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FUCOM METHOD IN GROUP DECISION-MAKING: SELECTION OF FORKLIFT IN A WAREHOUSE

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Abstract: *A warehouse system as a time transformation of the flows of goods plays an essential role in a complete logistics chain. The efficiency of a complete warehouse system largely depends on the efficiency of carrying out transport and handling operations. Therefore, it is essential to have adequate means of internal transport that will influence the efficiency of the warehouse system by its performance. In this paper, the evaluation and selection of side- loading forklift using the FUCOM-WASPAS model, which has been used for the first time in the literature in this paper, is performed. The FUCOM method was used to obtain the weight values of the criteria, while WASPAS was applied for the evaluation and ranking of forklifts. A possibility to apply the FUCOM method in group decision-making was presented. A comparative analysis, in which other methods of multi-criteria decision-making were applied, was carried out. The analysis showed the stability of the results obtained.*

Key words: *FUCOM method, Forklift, WASPAS method, Warehouse, group decision-making*

1. Introduction

In the day-to-day performance of various activities and processes, logistics as an integral and indispensable part of each business system plays a very important role (Stević et al., 2017a). There is a need to rationalize activities and processes that may significantly affect a company's competitive position (Stević et al., 2017b). A warehouse as a special logistics subsystem and transport represent the major cause of logistics costs and there is a constant search for potential places of savings in these subsystems. In the very beginning, a warehouse was just a place used to separate surplus products, while today its function is

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completely different (Stojčić et al., 2018). Compared to the former static function, today's warehouses represent dynamic systems in which the movement of goods is dominant. Taking into account the above considerations, it is necessary to perform transport and handling operations as rationally as possible. From this aspect, forklifts within internal transport and warehousing operations play an important role.

Internal transport is the basis of every production process, both in functional and organizational terms. Accordingly, rationalizing the movement of the means of transport and selecting the most convenient means of transport would lead to more efficient exploitation and reduction of costs. Forklifts are the most widely used, most useful and most practical means of internal transport. Forklifts are transport work machines for unloading, transport, warehousing and loading of various freight. There are a number of forklifts of different characteristics on the market. The side-loading forklift is intended for handling all types of freight.

In this paper, seven criteria that could be taken into account when selecting a side-loading forklift were chosen. The aim of the paper is to obtain the best solution, i.e. an appropriate side-loading forklift that will meet the requirements of the Euro-Roal company where the research was carried out using multi-criteria decision-making. The choice of a specific side-loading forklift is conditioned by the optimality of the criteria that refer to the purchase price, age, working hours, maximum load capacity, maximum lift height, ecological factor and the supply of spare parts. In the paper, the FUCOM (Full Consistency Method) and WASPAS (Weighted Aggregated Sum Product Assessment) method were used to enable the evaluation and selection of a used side-loading forklift at the Euro-Roal company. Using the FUCOM method, the determination of relative weights was performed, while using the WASPAS method, the ranking was completed.

The remainder of the paper is organized as follows. In the second section of the paper, the methods used in the work, the FUCOM and WASPAS methods, are presented. FUCOM provides a possibility to determine accurately the weight coefficients of all the elements that are mutually compared. WASPAS represents a relatively new method of multi-criteria decision-making (MCDM) that is derived from two methods: Weighted Sum Model (WSM) and Weighted Product Model (WPM). The third section of the paper demonstrates the applicability of FUCOM method in group decision-making. Based on the expert assessment of three decision-makers, the weight values of criteria are obtained. The fourth section is the evaluation and selection of forklifts using the WASPAS method, while in the fifth section, a comparative analysis is carried out using other methods. The paper ends with conclusions and directions for future research.

2. Methods

By applying multi-criteria decision-making methods, it is possible to select adequate strategies, rationalize certain logistics and other processes, and make appropriate decisions that affect the company's business or their subsystems, as evidenced by the following researches: Tzeng and Huang (2012), Prakash and Barua (2016), Żak and Węgliński (2014), Hanaoka and Kunadhamraks (2009), Zavadskas et al. (2018), Stojić et al. (2018), Radović et al. (2018), Sremac et al. (2018).

