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ORIGINAL SCIENTIFIC PAPER

Selection of an Electric Forklift for the Operational Planning Needs of the Warehouse System of GTC Doboj

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Abstract: The selection of handling equipment represents an important aspect of operational planning in logistics centers and affects the potential increase in work efficiency. Therefore, it is necessary to consider various factors when making decisions regarding the selection of handling equipment. This paper presents the selection of an electric forklift for the needs of loading and handling activities in a closed warehouse of the GTC (Goods Transport Center) Doboj. An MCDM model, consisting of FUCOM (Full Consistency Method) and MARCOS (Measurement of Alternatives and Ranking According to the COmpromise solution) was applied to evaluate electric forklifts. The FUCOM method was used to determine the values of criteria, and the MARCOS method was used to evaluate electric forklifts. After obtaining the results, sensitivity analysis and comparative analysis were performed.

Keywords: electric forklift, warehouse, GTC, FUCOM, MARCOS, MCDM

INTRODUCTION

The region of Doboj has an exceptionally favorable position in relation to main railway and road transportation routes. The city of Doboj is intersected by several main and regional railway and road routes with significant goods flows, making it predisposed to the formation and development of a goods transport center with comprehensive transportation and logistics services. Accordingly, it can be said that the need for its establishment has been evident for more than three decades, but circumstances have not allowed this project to come to life. Considering that the new European transport policy calls for a transition from road to rail transport, the development of a network of goods transport centers in Bosnia and Herzegovina has been a challenging issue for decades. In line with this, there are projects for the construction of the Goods Transport Center (GTC) Doboj, which relies partly on existing infrastructure. The GTC Doboj is located right next to the Doboj railway station and, with all its sub-systems, represents a compact entity. As part of the GTC Doboj, a closed warehouse with a length of 82 meters and a width of 46 meters, i.e. with a total area of 3772 m², is planned.

In order to adequately manage operational activities in the closed warehouse of GTC Doboj, it is necessary to determine potential flows of various goods gravitating around the center, the timing of certain operations, and suitable loading and handling equipment. This paper considers the introduction of an electric forklift for the purpose of performing the aforementioned activities in a closed warehouse. The aim is to select an appropriate electric forklift based on group decision-making involving the participation of a large number of decision-makers and the application of FUCOM and MARCOS methods and the Bonferroni operator.

After the introductory section, the paper is structured through the following sections. Section 2 presents the steps of the MCDM method, both for determining the weights of criteria and for evaluating forklifts. Section 3 outlines the formation of the MCDM model, along with displays of the obtained results, while Section 4 includes sensitivity analysis and the application of other MCDM methods through comparative analysis. Finally, Section 5 summarizes the results, presenting limitations and future research directions.

METHODS

FUCOM method

The FUCOM [1,2] method was developed by Pamučar et al. [3] for determining the weights of criteria:

Step 1. The first step is to rank the criteria from a predefined set of evaluation criteria $C = \{C_1, C_2, ..., C_n\}$.

$$C_{j_{(1)}} > C_{j_{(2)}} > \cdots > C_{j_{(k)}} \tag{1}$$

where k represents the rank of the observed criterion.

Step 2. In the second step, a mutual comparison of ranked criteria is made and comparative significance ($\varphi_{k/(k+1)}$), $= 1,2,\ldots,n$ is determined, where k represents the ranking of the evaluation criteria.

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

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

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

(2) In addition, the final values of the weighting 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 $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, we obtain that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$. Thus, we gain a second condition that should be satisfied by the final values of the weighting coefficients of the evaluation criteria:

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

Based on the established settings, we can define a final model for determining the final values of the weighting coefficients of the evaluation criteria

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

1.2. MARCOS method

In this section of the paper, the algorithm of the MARCOS method is presented [4,5]:

Step 1: Forming an initial decision matrix.

