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EVALUATION AND SELECTION OF THE PVC CARPENTRY MANUFACTURER USING THE FUCOM-MABAC MODEL

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Abstract: *Solving real-life problems using multi-criteria decision-making methods is now an everyday challenge. These methods represent a very useful tool and support for decision-making in all areas. Therefore, this paper comprises evaluation and selection of the PVC carpentry manufacturers using a combined multi-criteria model. Five potential manufacturers are evaluated on the basis of seven criteria. For the determination of criteria weights, the FUCOM (FUll COnsistency Method) is used, while the Multi-Attributive Border Approximation Area Comparison (MABAC) method is used for evaluating and selecting the PVC manufacturer. The results show that the third alternative is the most suitable solution, as demonstrated by the sensitivity analysis. Four other methods are used in the sensitivity analysis, namely, ARAS (Additive Ratio Assessment), WASPAS (Weighted Aggregated Sum Product Assessment), EDAS (Evaluation based on Distance from Average Solution), and SAW (Simple Additive Weighting). The obtained results using all the methods show the complete correlation of the ranks obtained using the MABAC method.*

Key Words: *PVC Manufacturer, FUCOM, MABAC, Criteria Weights*

1 Introduction

In solving real-life problems, there is a large number of influencing factors that can affect the final decision. In the case of a larger number of criteria involved in the decision-making process, according to Zavadskas et al. (2018), it is practically impossible to avoid the use of multi-criteria decision-making (MCDM) methods. According to Kumar, (2010) the MCDM can be perceived as a process of evaluating real-world situations based on various qualitative/quantitative criteria in certain/uncertain/risky environments in order to find a suitable course of action/choice/strategy/policy among several available options. According to Chen et al. (2015), the MCDM is an effective systematic and quantitative way of dealing with vital real-life problems in the presence of a number of alternatives and several usually conflicting criteria. A great number of works applying diverse MCDM

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techniques for engineering problems have recently been published (Zavadskas et al. 2016). Everyday use of MCDM methods (Petrović et al. 2016; Shetwan et al. 2018; Eshtaiwi et al. 2018; Karabašević et al. 2018) has certainly contributed to the rise in popularity of this area.

The main objective of the paper is to evaluate and select the PVC carpentry manufacturer using the FUCOM-MABAC model. The way of reaching the given goal is by satisfying a number of criteria such as: selection of a high-quality manufacturer at the lowest possible price, a short time for delivery and montage, possibility of deferred payment and a longer warranty period with the manufacturer's reliability.

In addition to the Introduction, the paper is structured through four more sections. The second section (Section 2) presents the FUCOM and MABAC methods with their detailed steps. In the third section (Section 3), a multi-criteria model is formed and the previously described methods for evaluating and selecting PVC manufacturers are applied. The fourth section (Section 4) presents a sensitivity analysis in which the stability of the applied model is proved. The paper ends with the conclusions along with the guidelines for future research.

2 Methods

2.1 FUll COnsistency Method - FUCOM

This method is a new MCDM method proposed in (Pamučar et al. 2018). The problems of multi-criteria decision-making are characterized by the choice of the most acceptable alternative out of a set of the alternatives presented on the basis of the defined criteria. A model of multi-criteria decision-making can be presented by a mathematical equation $\max\left[c_1(x), c_2(x), \dots, c_n(x)\right]$, $\mathrm{n} \geq 2$, on the condition that $x \in A = \left[a_1, a_2, \dots, a_m\right]$; where n represents the number of the criteria, m is the number of the alternatives, c_j represents the criteria ($j = 1, 2, \dots, n$) and A represents the set of the alternatives a_i ($i = 1, 2, \dots, m$). Values f_{ij} of each considered criterion c_j for each considered alternative a_i are known, namely $f_{ij} = c_j(a_i),\ \ \forall(i, j);\ i = 1, 2, \dots, m;\ j = 1, 2, \dots, n$. The relation shows that each value of the attribute depends on the j^{th} criterion and the i^{th} alternative.

