, service or process, according to the demands of current and /or potential customers. QFD method was described with the basic four stages, which are carried out through four matrices, the so-called "House of quality" [2]. At the entrance to every house of quality (matrix) is always the question: "What is required?", and the output is always the question of: "How to meet the demands?". From the previous matrix question: "How to meet the demands?", in the following matrix question is: "What is required?". So, every time the value of: "How to" in

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the following matrix value becomes: "What". Using of QFD method was represented in the design phase of products of different types and purposes. So, for example, customer demands in terms of design of market doors [3] may be considered, or demands during the construction of apartments [4]. Also, the papers that have implemented integrated QFD and Fuzzy AHP method can be found in the literature, for executing the selection of suppliers [5,6].

This paper discusses the problem of defining customer demands and defining characteristics of customer demands of different classes of passenger cars (B and C class). Based on the experience, knowledge and the results of good practice, the management team of the company defines the demands that customers expect that the company should meet in order for the passenger car to fully justify their expectations. In general, the demands do not have the same relative importance. Assessment of the relative importance is based on an estimate of the management team. The closer to the human way of thinking is that the members of the management team use linguistic expressions instead accurate numbers. Quantification of linguistic expressions can be made using different mathematical theories, such as probability theory, fuzzy set theory, the theory of rough sets and others. The theory of fuzzy sets allows the linguistic terms quantitative performance in the best way possible [7]. Determining the relative importance can be realized in different ways. In this paper, the fuzzy matrix of relative importance of defined demands was explained. A large number of papers in which the authors suggest the construction of fuzzy matrix of relative importance of different items can be found in the literature. Thus, for example, can be used in the selection of suppliers in companies with different activities [8,9], for determining the relative importance of the criteria by which suppliers are assessed [10], for the determination of relative importance of transport - storage system [11] and other.

Processing uncertainty in the constructed fuzzy matrices of comparing pairs of the relative importance of different items can be done in different ways. One of the most widely used methods is method of extended analysis which was developed in [12]. Many authors used this method. [13] suggests that the method of extended analysis have some limitations by comparison with the geometric mean method which has been developed in [14]. The main deficiency can be defined as the inability to process well enough the uncertainties which come from decision makers. Another limitation is the fact that the non-use of this method is based on the assumption that the relative importance of elements of the fuzzy matrix is being described using triangular fuzzy numbers (TFNs). Using fuzzy numbers which have a different form of membership functions is not possible.

The management team take the characteristics of the product under consideration. It is necessary to determine the strength of the relation between the demands and characteristics. In other words, the management team estimates how much each of characteristics meets the defined demands. In conventional QFD method, management team uses precise numbers for assessing the strength of mentioned relations. In this paper it is considered, to be more accurate, if the management team is using linguistic expressions which are modeled using the theory of fuzzy sets. Since characteristics can be benefits and costs type, it is necessary to normalize the estimated values of characteristics. In this paper, linear normalization procedure [15] is used. In this way, values in the domains of used TFNs which describe the characteristic values are mapped into the interval 0÷1. The final result which is the output from the first house of quality is the weighted normalized value of each treated characteristic.

Comparison of the considered types of products or companies under each defined characteristic is based on comparison of TFNs. Comparison of TFNs is performed by using method for comparison fuzzy numbers [16,17]. The degree of belief of how the characteristic of one type of product is better or worse than other types of products, can be determined as well. The obtained result represents the input information for quality managers. This way, they can make better valid decisions.

The paper was organised as followed: In the second section the problem statement was shown, and within it is given the suggested algorithm of Fuzzy AHP method. In section 3 an illustrated example is shown, and the discussions and conclusions are presented in the section 4.

2 PROBLEM STATEMENT

Suppose that the demands for these products may formally present as a set *I*, so that: *I* = {1,...,*i*,...,I}, where I is the total number of demands, and *i*, *i* = 1,...,I is index of demand. The number of demands is defined by the management team (for example: production manager, quality manager and marketing manager), based on knowledge, experience and good practice results. In this paper, two types of cars were considered, class B and class C, and based on that, demands are as follows: safety of drivers (*i*=1), manageability (*i*=2), interior (*i*=3), exterior (*i*=4), maintainability (*i*=5), type of drive (*i*=6), conditions of purchase (*i*=7).

The management team defines a set of characteristics of a product in order to meet customer demands. Characteristics of the product were presented formally as a set *K* = {1,...,*k*,...,K}, where K is the total number of characteristics, and *k*, *k* = 1,...,K is index of characteristic. The characteristics of the product under consideration are: transparency (*k*=1), sensors (*k*=2), braking stability (*k*=3), the number of drive wheels (*k*=4), control panel (*k*=5), line of vehicles (*k*=6), the environmental impact of fuel (*k*=7), fuel consumption per 100 km (*k*=8), price of vehicle (*k*=9).