Step 2: Forming an extended initial matrix. In this step, the initial matrix is extended by defining an ideal (AI) and anti-ideal (AAI) solution.

$$X = \begin{matrix} \\ AAI \\ A_1 \\ A_2 \\ \cdots \\ A_m \\ AI \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{bmatrix} x_{aa1} & x_{aa2} & \cdots & x_{aan} \\ x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \\ x_{ai1} & x_{ai2} & \cdots & x_{ain} \end{bmatrix} \end{matrix} \tag{6}$$

The anti-ideal solution (AAI) represents the worst alternative while the ideal solution (AI) represents an alternative with the best characteristics. Depending on the nature of the criteria, AAI and AI are defined:

$$AAI = \min x_{ij}\ \ if\ j \in B\ and\ \ max\ x_{ij}\ \ if\ j \in C \tag{7}$$

$$AI = \max x_{ij}\ \ if\ j \in B\ and\ \ min\ x_{ij}\ \ if\ j \in C \tag{8}$$

where B represents a benefit group of criteria, while C represents a non-benefit group of criteria.

Step 3: Normalization of the extended initial matrix (X). The elements of the normalized matrix $N = [n_{ij}]_{m \times n}$ are obtained:

$$n_{ij} = \frac{x_{ai}}{x_{ij}}\ \ if\ j \in C \tag{9}$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}}\ \ if\ j \in B \tag{10}$$

where the elements x_{ij} and x_{ai} represent the elements of the matrix X.

Step 4: Determining the weighted matrix $V = \left[v_{ij}\right]_{mxn}$. The weighted matrix V is obtained by multiplying the normalized matrix N by the weighting coefficients of the criterion w_j.

$$v_{ij} = n_{ij} \times w_j \tag{11}$$

Step 5: Calculation of the utility degree of the alternative K_i. By applying Equations (12) and (13), the utility degrees of the alternative in relation to an anti-ideal and ideal solution are calculated.

$$K_i^- = \frac{S_i}{S_{aai}} \tag{12}$$

$$K_i^+ = \frac{S_i}{S_{ai}} \tag{13}$$

where S_i (i=1,2,..,m) represents the sum of the elements of the weighted matrix V.

$$S_i = \sum_{i=1}^{n} v_{ij} \tag{14}$$

Step 6: Determining the utility function of alternatives $f(Ki)$. The utility function represents a compromise of the observed alternative in relation to an ideal and anti-ideal solution.

$$f(K_i) = \frac{K_i^+ + K_i^-}{\frac{1-f\left(K_i^+\right)}{f\left(K_i^+\right)} + \frac{1-f\left(K_i^-\right)}{f\left(K_i^-\right)}} \tag{15}$$

where $f(K_i^-)$ represents the utility function in relation to an anti-ideal solution, while $f(K_i^+)$ represents the utility function in relation to an ideal solution.

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \tag{16}$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \tag{17}$$

Step 7: Ranking the alternatives.

1.3. Bonferroni aggregator

For averaging weights in group decision-making process, the Bonferroni aggregator was used [6,7].

$$a_j = \left(\frac{1}{e(e-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{e} a_i^p \otimes a_j^q \right)^{\frac{1}{p+q}} \tag{18}$$

In this research, e represents the number of decision-makers for determining criteria weights, while $p, q \geq 0$ are a set of non-negative numbers.

EVALUATION AND SELECTION OF AN ELECTRIC FORKLIFT

Problem description and formation of an MCDM model

From a logistical standpoint, a warehouse is a place in a logistics network where goods are received, stored and forwarded to another direction within the network. It is a closed or semi-open space for storing and handling certain types of goods. The envisaged space for storing palletized units in the GTC Doboj is 78 meters long and 44 meters wide, with a total area of 3432 m². The space for storing bulk goods is 30 meters long and 20 meters wide, with a total surface area of 600 m². Transport corridors are 3 meters wide, while the railway track is 2.6 meters wide. The canopy facility, which serves for loading road transport vehicles and can also be used for temporary storage of palletized goods, is 46 meters long and 8 meters wide, with a total surface area of 368 m².