Real problems do not usually have the criteria of the same degree of significance. It is, therefore, necessary that the significance factors of particular criteria should be defined by using appropriate weight coefficients for the criteria so that their sum is one. Determining the relative criteria weights in multi-criteria decision-making models is always a specific problem inevitably accompanied by subjectivity. This process is very important and has a significant impact on the final decision-making result since the weight coefficients in some methods crucially influence the solution. Therefore, particular attention in this paper is paid to the problem of determining the criteria weights, and the new FUCOM model for determining the weight coefficients of criteria is proposed. This method enables precise determination of the values of the weight coefficients of all of the elements mutually compared at a certain level of the hierarchy, simultaneously satisfying the conditions of the comparison consistency, too.

In real life, pairwise comparison values $a_{ij} = w_i / w_j$ (where a_{ij} shows the relative preference of criterion *i* to criterion *j*) are not based on accurate measurements, but rather on subjective estimates. There is also a deviation of values a_{ij} from ideal ratios w_i / w_j (where w_i and w_j represent criteria weights of criterion *i* and criterion *j*). If, for example, it is determined that A is of much greater significance than B, B of greater importance than C, and C of greater importance than A, there is inconsistency in the problem solving and the reliability of the results decreases. This is especially true when there is a large number of pairwise comparisons of criteria. The FUCOM reduces the possibility of errors in comparison to the least possible extent due to: (1) a small number of comparisons (*n-1*) and (2) the constraints defined when calculating the optimal values of criteria. The FUCOM provides the ability to validate the model by calculating the error value for the obtained weight vectors by determining DFC. On the other hand, in the other models for determining criteria weights (the BWM, the AHP models), the redundancy of the pairwise comparison appears, which makes them less vulnerable to errors in judgment, while the FUCOM methodological procedure eliminates this problem.

In the following section, the procedure for obtaining the weight coefficients of criteria by using the FUCOM is presented.

Step 1 In the first step, the criteria from a predefined set of the evaluation criteria $C = \{C_1, C_2, ..., C_n\}$ are ranked. The ranking is performed according to the significance of the criteria, i.e. starting from the criterion which is expected to have the highest weight coefficient down to the criterion of the least significance. Thus, the criteria ranked according to the expected values of the weight coefficients are obtained:

$$C_{j(1)} > C_{j(2)} > ... > C_{j(k)} \tag{1}$$

where *k* represents the rank of the observed criterion. If there is a judgment of the existence of two or more criteria with the same significance, the sign of equality is placed instead of “>” between these criteria in expression (1).

Step 2 In the second step, comparison of the ranked criteria is carried out and the *comparative priority* ($\varphi_{k/(k+1)}$, $k = 1, 2, ..., n$, where *k* represents the rank of the criteria) of the evaluation criteria is determined. The comparative priority of evaluation criteria ($\varphi_{k/(k+1)}$) is an advantage of the criterion of the $C_{j(k)}$ rank compared to the criterion of the $C_{j(k+1)}$ rank. Thus, the vector of the comparative priorities of the evaluation criteria is obtained, as in expression: (2)

$$\Phi = \left(\varphi_{1/2}, \varphi_{2/3}, ..., \varphi_{k/(k+1)}\right) \tag{2}$$

where $\varphi_{k/(k+1)}$ represents the significance (priority) of the criterion of the $C_{j(k)}$ rank in comparison with the criterion of the $C_{j(k+1)}$ rank.

The comparative priority of the criteria is defined in one of the two ways defined in the following part:

a) Pursuant to their preferences, the decision-makers define comparative priority $\varphi_{k/(k+1)}$ among the observed criteria. Thus, for example, if two stones A and B, which, respectively, have the weights of $w_A = 300$ grams and $w_B = 250$ grams are observed, comparative priority ($\varphi_{A/B}$) of Stone A in relation to Stone B is $\varphi_{A/B} = 300/250 = 1.2$. Also, if weights A and B cannot be determined precisely, but a predefined scale is used, e.g. from 1 to 9, then it can be said that Stones A and B have weights $w_A = 8$ and $w_B = 7$, respectively. Then comparative priority ($\varphi_{A/B}$) of Stone A in relation to Stone B can be determined as $\varphi_{A/B} = 8/7 = 1.14$. This means that Stone A in relation to Stone B has a greater priority (weight) by 1.18 (in the case of precise measurements), i.e. by 1.14 (in the case of application of measuring scale). In the same manner, the decision-makers define the comparative priority among observed criteria $\varphi_{k/(k+1)}$. When solving real problems, the decision-makers compare the ranked criteria based on internal knowledge so that they determine comparative priority $\varphi_{k/(k+1)}$ based on subjective preferences. If the decision-maker thinks that the criterion of the $C_{j(k)}$ rank has the same significance as the criterion of the $C_{j(k+1)}$ rank, then the comparative priority is $\varphi_{k/(k+1)} = 1$.