2.1. FUCOM (Full COnsistency Method)

FUCOM (Pamučar et al., 2018) is a new MCDM method for determination of criteria weights. 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 $\max\left[f_1(x), f_2(x),..., f_n(x)\right]$, $n \geq 2$, with the condition that $x \in A = \left[a_1, a_2, ..., a_m\right]$; where n represents the number of the criteria, m is the number of the alternatives, f_j represents the criteria ($j = 1, 2, ..., n$) and A represents the set of the alternatives a_i ($i = 1, 2, ..., m$). The values f_{ij} of each considered criterion f_j for each considered alternative a_i are known, namely $f_{ij} = f_j(a_i), \quad \forall(i, j); \quad i = 1, 2, ..., m; \quad j = 1, 2, ..., n$. 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 weights of criteria 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 weight coefficients in some methods crucially influence the solution. Therefore, particular attention in this paper is paid to the problem of determining the weights of criteria, and the new FUCOM model for determining the weight coefficients of criteria is proposed. This method enables the precise determination of the values of the weight coefficients of all of the elements mutually compared at a certain level of hierarchy, simultaneously satisfying the conditions of comparison consistency.

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 the values a_{ij} from the ideal ratios w_i / w_j (where w_i and w_j represents 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 problem solving and the reliability of the results decreases. This is especially true when there are a large number of the pairwise comparisons of criteria. FUCOM reduces the possibility of errors in a 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. FUCOM provides the ability to validate the model by calculating the error value for the obtained weight vectors by determining deviation from full consistency (DFC). On the other hand, in other models for determining the weights of criteria (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 FUCOM is presented.

Step 1. In the first step, the criteria from the 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 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 the expression (1)

Step 2. In the second step, a 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 the 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 vectors of the comparative priorities of the evaluation criteria are obtained, as in the expression (2):

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

where $\varphi_{k/(k+1)}$ represents the significance (priority) that the criterion of the $C_{j(k)}$ rank has compared to the criterion of the $C_{j(k)}$ 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, decision-makers define the 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 $w_B = 255$ grams are observed, the comparative priority ($\varphi_{A/B}$) of Stone A in relation to Stone B is $\varphi_{A/B} = 300/255 = 1.18$. Additionally, if the 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 the 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, decision-makers define the comparative priority among the observed criteria $\varphi_{k/(k+1)}$. When solving real problems, decision-makers compare the ranked criteria based on internal knowledge, so they determine the 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 the comparison of criteria, decision-makers compare the criteria and thus determine the significance of each individual criterion in the expression (1). The comparison is made with respect to the first-ranked (the most significant) criterion. Thus, the significance of the 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 $\varpi_{C_{j(1)}} = 1$), a 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 the 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 the 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 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 using integer, decimal values or the 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 the evaluation criteria $(w_1, w_2, ..., w_n)^T$ are calculated. The final values of the weight coefficients should satisfy the two conditions:

(1) that the ratio of the weight coefficients is equal to the comparative priority among the 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 the weight coefficients $(w_1, w_2, ..., w_n)^T$ 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 the 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 model (5), the final values of the evaluation criteria $(w_1, w_2, ..., w_n)^T$ and the degree of DFC (χ) are generated.

2.2. WASPAS method

The weighted aggregated sum product assessment (WASPAS) method (Zavadskas et al., 2012) represents a relatively new MCDM method that is derived from two methods: Weighted Sum Model (WSM) and Weighted Product Model (WPM).

The WASPAS method consists of the following steps:

Step 1. Forming the initial decision-making matrix (X). The first step is to evaluate *m* alternatives according to *n* criteria. The alternatives are shown by vectors $A_i = (x_{i1}, x_{i2}, ..., x_{in})$ where x_{ij} is the value of *i^th^* alternative according to *j^th^* criterion ($i = 1, 2, ..., m;\ j = 1, 2, ..., n$).

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

where *m* denotes the number of the alternative, and *n* denotes the total number of criteria.

Step 2. In this step, normalization of the initial matrix is required by applying the following equations:

$$n_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \quad for \quad C_1, C_2, ..., C_n \in B \tag{7}$$

$$n_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \quad for \quad C_1, C_2, ..., C_n \in C \tag{8}$$