The loading area for pallet picking is 5 meters wide and is integrated with the storage facility allowing the merging of goods receiving and dispatch functions. Palletized goods transported by railway wagons and road vehicles will be stored in a selective racking warehouse in height, in four rows, with a pallet height of 1.3 meters, and a vertical aisle space of 1.5 meters between rows. The racks are made of metal construction which are attached to concrete load-bearing structures under the roof at the top parts. The layout of the selective racking warehouse provides direct access for forklifts to any pallet at any time. The average weight of a pallet is 1.2 [t], as they are Euro pallets with dimensions of 800 x 1200 mm. The height of the closed warehouse is 10 meters, so if necessary, palletized units can be expanded vertically, with a change in equipment.

For the formation of the MCDM model, nine criteria and five alternatives have been considered, which are explained in more detail below.

Criterion 1 – **Forklift Price expressed in BAM** represents a very important criterion that significantly influences the decision when selecting a forklift. Price is closely related to quality.

Criterion 2 – **Forklift Lifting Height expressed in mm** plays an important role in the operational characteristics of forklifts, determining the height of load stacking. It affects the work technology and warehouse capacity.

Criterion 3 - **Battery Capacity expressed in KWh** refers to the energy stored in the battery and is expressed in Ah (ampere-hours) or in Wh (watt-hours). The motor operating time represents the quotient of battery capacity in Wh (i.e. in kWh) and the motor power.

Criterion 4 – **Electric Motor Power expressed in KW** is based on the maximum power for continuous loading of forklifts. Electric forklifts are powered by a direct current motor that uses batteries of a certain capacity ranging from 10 to 75 KWh. Depending on the load, the motor draws the necessary current from the batteries.

Criterion 5 - **The Operating Time of the Forklift under Load** refers to the capacity of the current in the battery and the amount of current the battery possesses until discharge. The battery will discharge over time depending on operating mode of the forklift.

Criterion 6 - **Battery Charging Time** depends on the type of charger and the type of battery. For instance, lithium-ion batteries used in new electric forklifts can be rapidly charged and do not require cooling periods like lead-acid batteries.

Criterion 7 - **Forklift Load Capacity (*t*)** determines the modes of loading and at what heights individual forklifts can operate without the risk of overturning the load.

Criterion 8 - **The Lifting Speed of a Loaded Forklift (V**do) affects the time taken to lift the load:

$$\frac{H_0}{v_{do}} + t_g \tag{19}$$

Criterion 9 – **Forklift Service and Maintenance** is a continuous process. The need for forklift maintenance arises from its susceptibility to failure during operation. The aim of maintenance is to execute work according to plan, minimize forklift downtime, and apply modern technologies and equipment to maintenance tasks in order to ensure quality.

Alternative solutions are as follows: A1 - Toyota 8FBMT18, A2 - Linde H25D-04, A3 - Hyundai 22B-9, A4 - Still RX RX20-16, A5 - Jungheinrich EFG 320.

Table 1 illustrates the structure of the MCDM model with all characteristics.

Determining the values of criteria using the FUCOM method

In the group decision-making, nine decision-makers participated in the mutual evaluation of criteria. Initially, as the first step, they ranked the criteria according to importance, and the ratings are shown in Table 2.

DM1: C1>C2>C5>C7>C6>C3>C4>C8>C9
DM2: C1>C2>C7>C5>C6>C3>C4>C8>C9
DM3: C1>C5>C2>C3>C6>C4>C7>C9>C8
DM4: C1>C6>C2>C7>C5>C3>C4>C9>C8
DM5: C1>C7>C2>C6>C5>C3>C4>C9>C8
DM6: C1>C2>C5>C7>C3>C6>C4>C8>C9
DM7: C1>C5>C3>C6>C2>C7>C9>C4>C8
DM8: C1>C2>C3>C5>C6>C9>C7>C4>C8
DM9: C1>C5>C2>C4>C3>C6>C9>C8>C7