b) Based on a predefined scale for comparing criteria, the decision-makers compare the criteria and thus determine the significance of each individual criterion in expression (1). The comparison is made with respect to the first-ranked (the most significant) criterion. Thus, the significance of criteria ($\varpi_{C_{j(k)}}$) for all of the criteria ranked in Step 1 is obtained. Since the first-ranked criterion is compared with itself (its significance is $\varpi_{C_{j(1)}} = 1$), the conclusion can be drawn that the *n-1* comparison of the criteria should be performed.

For example: a problem with three criteria ranked as C2>C1>C3 is being subjected to consideration. Suppose that scale $\varpi_{C_{j(k)}} \in [1,9]$ is used to determine the priorities of the criteria and that, based on the decision-maker's preferences, the following priorities of criteria $\varpi_{C_2} = 1$, $\varpi_{C_1} = 3.5$ and $\varpi_{C_3} = 6$ are obtained. On the basis of the obtained priorities of the criteria and condition $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}$ we obtain the following calculations $\frac{w_2}{w_1} = \frac{3.5}{1}$, i.e. $w_2 = 3.5 \cdot w_1$, $\frac{w_1}{w_3} = \frac{6}{3.5}$ i.e. $w_1 = 1.714 \cdot w_3$. In that way, the following comparative priorities are calculated: $\varphi_{C_2/C_1} = 3.5/1 = 3.5$ and $\varphi_{C_1/C_3} = 6/3.5 = 1.714$ (expression (2)).

As we can see from the example shown in Step 2b, the FUCOM model allows the pairwise comparison of the criteria by means of integer, decimal values or values from the predefined scale for the pairwise comparison of the criteria.

Step 3 In the third step, the final values of the weight coefficients of evaluation criteria $\left(w_1, w_2, ..., w_n\right)^T$ are calculated. The final values of the weight coefficients should satisfy two conditions, namely: (1) that the ratio of the weight coefficients is equal to the comparative priority among observed criteria ($\varphi_{k/(k+1)}$) defined in *Step 2*, i.e. that the following condition is met:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

(2) In addition to the condition (3), the final values of the weight coefficients should satisfy the condition of mathematical transitivity, i.e. that $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since $\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is obtained. Thus, yet another condition that the final values of the weight coefficients of the evaluation criteria need to meet is obtained, namely:

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{4}$$

Full consistency, i.e. minimum DFC (χ) is satisfied only if transitivity is fully respected, i.e. when the conditions of $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}$ and $\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}$ are met. In that way, the requirement for maximum consistency is fulfilled, i.e. DFC is $\chi = 0$ for the obtained values of the weight coefficients. In order for the conditions to be met, it is necessary that the values of weight coefficients $\left(w_1, w_2, ..., w_n\right)^T$ meet the condition of $\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \le \chi$ and $\left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi$, with the minimization of value χ. In that manner the requirement for maximum consistency is satisfied. Based on the defined settings, the final model for determining the final values of the weight coefficients of the evaluation criteria can be defined.

$$\begin{aligned}
&\min \chi \\
&s.t. \\
&\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| \le \chi,\ \forall j \\
&\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \chi,\ \forall j \\
&\sum_{j=1}^{n} w_j = 1,\ \forall j \\
&w_j \ge 0,\ \forall j
\end{aligned} \tag{5}$$

By solving the model (5), the final values of evaluation criteria $\left(w_1, w_2, ..., w_n\right)^T$ and the degree of DFC (χ) are generated.