Step 3. Weighting the normalized matrix, so that the previously obtained matrix needs to be multiplied by the weight values of criteria:

$$V_n = \left[v_{ij} \right]_{m \times n} \tag{9}$$

$$V_{ij} = w_j \times n_{ij}, \quad i = 1, 2, ..., m, j \tag{10}$$

Step 4. Summing all the values of the alternatives obtained (summing by rows):

$$Q_i = \left[q_{ij} \right]_{1 \times m} \tag{11}$$

$$q_{ij} = \sum_{j=1}^{n} v_{ij} \tag{12}$$

Step 5: Determining a weighted product model by applying the following equation:

$$P_i = \left[p_{ij} \right]_{1 \times m} \tag{13}$$

$$p_{ij} = \prod_{j=1}^{n} \left(v_{ij} \right)^{w_j} \tag{14}$$

Step 6. Determining the relative values of alternatives A_i:

$$A_i = \left[a_{ij} \right]_{1 \times m} \tag{15}$$

$$A_i = \lambda \times Q_i + \left(1 - \lambda\right) \times P_i \tag{16}$$

The coefficient λ ranges from 0, 0.1, 0.2,....1.0

Step 7. Ranking the alternatives. The highest value of alternatives implies the best-ranked one, while the smallest value refers to the worst alternative.

3. FUCOM method in group decision-making processes

The optimal choice of overhaul mechanization, in this case a forklift, depends solely on the precise determination and selection of appropriate criteria and their evaluation. The weights of the selected criteria were determined on the basis of their importance and needs of Euro-Roal, which were presented by experts and employees responsible for overhaul mechanization. Table 1 gives the name, label and description of the criteria used for the selection of a forklift.

Table 1. Criteria for forklift selection

Name and label of criteria	Criterion description
Purchase price (C_1)	Forklift prices on the market are different and depend on manufacturers. When making an investment decision, the purchase price should not be decisive to the buyer, but it has a significant impact on the final decision. In an unsystematic approach, once the basic conditions are met, the purchase price is often a decisive factor.

Age (C_2)	The age or year of production characterizes the production period of a forklift. Forklifts manufactured recently have better specifications and options for adjustment to the requirements.
Working hours (C_3)	Forklift utilization time is one of the most important criteria when selecting a forklift. The less the hours of the forklift utilization are, the lesser possibility of its breakdown is.
Maximum load capacity (C_4)	Maximum load capacity is a criterion that represents the load capacity that a forklift can lift and it is expressed in kilograms.
Maximum lift height (C_5)	Maximum lift height is a criterion that represents the height that a forklift can reach when lifting.
Ecological factors (C_6)	Impact of forklift operation on the environment.
Supply of spare parts (C_7)	In experience, some representatives working in the market of the Republic of Serbia do not have in stock all necessary spare parts that are subject to frequent replacements, and their delivery is being waited for weeks, so the repairs of the means are long lasting. This criterion is in a group of qualitative criteria and is expressed by a fuzzified Likert scale.

Table 2 shows seven criteria that were evaluated by three decision-makers. The decision-makers evaluated the criteria according to their importance to the company.

Table 2. Comparison of criteria

	DM1	DM2	DM3
C1	5	5	5
C2	4	2	2
C3	1	1	1
C4	2	3	3
C5	3	4	4
C6	7	7	7
C7	6	6	6

Determining the significance of criteria according to Petrović et al. (2017) is one of the most important stages in a decision-making process.

3.1. Determining the weight values of criteria for DM1

Step 1. In the first step, the decision-makers rank the criteria:

$C_3 > C_4 > C_5 > C_2 > C_1 > C_7 > C_6$.

Step 2. In the second step (step 2b), the decision-maker performs a parwise comparison of ranked criteria from step 1. The comparison is made with respect to the first-ranked criterion C_1. The comparison is based on the scale $[1,9]$. Thus, we obtain the significance of the criteria ($\varpi_{C_{j(k)}}$) for all the criteria ranked in step 1 (Table 3).

Table 3. The significance of criteria

Criteria	C3	C4	C5	C2	C1	C7	C6
$\varpi_{C_{j(k)}}$	1	2.2	3,8	4.5	5	6,5	7

Based on the obtained significance of the criteria, the comparative significance of the criteria is calculated:

$\varphi_{C_3/C_4} = 2.20/1.0 = 2.20$; $\varphi_{C_4/C_5} = 3.8/2.20 = 1.73$; $\varphi_{C_5/C_2} = 4.50/3.8 = 1.18$; $\varphi_{C_2/C_1} = 5.00/4.50 = 1.11$; $\varphi_{C_1/C_7} = 6.50/5.00 = 1.30$; $\varphi_{C_7/C_3} = 7.00/6.50 = 1.08$

Step 3. The final values of weight coefficients should meet two conditions: (1) The final values of weight coefficient should meet the condition (3), i.e. that:

$$w_3/w_4 = 2.20;\ w_4/w_5 = 1.73;\ w_5/w_2 = 1.18;\ w_2/w_1 = 1.11;\ w_1/w_7 = 1.30;\ w_7/w_6 = 1.08$$