Table 2. Evaluation of criteria in group decision-making

DM1	1.11	1.67	2.00	1.16	1.43	1.19	2.78	3.85
DM2	1.14	1.56	1.85	1.22	1.32	1.16	2.63	3.57
DM3	1.20	1.23	1.50	1.02	1.26	1.60	2.00	1.92
DM4	1.09	1.38	2.14	1.34	1.02	1.21	2.94	2.61
DM5	1.22	1.32	1.39	1.28	1.25	1.09	1.67	1.61
DM6	1.07	1.23	1.69	1.11	1.32	1.20	1.75	2.23
DM7	1.19	1.09	1.47	1.02	1.11	1.25	1.61	1.39
DM8	1.04	1.06	1.43	1.09	1.16	1.32	1.52	1.28
DM9	1.09	1.14	1.12	1.07	1.17	1.45	1.26	1.20

After applying all the steps of the FUCOM method for each DM, the results presented in nine models were obtained (Table 3).

Table 3. Results of applying the FUCOM method and criterion weights for each DM

	C1	C2	C3	C4	C5	C6	C7	C8	C9
DM1	0.166	0.150	0.099	0.083	0.143	0.116	0.140	0.060	0.043
DM2	0.162	0.142	0.104	0.088	0.133	0.123	0.140	0.062	0.045
DM3	0.149	0.124	0.121	0.099	0.146	0.118	0.093	0.074	0.077
DM4	0.157	0.144	0.113	0.073	0.117	0.154	0.129	0.053	0.060
DM5	0.143	0.117	0.108	0.103	0.111	0.114	0.131	0.085	0.089
DM6	0.146	0.136	0.119	0.086	0.131	0.111	0.122	0.083	0.065
DM7	0.134	0.113	0.123	0.091	0.131	0.121	0.107	0.083	0.096
DM8	0.132	0.127	0.124	0.092	0.121	0.114	0.100	0.087	0.103
DM9	0.128	0.118	0.113	0.115	0.120	0.110	0.088	0.102	0.107

To obtain the final weights that are further implemented in the model, the Bonferroni operator for averaging was applied, resulting in the final weights of the criteria as follows: w1=0.145, w2=0.129, w3=0.114, w4=0.092, w5=0.128, w6=0.119, w7=0.115, w8=0.077, w9=0.076.

Table 1. Data required for the formation of an electric forklift evaluation and selection model

	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	69,900	6500	34.56	10	8h 18 m	3h 19m	1.8	0.60	**Sarajevo, B&H**
A2	89,500	4700	36.8	13	6h 30m	2h 35m	2.5	0.58	**Banja Luka, B&H**
A3	88,600	4300	31.68	12	6h 34m	2h 37m	2.2	0.54	**Laktaši, B&H**
A4	71,000	3742	30	11	6h 16m	2h 30m	1.6	0.53	**Sarajevo, B&H**
A5	76,500	4500	28.8	8	7h 32m	3h 01m	2	0.46	**Novi Banovci, Serbia**

Selection of an electric forklift using the MARCOS method

The initial decision matrix is shown in Table 4, and is obtained based on specifications for each alternative and the evaluation of qualitative criteria such as the ninth criterion.

Table 4. Initial decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Antiideal	89500	3742	28.80	8.00	6.27	3.32	1.60	0.46	2.00
A1	69900	6500	34.56	10	8.3	3.32	1.8	0.6	7
A2	89500	4700	36.8	13	6.5	2.58	2.5	0.58	5
A3	88600	4300	31.68	12	6.57	2.62	2.2	0.54	9
A4	71000	3742	30	11	6.27	2.5	1.6	0.53	3
A5	76500	4500	28.8	8	7.53	3.02	2	0.46	2
Ideal	69900	6500	36.80	13.00	8.30	2.50	2.50	0.60	9.00

Applying the MARCOS method, the alternative solutions (Table 5) are ranked according to the following results.