2.2 MABAC method

The MABAC Method (Multi-Attributive Border Approximation Area Comparison) was developed by Pamučar and Ćirović, (2015). The basic setting of the MABAC Method is reflected in defining the distance of the criterion function of each observed alternative from the boundary approximation domain. In the following section, the implementation procedure for the MABAC Method consisting of 6 steps is shown.

Step 1 Forming initial decision matrix (X)

As the first step, *m* alternatives are evaluated by *n* criteria. Alternatives are shown with vectors $A_i=(x_{i1}, x_{i2,...,} x_{in})$, where x_{ij} is the value of i-... alternative by j-... criteria (i=1,2,...,m; j=1,2,...,n)

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{array} \tag{6}$$

where *m* denotes the number or alternative, while *n* is the total number of criteria.

Step 2 Normalization of the elements of starting matrix *(X)*

$$N = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} t_{11} & t_{12} & \dots & t_{1n} \\ t_{21} & t_{22} & & t_{2n} \\ \dots & \dots & \dots & \dots \\ t_{m1} & t_{m2} & \dots & t_{mn} \end{bmatrix} \end{array} \tag{7}$$

The elements of normalized matrix (N) are determined using the expression:

For the criteria belonging to a "benefit" type (greater value of criteria is more desirable):

$$t_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{8}$$

For the criteria belonging to a "cost" type (lower value of criteria is more desirable)

$$t_{ij} = \frac{x_{ij} - x_i^{+}}{x_i^{-} - x_i^{+}} \tag{9}$$

where x_{ij}, x^+ and x^- are representing elements of the starting matrix of making decision (X), where x_{ij} , x^+ and x- are defined as: x_j^+ =max ($x_1, x_2, .., x_n$) and representing maximal values of observed criteria by alternatives; x_j^- =min ($x_1, x_2, .., x_m$) and representing minimal values of observed criteria by alternatives.

Step 3 Calculation of the element of weighted normalized matrix *(V)*

Elements of weighted normalized matrix (V) are being calculated on the base of expression (10):

$$v_{ij} = w_i \cdot t_{ij} + w_i \tag{10}$$

where Tij are representing the elements of normalized matrix N, *wi* represents weighting coefficients of criteria.

Step 4 Determining the matrix of bordering approximative fields (G)

Bordering approximative field (GAO) is determined by expression (11):

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m} \tag{11}$$

with v_{ij} representing the elements of weighted matrix V, *m* represents the total number of alternatives. Matrix of bordering approximative fields is being formed according to criteria G (12) in format *n* x 1.

$$\begin{array}{cc} & \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ G = & \begin{bmatrix} g_1 & g_2 & \cdots & g_n \end{bmatrix} \end{array} \tag{12}$$

Step 5 The calculation of the distance matrix element is an alternative to boundary approximative area (*Q):*

$$Q = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{13}$$

Distance of alternatives from boundary approximative area (q_{uid}) is determined as a difference of elements of heavier matrix (V) and values of bordering approximative areas (G).

$$Q = V - G = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} - \begin{bmatrix} g_1 & g_2 & \cdots & g_n \end{bmatrix} \tag{14}$$

where q_{ij} represents the bordering approximative areas for criterion Ci, *vij* represents elements of weighted matrix (V), *n* represents number of criteria, *m* represents number of alternatives. Alternative Ai may belong to bordering approximative area (G), upper bordering approximative area (G^+) or lower bordering approximative area (G^-). Upper approximative area (G^+) represents the area in which ideal alternative (A+) is located, while lower approximative area (G^-) represents the area in which anti-ideal alternative is located (A^-).

$$A_i \in \begin{cases} G^+ \ if \ q_{ij} > g_i \\ G \ \ if \ q_{ij} = g_i \\ G^- \ if \ q_{ij} < g_i \end{cases} \tag{15}$$

In order for an alternative *Ai* to be selected as the best from a given set, it is necessary for it to belong to the upper approximating field by as many criteria as possible (G^+). If, for example, an alternative *Ai* belongs to the upper approximative area by 5 criteria (out of 6 in total), and to the lower approximative area by one criterion, (G^-) that means that, by 5 criteria, this alternative is close to or equal with the ideal alternative, while by one criterion it is close to or equal to anti-ideal alternative. If value $q_{ij} > 0$, i.e. $q_{ij} \in G^+$, then alternative Ai is close or equal to the ideal alternative. Value $q_{ij} > 0$, i.e. $q_{ij} \in G^-$, shows that alternative Ai is close or equal to the anti/ideal alternative.