(2) In addition to the condition (3), the final values of weight coefficients should meet the condition of mathematical transitivity, i.e. that:

$$\frac{w_3}{w_5} = 2.20\times1.73 = 3.81;\ \frac{w_4}{w_2} = 1.73\times1.18 = 2.04;\ \frac{w_5}{w_1} = 1.18\times1.11 = 1.31;$$

$$\frac{w_2}{w_7} = 1.11\times1.30 = 1.44;\ \frac{w_1}{w_6} = 1.30\times1.08 = 1.40$$

Using the expression (5), we can define the final model for determining weight coefficients:

$$\min \chi$$

$$s.t.$$

$$\left|\frac{w_8}{w_4} - 2.20\right| \le \chi, \left|\frac{w_4}{w_5} - 1.73\right| \le \chi, \left|\frac{w_5}{w_2} - 1.18\right| \le \chi, \left|\frac{w_2}{w_1} - 1.11\right| \le \chi, \left|\frac{w_1}{w_7} - 1.30\right| \le \chi, \left|\frac{w_7}{w_6} - 1.08\right| \le \chi,$$

$$\left|\frac{w_8}{w_5} - 3.81\right| \le \chi, \left|\frac{w_4}{w_2} - 2.04\right| \le \chi, \left|\frac{w_5}{w_1} - 1.31\right| \le \chi, \left|\frac{w_2}{w_7} - 1.44\right| \le \chi, \left|\frac{w_1}{w_6} - 1.40\right| \le \chi,$$

$$\sum_{j=1}^{7} w_j = 1,$$

$$w_j \ge 0,\ \forall j$$

By solving this model, we obtain the final values of weight coefficients for: purchase price, age, working hours, maximum load capacity, maximum lift height, ecological factor, supply of spare parts $(0.082, 0.091, 0.410, 0.186, 0.108, 0.059, 0.068)^T$ and the deviation from a complete consistency, a result $x = 0.001$.

After calculating, it can be concluded that the most important criterion is working hours. For this element, the final value of the weight coefficient is 0.410.

3.2. Determining the weight values of criteria for DM2

Step 1. In the first step, the decision-makers ranked the criteria:

$C_3 > C_2 > C_4 = C_5 > C_1 > C_7 > C_6$.

Step 2. In the second step (step 2b), the decision-maker performs a pairwise comparison of ranked criteria from step 1. The comparison is made with respect to the first-ranked criterion C1. The comparison is based on the scale $\left[1,9\right]$. Thus, we obtain the significance of the criteria ($\varpi_{C_{j(k)}}$) for all the criteria ranked in step 1 (Table 4).

Table 4. The significance of criteria

Criteria	C_3	C_2	C_4	C_5	C_1	C_7	C_6
$\varpi_{C_{j(k)}}$	1	2.8	3.5	3.5	4.2	5.5	6.5

Based on the obtained significance of the criteria, the comparative significance of the criteria is calculated:

$\varphi_{c_3/c_2} = 2.80/1.0 = 2.80$; $\varphi_{c_2/c_4} = 3.5/2.80 = 1.25$; $\varphi_{c_4/c_5} = 3.50/3.50 = 1.00$;

$\varphi_{c_5/c_1} = 4.20/3.50 = 1.20$; $\varphi_{c_1/c_7} = 5.50/4.20 = 1.30$; $\varphi_{c_7/c_6} = 6.50/5.50 = 1.18$

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

(1) The final values of weight coefficient should meet the condition (3), i.e. that:

$$w_3/w_2 = 2.80; w_2/w_4 = 1.25; w_4/w_5 = 1.00; w_5/w_1 = 1.20; w_1/w_7 = 1.30;$$

$$w_7/w_6 = 1.18$$

(2) In addition to the condition (3), the final values of weight coefficients should meet the condition of mathematical transitivity, i.e. that:

$$\frac{w_3}{w_4} = 2.80 \times 1.25 = 3.50; \frac{w_2}{w_5} = 1.25 \times 1.00 = 1.25; \frac{w_4}{w_1} = 1.00 \times 1.20 = 1.20;$$

$$\frac{w_5}{w_7} = 1.20 \times 1.30 = 1.56; \frac{w_1}{w_6} = 1.30 \times 1.18 = 1.53$$