The relative importance of each pair of demands is described by using the five linguistic expressions which was modeled as TFNs. These linguistic expressions are: $\tilde{R}_1 = (1, 1, 2.5)$, $\tilde{R}_2 = (1, 2, 3)$, $\tilde{R}_3 = (2, 3, 4)$, $\tilde{R}_4 = (3, 4, 5)$, $\tilde{R}_5 = (3.5, 5, 5)$. It can be considered that the management team is making decisions based on consensus. Domains of these TFNs belong to the set of real numbers in the interval 1÷5. Value 1, respectively 5 indicates that the demands *i* according to demand *i*' has almost the equal, or extreme greater relative importance, respectively.

Evaluation of bond strength between the defined demands and characteristics is described using seven linguistic expressions: $\tilde{V}_1 = (1, 1, 2.5)$, $\tilde{V}_2 = (1, 2, 3)$, $\tilde{V}_3 = (1, 3, 5)$, $\tilde{V}_4 = (3, 5, 7)$, $\tilde{V}_5 = (5, 7, 9)$, $\tilde{V}_6 = (7, 8, 9)$, $\tilde{V}_7 = (7.5, 9, 9)$. These domains of TFNs are defined on common measurement scale [18]. A value 1 or 9 indicate that the bond strength between each pair (*i*, *k*) is extremely small or extremely large, respectively.

2.1 Suggested algorithm

The proposed Algorithm can be realized through the following steps:

Step 1. The fuzzy pair wise comparison matrix of the relative importance of customer demands is stated.

$$[\tilde{R}_{ii'}]_{\mathrm{IxI}}, \; i, i' = 1,...,\mathrm{I} \; ; \; i \neq i'$$

Step 2. Transformed the fuzzy pair wise comparison matrix into pair wise comparison matrix by using defuzzification procedure.

$$[R_{ii'}]_{\mathrm{IxI}}, \; i, i' = 1,...,\mathrm{I} \; ; \; i \neq i'$$

$R_{ii'}$ is defuzzyficated $\tilde{R}_{ii'}$

Step 3. Check of consistency of constructed pair wise comparison matrix by using enginee vector [18].

Step 4. By using extent analysis method [12], the weights vector of demands is given.

$$W = (W_1, \dots, W_i, \dots, W_I)$$

Step 5. The normalized fuzzy decision matric is stated.

$$[\tilde{r}_{ki}]_{\mathrm{KxI}}$$

For benefit type: $\tilde{r}_{ki} = (\frac{l_{ki}}{n^*}, \frac{m_{ki}}{n^*}, \frac{n_{ki}}{n^*})$; For cost type: $\tilde{r}_{ki} = (\frac{l^-}{n_{ki}}, \frac{l^-}{m_{ki}}, \frac{l^-}{l_{ki}})$

$n^* = max\, n_{ki}$, $i = 1, \dots, \mathrm{I}$; $l^- = \min l_{ki}$, $i = 1, \dots, \mathrm{I}$

Step 6. The weighted normalized decision matrix is constructed.

$$[\tilde{d}_{ki}]_{\mathrm{KxI}}$$

$$\tilde{d}_{ki} = W_i \cdot \tilde{r}_{ki} \text{ , } i = 1, \dots, \mathrm{I} \text{ ; } k = 1, \dots, \mathrm{K}$$

Step 7. Calculate the weighted normalized value of each characteristic for each considered product (1).

$$\widetilde{D}_K = \frac{1}{\mathrm{I}} \cdot \sum_{i=1}^{\mathrm{I}} \tilde{d}_{ki} \qquad (1)$$

Step 8. Calculating the degree of belief (2) for that one of products is better than other at the level of each characteristic.

$$Bel\left(\widetilde{D}_K > \widetilde{D}_{K'}\right) = bk, k = 1, \dots, \mathrm{K} \qquad (2)$$

3 ILLUSTRATED EXAMPLE

In this paper two types of passenger cars are discussed, car B class and C class car. Assessment of the relative importance of each pair of demands is considered (Step 1 of the proposed Algorithm):

$$[\tilde{R}_{ii'}] = \begin{bmatrix} 1 & \tilde{R}_2 & \tilde{R}_4 & \tilde{R}_4 & \tilde{R}_3 & \tilde{R}_1 & \tilde{R}_2 \\ & 1 & \tilde{R}_3 & \tilde{R}_2 & \tilde{R}_4 & \tilde{R}_5 & \tilde{R}_1 \\ & & 1 & 1 & \frac{1}{\tilde{R}_1} & \tilde{R}_2 & 1 \\ & & & 1 & \tilde{R}_1 & \tilde{R}_1 & \frac{1}{\tilde{R}_1} \\ & & & & 1 & \tilde{R}_1 & 1 \\ & & & & & 1 & \frac{1}{\tilde{R}_1} \\ & & & & & & 1 \end{bmatrix}$$