Step 6 Alternatives ranking

Calculation of values of the criteria functions by alternatives is obtained as the sum of distance of the alternatives from bordering approximative fields (q_i). By summarizing the elements of Q matrix by rows, we obtain the final values of the criterion functions of alternatives (16) where *n* represents the number of criteria, and *m* represents the number of alternatives.

$$S_i = \sum_{j=1}^{n} q_{ij}, \ j = 1, 2, \ldots, n, \ i = 1, 2, \ldots, m \tag{16}$$

3 Evaluation of PVC carpentry manufacturer

On today's market, according to Stević et al. (2018), there is a large number of PVC carpentry manufacturers that bid a very diverse offer from their wide range of production. The research in this paper has led to the selection of five manufacturers, all located at the maximal distance of 70 km. The surface of apartment which requires the selection of the most suitable manufacturer of PVC carpentry is 64 m^2 and Fig. 1 shows dimensions of all the apartment surfaces in need of PVC carpentry. In addition, a selection of six-chamber PVC profiles with thermal insulation glasses of 24 mm was carried out in advance.

From Fig. 1 it can be seen that, according to the wishes of buyers who are also decision-makers, a montage of carpentry together with window blinds and mosquito nets is needed. Only Position 5 is without mosquitoes nets, and it is necessary to install internal and external benches. Position 1 as a single-hung window with Position 2 (a double-hung window) makes a corner window in the living room. Also, Position 3 is a single-hung window belonging to the living room. Position 4 of the single-hung window belongs to the bedroom, while Position 5 of the single-hung window and Position 6 of the balcony door belong to the dining room.

The criteria formulated in this research representing the basis for decision-making of those who select the most favorable manufacturer are: product quality, product price, timeframe guarantee, manufacturer's reliability, delivery time, payment methods and the possibility of walls treatment after the montage of new carpentry, marked hereinafter as C_1–C_7, respectively. The second criterion is a cost criterion that needs to be minimized, while the rest belongs to benefit criteria that are of maximizing type.