Using the expression (5), we can define the final model for determining weight coefficients.

$$\min \chi$$

$$s.t.$$

$$\left|\frac{w_3}{w_2} - 2.80\right| \le \chi, \left|\frac{w_2}{w_4} - 1.25\right| \le \chi, \left|\frac{w_4}{w_5} - 1.00\right| \le \chi, \left|\frac{w_5}{w_1} - 1.20\right| \le \chi, \left|\frac{w_1}{w_7} - 1.30\right| \le \chi, \left|\frac{w_7}{w_6} - 1.18\right| \le \chi,$$

$$\left|\frac{w_3}{w_4} - 3.50\right| \le \chi, \left|\frac{w_2}{w_5} - 1.25\right| \le \chi, \left|\frac{w_4}{w_1} - 1.20\right| \le \chi, \left|\frac{w_5}{w_7} - 1.56\right| \le \chi, \left|\frac{w_1}{w_6} - 1.53\right| \le \chi,$$

$$\sum_{j=1}^{7} w_j = 1,$$

$$w_j \ge 0, \ \forall j$$

By solving this model, we obtain the final values of weight coefficients: purchase price, age, working hours, maximum load capacity, maximum lift height, ecological factor, supply of spare parts $(0.094, 0.140, 0.398, 0.115, 0.116, 0.064, 0.077)^T$ and the deviation from a complete consistency, a result $x = 0.004$.

After calculating, it can be concluded that the most important criterion is working hours. For this element, the final value of the weight coefficient is 0.398.

3.3. Determining the weight values of criteria for DM3

Step 1. In the first step, the decision-makers ranked the criteria:

$C_3 > C_2 > C_4 = C_5 > C_1 > C_7 > C_6$.

Step 2. In the second step (step 2b), the decision-maker performs a pairwise comparison of ranked criteria from step 1. The comparison is made with respect to the first-ranked criterion C1. The comparison is based on the scale $[1,9]$. Thus, we obtain the significance of criteria ($\varpi_{C_{j(k)}}$) for all the criteria ranked in step 1 (Table 5).

Table 5. The significance of criteria

Criteria	C3	C2	C4	C5	C1	C7	C6
$\varpi_{C_{j(k)}}$	1	2.8	3.5	3.5	4.5	6	7

Based on the obtained significance of the criteria, the comparative significance of the criteria is calculated:

$\varphi_{c_3/c_2} = 2.80/1.0 = 2.80$; $\varphi_{c_2/c_4} = 3.5/2.80 = 1.25$; $\varphi_{c_4/c_5} = 3.50/3.50 = 1.00$;

$\varphi_{c_5/c_1} = 4.50/3.50 = 1.29$; $\varphi_{c_1/c_7} = 6.00/4.50 = 1.34$; $\varphi_{c_7/c_6} = 7.00/6.00 = 1.17$

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

1) The final values of weight coefficients should meet the condition (3), i.e. that:

$w_3/w_2 = 2.80; w_2/w_4 = 1.25; w_4/w_5 = 1.00; w_5/w_1 = 1.29; w_1/w_7 = 1.34;$

$w_7/w_6 = 1.17$

(2) In addition to the condition (3), the final values of weight coefficients should meet the condition of mathematical transitivity, i.e. that:

$$\frac{w_3}{w_4} = 2.80 \times 1.25 = 3.50; \frac{w_2}{w_5} = 1.25 \times 1.00 = 1.25; \frac{w_4}{w_1} = 1.00 \times 1.29 = 1.29;$$

$$\frac{w_5}{w_7} = 1.29 \times 1.34 = 1.73; \frac{w_1}{w_6} = 1.73 \times 1.17 = 2.02$$

Using the expression (5), we can define the final model for determining weight coefficients:

$$\min \chi$$

$$s.t.$$

$$\left|\frac{w_3}{w_2} - 2.80\right| \le \chi, \left|\frac{w_2}{w_4} - 1.25\right| \le \chi, \left|\frac{w_4}{w_5} - 1.00\right| \le \chi, \left|\frac{w_5}{w_1} - 1.29\right| \le \chi, \left|\frac{w_1}{w_7} - 1.34\right| \le \chi, \left|\frac{w_7}{w_6} - 1.17\right| \le \chi,$$

$$\left|\frac{w_3}{w_4} - 3.50\right| \le \chi, \left|\frac{w_2}{w_5} - 1.25\right| \le \chi, \left|\frac{w_4}{w_1} - 1.29\right| \le \chi, \left|\frac{w_5}{w_7} - 1.73\right| \le \chi, \left|\frac{w_1}{w_6} - 2.02\right| \le \chi,$$

$$\sum_{j=1}^{7} w_j = 1,$$

$$w_j \ge 0, \ \forall j$$

By solving this model, we obtain the final values of weight coefficients: purchase price, age, working hours, maximum load capacity, maximum lift height, ecological factor, supply of spare parts (0.095, 0.170, 0.418, 0.110, 0.112, 0.050, 0.065)^T and the deviation from a complete consistency, a result $x = 0.001$.