Table 5. Results of integrated FUCOM-MARCOS model

Alternatives	Si	Ki-	Ki+	fK-	fK+	fKi	Rank
AAI	0.669	1.000					
A1	0.888	1.328	0.893	0.402	0.598	0.703	1
A2	0.860	1.285	0.864	0.402	0.598	0.680	2
A3	0.844	1.262	0.848	0.402	0.598	0.668	3
A4	0.770	1.151	0.774	0.402	0.598	0.610	4
A5	0.750	1.121	0.754	0.402	0.598	0.593	5
AI	0.995		1.000				

After conducting the FUCOM-MARCOS model procedure, the ranking of potential solutions is as follows: A1>A2>A3>A4>A5.

SENSITIVITY ANALYSIS AND COMPARATIVE ANALYSIS

The most common verification systems for initially obtained results in such models are sensitivity analysis and comparative analysis [8-10]. Primarily, the impact of changing the values of nine criteria was determined. A total of 90 new scenarios, altering the values of each criterion, have been formed (Figure 1).

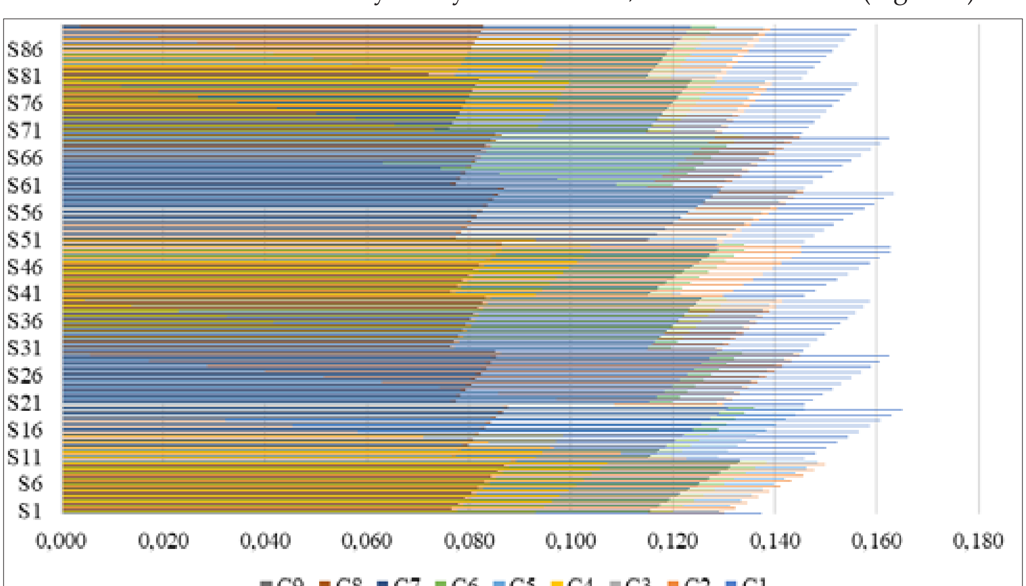

Figure 1. Simulated values of criterion weights in sensitivity analysis

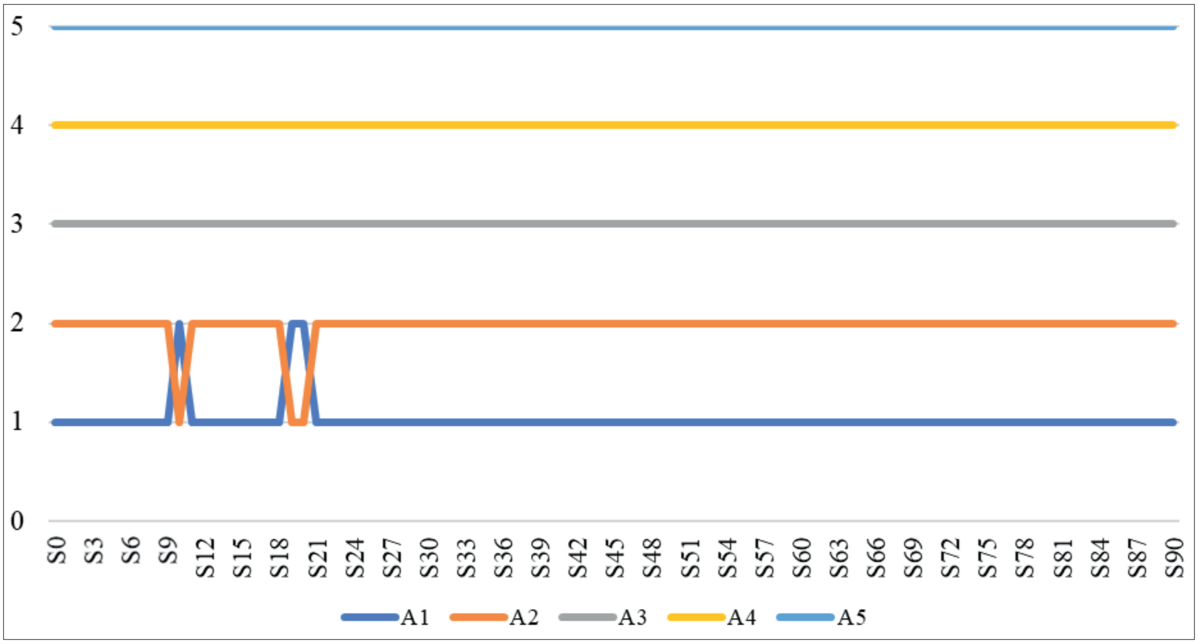

Figure 2. Results of sensitivity analysis

The criterion values are simulated in a way that the values of the criteria are reduced to a negligible value in certain scenarios, while other criteria become more significant. After defining 90 scenarios, an analysis that included 90 new models was conducted, which is given in Figure 2.

The sensitivity analysis results indicate that the first two criteria have a significant impact on the ranking of solution alternatives, because when the values of C1 and C2 are reduced in scenarios (in S10 for the first criterion and S19, S20 for the second criterion), two best alternatives change. This occurs only when the value of the first or second criterion is reduced to a negligible value, i.e. when it tends to zero.