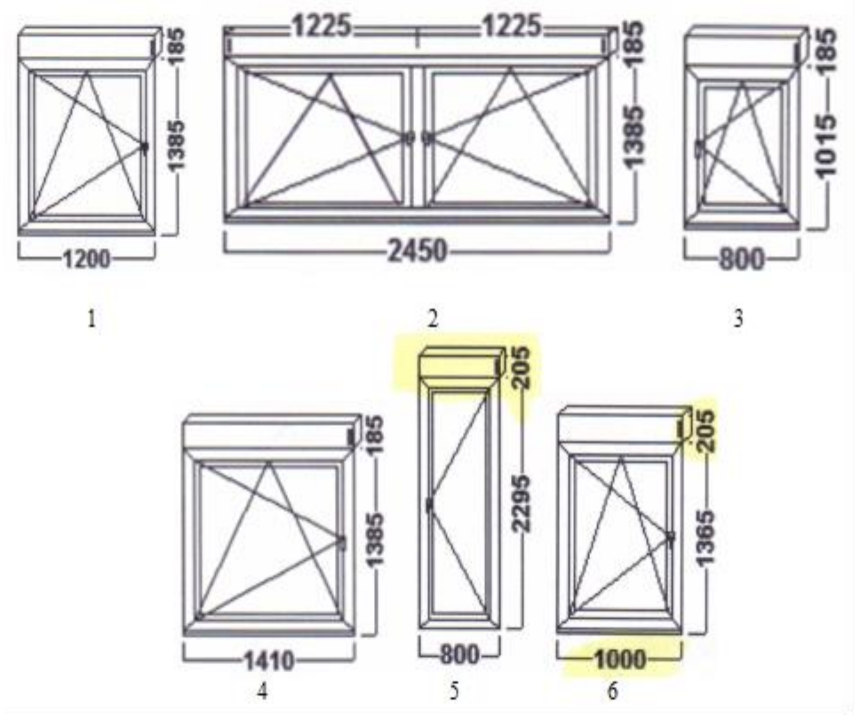

Fig. 1 Dimensions of elements needed for montage

Table 1 presents the criteria used to evaluate and select the manufacturer, while Table 2 shows the scale for assessing qualitative criteria. Some of these criteria can be successfully applied to evaluation of suppliers in the companies manufacturing PVC carpentry, which is confirmed by the research carried out in (Stojić et al. 2018).

Table 1 Criteria used in the research

Mark of criteria	Name of criteria
C_1	product quality
C_2	product price
C_3	timeframe guarantee
C_4	manufacturer's reliability
C_5	delivery time
C_6	payment methods
C_7	treatment of walls after the montage of new carpentry

Table 2 Linguistic scale for evaluating the benefit criteria (Stević et al. 2017)

Linguistic Scale	For Criteria Max Type (Benefit criteria)
Very Poor (VP)	1
Poor (P)	3
Medium (M)	5
Good (G)	7
Very Good (VG)	9

Table 2 shows only the benefit criteria scale since the only cost criterion is the product price that is quantitatively expressed. In addition to this criterion, the warranty period is also displayed through its real values. The criterion of delivery time could not be quantified because certain manufacturers display, as this criterion, time - by agreement. Therefore, this criterion is qualitative and benefit.

3.1 Determining criteria weight using the FUCOM method

Step 1 In the first step, the decision-makers perform the ranking of the criteria: C1> C2> C5> C3=C6>C4>C7.

Step 2 In the second step (Step 2b), the decision-maker perform pairwise comparison of the ranked criteria from Step 1. The comparison is made with respect to the first-ranked C2 criterion. The comparison is based on the scale $\left[1,9\right]$. Thus, the priorities of criteria ($\varpi_{C_{j(k)}}$) for all of the criteria ranked in Step 1 are obtained (Table 3).

Table 3 Priorities of criteria

Criteria	C_1	C_2	C_5	C_3	C_6	C_4	C_7
$\varpi_{C_{j(k)}}$	1	1.3	2	2.5	2.5	2.8	3.5

Based on the obtained priorities of the criteria, the comparative priorities of the criteria are calculated: $\varphi_{C_1/C_2}=1.3/1=1.3$, $\varphi_{C_2/C_5}=2/1.3=1.54$,

$\varphi_{C_5/C_3}=2.5/2=1.25$, $\varphi_{C_3/C_6}=2.5/2.5=1$, $\varphi_{C_6/C_4}=2.8/2.5=1.12$ and $\varphi_{C_4/C_7}=3.5/2.8=1.25$.

Step 3 The final values of the weight coefficients should meet the following two conditions:

a) The final values of the weight coefficients should meet the condition (3), i.e. that $\frac{w_1}{w_2}=1.3$, $\frac{w_2}{w_5}=1.54$, $\frac{w_5}{w_3}=1.25$, $\frac{w_3}{w_6}=1$, $\frac{w_6}{w_4}=1.12$ and $\frac{w_4}{w_7}=1.25$.

b) In addition to the condition (3), the final values of the weight coefficients should meet the condition of mathematical transitivity, i.e. that $\frac{w_1}{w_5}=1.3\times 1.54=2$, $\frac{w_2}{w_3}=1.54\times 1.25=1.82$, $\frac{w_5}{w_6}=1.25\times 1=1.25$, $\frac{w_3}{w_4}=1\times 1.12=1.12$ and $\frac{w_6}{w_7}=1.12\times 1.25=1.34$. By applying expression (5), the final model for determining the weight coefficients can be defined as:

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_1}{w_2}-1.30\right|\le\chi,\ \left|\frac{w_2}{w_5}-1.54\right|\le\chi,\ \left|\frac{w_5}{w_3}-1.25\right|\le\chi,\ \left|\frac{w_3}{w_6}-1.00\right|\le\chi,,\ \left|\frac{w_6}{w_4}-1.12\right|\le\chi,\ \left|\frac{w_4}{w_7}-1.25\right|\le\chi, \\ \left|\frac{w_1}{w_5}-2.00\right|\le\chi,\ \left|\frac{w_2}{w_3}-1.92\right|\le\chi,\ \left|\frac{w_5}{w_6}-1.25\right|\le\chi,\ \left|\frac{w_3}{w_4}-1.12\right|\le\chi,\ \left|\frac{w_6}{w_7}-1.34\right|\le\chi, \\ \sum_{j=1}^{7} w_j=1,\ w_j\ge 0,\forall j \end{cases}$$

By solving this model, the final values of the weight coefficients $\left(0.266,0.207,0.134,0.108,0.108,0.098,0.079\right)^T$ and DFC of the results $\chi=0.018$ are obtained. The value of the criteria according to the marks given at the beginning is shown in Table 4. The model is solved using the Lingo17 software.

Table 4 Criteria weights

Criteria	C1	C2	C3	C4	C5	C6	C7
ϖ_j	0.266	0.207	0.108	0.098	0.134	0.108	0.079

From Table 4 it can be concluded that the most important criterion for the selection of the PVC carpentry manufacturer is the first one, i.e. product quality, followed by product price and guarantee period, while the other criteria have somewhat less significance.

3.2 Evaluation of the manufacturer PVC carpentry using the MABAC method

The initial matrix presented in Table 5 consists of five alternatives that are presented in detail at the end of the previous subsection and seven criteria. Evaluation of the alternative is performed on the linguistic scale shown in Table 2.

Upon request for the production and montage of PVC carpentry, as noted earlier, five manufacturers have been selected and their locations are located at a distance of up to 70 km.

Table 5 Initial matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	7	5776.000	5	5	5	3	5
A_2	7	8252.780	2	3	5	3	1
A_3	7	3490.030	5	5	5	3	7
A_4	3	4355.000	5	3	3	3	1
A_5	5	5795.000	0	3	1	1	1

Normalization is performed as follows:

For criteria C_1, C_3, C_4, C_5, C_6, and C_7 that belong to the benefit criteria, the normalization is carried out using equation (8)

$$t_{11} = \frac{7-3}{7-3} = 1.00$$

For criterion C_2, belonging to the cost criteria the normalization is carried out using equation (9)

$$t_{12} = \frac{5776 - 8252.780}{3490.030 - 8252.780} = 0.52$$

A complete normalized matrix is shown in Table 6.

Table 6 Normalized matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	1	0.52	1	1	1	1	0.667
A_2	1	0	0.4	0	1	1	0
A_3	1	1	1	1	1	1	1
A_4	0	0.818	1	0	0.5	1	0
A_5	0.5	0.516	0	0	0	0	0

After normalization, the normalized matrix is weighted by applying equation (10):

$v_{ij} = w_i \cdot t_{ij} + w_i$ and the weighted normalized matrix is obtained and shown in Table 7.

Table 7 Weighted normalized matrix

V	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	0.532	0.315	0.216	0.196	0.268	0.216	0.132
A_2	0.532	0.207	0.151	0.098	0.268	0.216	0.079
A_3	0.532	0.414	0.216	0.196	0.268	0.216	0.158
A_4	0.266	0.376	0.216	0.098	0.201	0.216	0.079
A_5	0.399	0.314	0.108	0.098	0.134	0.108	0.079

The next step is to obtain a matrix of 1x7 boundary approximative values (Table 8) by applying the geometric mean or equation $GM = \left(\prod_{i=1}^{n} A_{ij}\right)^{1/n}$.