After calculating, it can be concluded that the most important criterion (Table 6) is working hours. For this element, the final value of the weight coefficient is 0.418.

Table 6. The criterion values for each decision-maker and values obtained by applying a geometric mean

DM1	DM2	DM3	The values obtained by applying a geometric mean
0.082	0.094	0.095	0.090
0.091	0.140	0.170	0.129
0.410	0.398	0.418	0.409
0.186	0.115	0.110	0.133
0.108	0.116	0.112	0.112
0.059	0.064	0.050	0.057
0.068	0.077	0.065	0.070

The final values of weight coefficients were obtained by LINGO software. From the table of results, it is clear that in this case working hours (C_3) and maximum load capacity (C_4) are the most important criteria.

4. The selection of forklift in a warehouse using the WASPAS method

The Euro-Roal company owns several forklifts over 20 years of age and, in order to improve and refine their fleet, 10 alternatives (Figure 1) (side-loading forklifts) will be evaluated. One of them, which would be suitable for the Euro-Roal, will be selected.

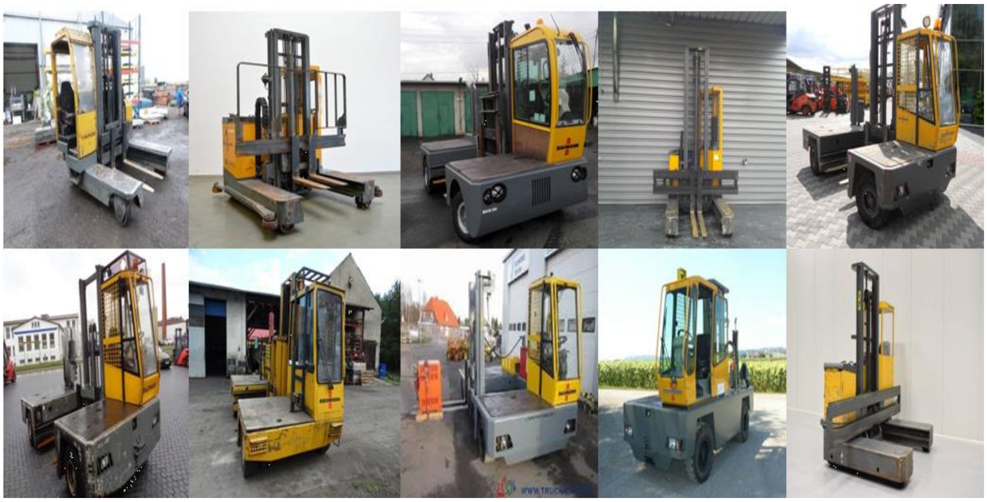

Figure 1. The alternatives in a multi-criteria model

Table 7 shows a formed multi-criteria model consisting of ten alternatives and seven criteria.

Table 7. Initial decision-making matrix

Alternatives	CRITERIA						
	C1	C2	C3	C4	C5	C6	C7
Forklift 1	7.950	10	5012	4000	5400	5	7.67
Forklift 2	12.900	10	7140	3000	3500	7	7.67
Forklift 3	17.800	9	6500	5000	4500	7	5
Forklift 4	19.300	19	4312	3000	6000	3	3.67
Forklift 5	10.870	18	12000	3000	4000	5	3
Forklift 6	30.400	7	4800	4000	4000	7.67	9
Forklift 7	8.093	25	12000	4000	5900	3	5
Forklift 8	29.800	11	3720	3000	5100	9	9
Forklift 9	13.750	17	15350	4500	4800	3	5
Forklift 10	18.297	13	6122	3000	4000	5	7
	min	min	min	max	max	max	max
	7.950	7	3720	5000	6000	5	7