The elements of fuzzy pair wise comparison matrix are defuzzification by using moment method [19]. The coefficient of consistency CI is determined by enginee vector (Step 2 to Step 3 of the proposed Algorithm).

$$[R_{ii'}] = \begin{bmatrix} 1 & 2 & 4 & 4 & 3 & 1 & 2 \\ 0,5 & 1 & 3 & 2 & 4 & 5 & 1 \\ 0,25 & 0,33 & 1 & 1 & 1 & 2 & 1 \\ 0,25 & 0,5 & 1 & 1 & 1 & 1 & 1 \\ 0,33 & 0,25 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0,2 & 0,5 & 1 & 1 & 1 & 1 \\ 0,5 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

$$\mathrm{CI} = 0,0277$$

By using procedure (Step 4 of the proposed Algorithm), the weights vector is calculated:

$$\mathrm{W}_1 = 0.31;\ \mathrm{W}_2 = 0.33;\ \mathrm{W}_3 = 0.08;\ \mathrm{W}_4 = 0.1;\ \mathrm{W}_5 = 0.08;\ \mathrm{W}_6 = 0.01;\ \mathrm{W}_7 = 0.09$$

The fuzzy decision matrix and the normalized fuzzy decision matrix are given by analogy Step 5 of the proposed Algorithm).

Table 1. *The fuzzy decision matrix*

	k = 1	*k* = 2	*k* = 3	*k* = 4	*k* = 5	*k* = 6	*k* = 7	*k* = 8	*k* = 9
i = 1	$\tilde{V}_4/\tilde{V}_4$	$\tilde{V}_5/\tilde{V}_3$	$\tilde{V}_6/\tilde{V}_3$	$\tilde{V}_2/\tilde{V}_2$	$\tilde{V}_1//\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$
i = 2	$\tilde{V}_4/\tilde{V}_3$	$\tilde{V}_6/\tilde{V}_3$	$\tilde{V}_7/\tilde{V}_4$	$\tilde{V}_4/\tilde{V}_3$	$\tilde{V}_3/\tilde{V}_2$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$
i = 3	$\tilde{V}_4/\tilde{V}_4$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$
i = 4	$\tilde{V}_3/\tilde{V}_2$	$\tilde{V}_2/\tilde{V}_2$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_3/\tilde{V}_2$	$\tilde{V}_4/\tilde{V}_3$	$\tilde{V}_5/\tilde{V}_3$	$\tilde{V}_4/\tilde{V}_3$	$\tilde{V}_2/\tilde{V}_3$	$\tilde{V}_2/\tilde{V}_3$
i = 5	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_4/\tilde{V}_2$	$\tilde{V}_3/\tilde{V}_3$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_3/\tilde{V}_2$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_4/\tilde{V}_3$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_5/\tilde{V}_7$
i = 6	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_5/\tilde{V}_3$	$\tilde{V}_4/\tilde{V}_3$	$\tilde{V}_3/\tilde{V}_2$	$\tilde{V}_3/\tilde{V}_2$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_1/\tilde{V}_1$	$\tilde{V}_5/\tilde{V}_3$
i = 7	$\tilde{V}_3/\tilde{V}_3$	$\tilde{V}_4/\tilde{V}_3$	$\tilde{V}_4/\tilde{V}_3$	$\tilde{V}_4/\tilde{V}_3$	$\tilde{V}_3/\tilde{V}_2$	$\tilde{V}_6/\tilde{V}_3$	$\tilde{V}_5/\tilde{V}_3$	$\tilde{V}_4/\tilde{V}_3$	$\tilde{V}_6/\tilde{V}_6$
	max	max	max	max	max	max	max	min	min

An example of the determination member of the normalized fuzzy decision matrix (step 5):

For car class B: $\tilde{r}_{11} = \tilde{V}_4 = (0.33, 0.56, 0.78)$

For car class C: $\tilde{r}_{21} = \tilde{V}_3 = (0.11, 0.33, 0.56)$

An example of the determination member of the weighted normalized decision matrix (step 6):

For car class B: $\tilde{d}_{11} = (0.33, 0.56, 0.78) \cdot 0.31 =$ (0.102, 0.174, 0.242)