Table 8 Matrix of boundary approximative areas

G	0.437	0.317	0.175	0.129	0.220	0.188	0.101

The next step is to determine the Q matrix shown in Table 9 which represents the difference between the two previous matrices and is obtained by applying equation (14):

$$q_{11} = 0,532 - 0,437 = 0,095$$

Table 9 Matrix of bordering approximative field

Q=V-G	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	0.095	-0.002	0.041	0.067	0.048	0.028	0.031
A_2	0.095	-0.110	-0.024	-0.031	0.048	0.028	-0.022
A_3	0.095	0.097	0.041	0.067	0.048	0.028	0.057
A_4	-0.171	0.060	0.041	-0.031	-0.019	0.028	-0.022
A_5	-0.038	-0.003	-0.067	-0.031	-0.086	-0.080	-0.022

The results obtained using the FUCOM-MABAC model are shown in Table 10, where it can be noted that the alternative of the three is the best solution.

Table 10 Results of the FUCOM-MABAC model

A_1	0.307	**2**
A_2	-0.016	**3**
A_3	0.433	**1**
A_4	-0.115	**4**
A_5	-0.327	**5**

Characteristics of the selected manufacturer are as follows:

- PVC positions are made of the German six-chamber Inoutic PVC profile of Prestige system with three grey seals,
- depth of construction is 76 mm white colored with 1.5 mm reinforcement,
- dimensions of window frame are 76/85 mm and blinds of 84 mm in height,
- window blinds made of PVC system INOUTIC PROTEX with aluminum cover,
- box dimensions of 205x185 mm, except on the balcony door and the

corresponding window of dimensions 205x205 mm,

- all positions are with internal opening and integrated roller mosquitoes nets except Position 5 which is without mosquitoes net,
- Frame Roto NT, and
- glass: IZO Flot 24 mm thick (4+16+argon+4Low-e).

4 Sensitivity analysis

An important feature of the multi-criteria decision-making method is the sensitivity analysis of the applied model, and at the same time, the decision-maker enables testing of different sets of alternative solutions. The sensitivity analysis shows the relations of changing the priority of the alternative as a function of the significance of the attributes, that is, the criteria. In order to check the stability of the applied model, the sensitivity analysis is performed. It represents, beside the MABAC method, application of the following methods: ARAS (Zavadskas and Turskis, 2010) SAW (Maccrimmon, 1968), WASPAS (Zavadskas et al. 2012) and EDAS (Keshavarz Ghorabaee et al. 2015). The results of the applied FUCOM-MABAC model are shown in Table 11.

Table 11 Results of sensitivity analysis

	MABAC		SAW		WASPAS		ARAS		EDAS	
A_1	0.307	2	0.961	2	0.942	2	2.287	2	2.287	2
A_2	-0.016	3	0.748	3	0.699	3	1.519	3	1.519	3
A_3	0.433	1	1.065	1	1.058	1	2.410	1	2.410	1
A_4	-0.115	4	0.686	4	0.648	4	1.479	4	1.479	4
A_5	-0.327	5	0.487	5	0.243	5	1.270	5	1.270	5

On the basis of the results shown in Table 11 it can be concluded that the model is very stable and that the ranks obtained by the FUCOM-MABAC model are in complete correlation with those obtained by means of the other four methods.

5 Conclusions

This paper presents the results of the research which again demonstrates the applicability of multi-criteria decision-making methods in making everyday decisions. Making such decisions can be of significant importance to each individual. Solving the problem of the selection of the PVC carpentry manufacturer has included all the relevant criteria which are of influence upon the final decision. The objective was to obtain the most suitable offer, that is, the one which involves high quality, which means high quality, the lowest possible price, short times for delivery and montage, possibility of deferred payment, a longer warranty period with the manufacturer's reliability but it is not necessary to ignore other relevant facts that may have an impact on the formation of a final decision. Finally, when the final decision is made on the basis of the obtained results, it can be freely stated that the third manufacturer truly represents the most favorable solution since all the essential criteria that are mentioned above are satisfied to a great extent. Regarding the practical aspect, the contribution of this research is to the solving real-life problems by using the FUCOM-MABAC model. From the scientific aspect, the contribution of the applied model can be to the integration of the FUCOM and MABAC methods, which was first used in this paper in the literature. Future research is related to the application of the FUCOM method in combination with other methods and the taking of a larger set of relevant criteria for evaluation of a multi-criteria model.

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