The criteria that prefer minimal values are normalized by applying the following procedure (Table 8):

$$x_{11}=\frac{7950}{7950}=1; x_{21}=\frac{7950}{12900}=0.616; x_{31}=\frac{7950}{17800}=0.446; x_{41}=\frac{7950}{19300}=0.411;$$

$$x_{51}=\frac{7950}{10870}=0.731 \quad . \quad . \quad . \quad x_{10-1}=\frac{7950}{18297}=0.434;$$

The criteria that prefer maximum values are normalized by applying the following procedure (Table 8):

$$x_{14}=\frac{4000}{5000}=0.80; x_{24}=\frac{3000}{5000}=0.60; x_{34}=\frac{5000}{5000}=1.00; x_{44}=\frac{3000}{5000}=0.60;$$

$$x_{54}=\frac{3000}{5000}=0.60; \quad . \quad . \quad . \quad x_{10-4}=\frac{3000}{5000}=0.60;$$

Table 8. Normalized matrix

Alternatives	CRITERIA						
	C1	C2	C3	C4	C5	C6	C7
Forklift 1	1.000	0.700	0.742	0.800	0.900	0.556	0.852
Forklift 2	0.616	0.700	0.521	0.600	0.583	0.778	0.852
Forklift 3	0.447	0.778	0.572	1.000	0.750	0.778	0.556
Forklift 4	0.412	0.368	0.863	0.600	1.000	0.333	0.408
Forklift 5	0.731	0.389	0.310	0.600	0.667	0.556	0.333
Forklift 6	0.262	1.000	0.775	0.800	0.667	0.852	1.000
Forklift 7	0.982	0.280	0.310	0.800	0.983	0.333	0.556
Forklift 8	0.267	0.636	1.000	0.600	0.850	1.000	1.000
Forklift 9	0.578	0.412	0.242	0.900	0.800	0.333	0.556
Forklift 10	0.434	0.538	0.608	0.600	0.667	0.556	0.778
W	0.090	0.129	0.409	0.133	0.112	0.057	0.070

Weighting the normalized matrix, so that the previously obtained matrix needs to be multiplied by the weight values of criteria:

$$x_{11}=0.090\times1.000=0.090; x_{21}=0.090\times0.616=0.055 \quad . \quad . \quad . \quad x_{10-1}=0.090\times0.434=0.039$$

In Table 9, after obtaining the values v_{ij}, the matrix is weighted, so that obtained values are multiplied by the values of weight coefficients.

Table 9. Weighted normalized matrix

Alternatives	CRITERIA						
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
Forklift 1	0.090	0.090	0.304	0.106	0.101	0.032	0.060
Forklift 2	0.055	0.090	0.213	0.080	0.065	0.044	0.060
Forklift 3	0.040	0.100	0.234	0.133	0.084	0.044	0.039
Forklift 4	0.037	0.048	0.353	0.080	0.112	0.019	0.029
Forklift 5	0.066	0.050	0.127	0.080	0.075	0.032	0.023
Forklift 6	0.024	0.129	0.317	0.106	0.075	0.049	0.070
Forklift 7	0.088	0.036	0.127	0.106	0.110	0.019	0.039
Forklift 8	0.024	0.082	0.409	0.080	0.095	0.057	0.070
Forklift 9	0.052	0.053	0.099	0.120	0.090	0.019	0.039
Forklift 10	0.039	0.069	0.249	0.080	0.075	0.032	0.054

$$Q_1 = 0.090 + 0.090 + 0.304 + 0.106 + 0.101 + 0.032 + 0.060 = 0.783$$

Determining a weighted product model using the following equation:

$$p_1 = (1.000)^{0.090} \times (0.700)^{0.129} \times (0.742)^{0.409} \times (0.800)^{0.133} \times (0.900)^{0.112} \times (0.556)^{0.557} \times (0.852)^{0.070} = 0.776$$

Determining the relative values of alternatives A_i:

$$A_1 = 0.5 \times 0.783 + (1 - 0.5) \times 0.782 = 0.779$$

Ranking the alternatives. The highest value of alternatives shows the best-ranked one, while the smallest value refers to the worst alternative. Table 10 presents the results of ranking of forklifts based on the previous calculation.