For car class C: $\tilde{d}_{21} = (0.11, 0.33, 0.56) \cdot 0.33 = (0.036, 0.109, 0.185)$

By using procedure (Step 7 and Step 8) of the proposed Algorithm, the weighted normalized values of characteristics are calculated. Also, was calculated the rate of belief that one product is better than another at the level of each characteristic. An example of determination of weighted normalized value of each characteristic for each considered product:

For car class B: $\widetilde{D}_1^1 = \frac{1}{7} \cdot (0.268, 0.476. 0{,}692) = (0.038, 0.068, 0.099)$

For car class C: $\widetilde{D}_1^2 = \frac{1}{7} \cdot (0.195, 0.389. 0{,}597) = (0.028, 0.056, 0.085)$

An example of determination of degree of belief that one product is better than the other at the level of each characteristic:

$$Bel\left(\widetilde{D}_1^1 > \widetilde{D}_1^2\right) = 1 \qquad Bel\left(\widetilde{D}_1^2 > \widetilde{D}_1^1\right) = \frac{0.038 - 0.085}{0.056 - 0.85 - (0.038 - 0.068)} = \frac{-0.047}{-0.059} = 0.8$$

$$Bel\left(\widetilde{D}_2^1 > \widetilde{D}_2^2\right) = 1 \qquad Bel\left(\widetilde{D}_2^2 > \widetilde{D}_2^1\right) = 0.5$$

$$Bel\left(\widetilde{D}_3^1 > \widetilde{D}_3^2\right) = 1 \qquad Bel\left(\widetilde{D}_3^2 > \widetilde{D}_3^1\right) = 0.08$$

$$Bel\left(\widetilde{D}_4^1 > \widetilde{D}_4^2\right) = 1 \qquad Bel\left(\widetilde{D}_4^2 > \widetilde{D}_4^1\right) = 0.66$$

$$Bel\left(\widetilde{D}_5^1 > \widetilde{D}_5^2\right) = 1 \qquad Bel\left(\widetilde{D}_5^2 > \widetilde{D}_5^1\right) = 0.73$$

$$Bel\left(\widetilde{D}_6^1 > \widetilde{D}_6^2\right) = 1 \qquad Bel\left(\widetilde{D}_6^2 > \widetilde{D}_6^1\right) = 0.63$$

$$Bel\left(\widetilde{D}_7^1 > \widetilde{D}_7^2\right) = 1 \qquad Bel\left(\widetilde{D}_7^2 > \widetilde{D}_7^1\right) = 0.69$$

$$Bel\left(\widetilde{D}_8^1 > \widetilde{D}_8^2\right) = 1 \qquad Bel\left(\widetilde{D}_8^2 > \widetilde{D}_8^1\right) = 0.99$$

$$Bel\left(\widetilde{D}_9^1 > \widetilde{D}_9^2\right) = 0.9 \qquad Bel\left(\widetilde{D}_9^2 > \widetilde{D}_9^1\right) = 1$$

4 CONCLUSION

The first type of car (class B) is better than the class C within the first eight characteristics. Type of car class C is better than the B class car only according to the characteristic that are marked as the price of the vehicle.

Based on the calculated rate of belief follows that both types of cars equally meet the customer demands, except for the characteristic of braking stability. In other words, the quality of the car type B is significantly better than the car type C respecting this characteristic.

In this paper, the problem of improvement of outputs which is obtained in the first "house of quality" of QFD method was considered. Improvement has been made in the following way: demands that should be met and characteristics that cars class B and class C have, are defined on the basis of good practice applying benchmarking methods; the relative importance of the demands is specified using by fuzzy pair-wise comparison matrix; the weights of demand are calculated by using extent analysis method [12]; the values of characteristics are assessed by management team which use linguistic expressions. The all uncertainties and imprecisions are modeled by using fuzzy sets theory [7,20]. The weighted normalized values of characteristics are given by TFNs. The results of comparison of these TFNs, and calculated the degrees present input data for the second "house of quality" of QFD method.

NOMENCLATURE

Bel degree of belief

CI coefficient of consistency

$\tilde{d}_{ki}$ fuzzy number, symbol of weighted normalized decision matrix

$\widetilde{D}_K$ fuzzy number, weighted normalized value

l^- cost type

n^* benefit type

$\tilde{r}_{ki}$ fuzzy number, symbol of normalized fuzzy decision matrix

$\tilde{R}_{ii'}$ fuzzy number, relative importance of customer demands

$R_{ii'}$ defuzzyficated $\tilde{R}_{ii'}$

W_i weight vector of demand

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