Table 10. Results and ranking the forklifts

	P	A	Rank
Forklift 1	0.776	0.779	2
Forklift 2	0.600	0.604	6
Forklift 3	0.656	0.666	4
Forklift 4	0.630	0.653	5
Forklift 5	0.426	0.439	10
Forklift 6	0.734	0.752	3
Forklift 7	0.458	0.492	8
Forklift 8	0.768	0.793	1
Forklift 9	0.412	0.442	9
Forklift 10	0.593	0.595	7

Determining the relative weights of criteria was performed by the FUCOM method, while the ranking was performed using the WASPAS method. Based on the results of the applied model, a solution that meets the current needs of the Euro-Roal company has been found, which is Alternative 8, i.e. the BAUMANN EHX 30/14/51 forklift

5. Sensitivity analysis and discussion

A logical sequence in most processes of multi-criteria decision-making is sensitivity analysis. For the sensitivity analysis of this model, the results of the SAW method (MacCrimmon, 1968), the WASPAS method and the ARAS method (Zavadskas & Turskis, 2010) were compared.

Table 11 and Figure 2 show the results and ranking the forklifts according to SAW, WASPAS and ARAS methods.

Table 11. The results of sensitivity analysis according to SAW, WASPAS and ARAS methods

	SAW		**WASPAS**		**ARAS**	
A1	0.782	2	0.779	2	0.779	2
A2	0.608	6	0.604	6	0.607	6
A3	0.675	5	0.666	4	0.666	5
A4	0.677	4	0.653	5	0.671	4
A5	0.452	10	0.439	10	0.445	10
A6	0.769	3	0.752	3	0.768	3
A7	0.526	8	0.492	8	0.508	8
A8	0.817	1	0.793	1	0.817	1
A9	0.471	9	0.442	9	0.453	9
A10	0.598	7	0.595	7	0.594	7

Alternative 1 according to SAW, WASPAS and ARAS has the same rank (2). Alternative 2 according to SAW, WASPAS and ARAS has the same rank (6). Alternative 3 according to the SAW and ARAS methods is ranked fifth, whereas according to the WASPAS method, it is positioned fourth. Alternative 4 according to the SAW and ARAS methods is ranked fourth, whereas according to the WASPAS method, the fifth position is taken. Alternative 5 according to SAW, WASPAS and ARAS has the same rank (10). Alternative 6 according to SAW, WASPAS and ARAS has the same rank (3). Alternative 7 according to SAW, WASPAS and ARAS has the same rank (8). Alternative 8 is the best solution according to all methods. Alternative 9 according to SAW, WASPAS and ARAS has the same rank (9). Alternative 10 according to SAW, WASPAS and ARAS has the same rank (7).

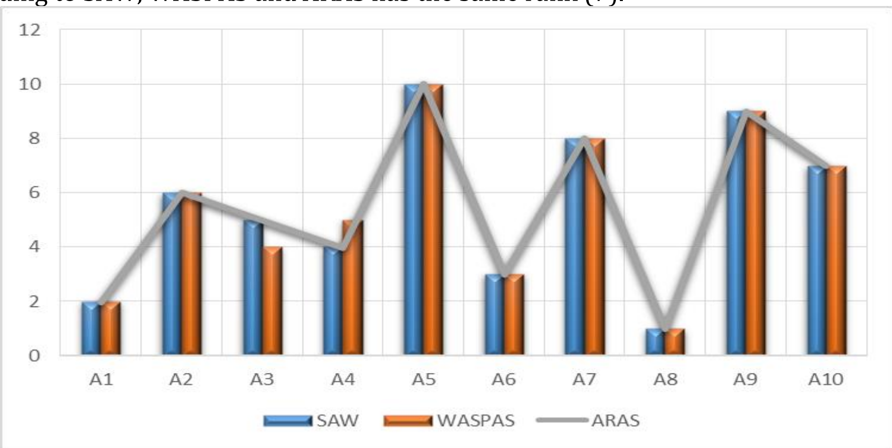

Figure 2. Sensitivity analysis

6. Conclusion

In this paper, a selection of transport and handling means was carried out in a warehouse system applying a combined FUCOM-WASPAS model. FUCOM was implemented throughout a group decision-making process where an expert team was formed to evaluate the significance of the criteria. Obtaining the final weight values of the criteria was achieved using a geometric mean. The research has been conducted in a company whose primary task is to trade and distribute aluminum profiles. The applied model allows for an objective consideration of input parameters that have an impact on making a final decision. Comparative analysis, which implies the application of two additional MCDM methods, presents the stability of originally obtained results if the model is generally observed throughout all possible variants. If individual positions are taken into account then the model shows the sensitivity to certain changes. Future research regarding this paper relates to the formation of a model for determining the efficiency of using the selected side-loading forklift.

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