Figure 3 shows the results of the comparative analysis. Six other MCDM methods were applied: SAW [11], WASPAS [12], AROMAN [13], EDAS [14], MABAC [15] and CRADIS [16].

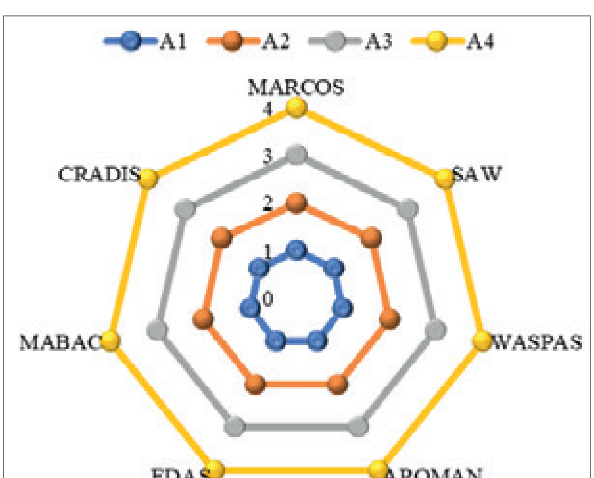

Figure 3. Results of comparative analysis

The results of the comparative analysis show the stability of the initial results as there are no changes in the rankings of alternatives.

CONCLUSION

Operational planning of technological processes at the GTC Doboj should create a sketch of the near future that should anticipate all possible handling activities in a closed warehouse which impacts warehouse operations. The aim is to make a projection of future activities with forklifts and select a forklift that will properly respond to the technological handling processes. The methodology for determining the required forklift at the Goods Transport Center Doboj requires an approach based on the technical characteristics of forklifts, the technical characteristics of the closed warehouse, the work technology in the closed warehouse and contemporary decision-making methods. Through the applied MCDM model, which consists of FUCOM and MARCOS methods, the selection of an electric forklift based on the preferences of nine decision-makers regarding the significance of evaluation parameters, i.e. criteria, was proposed. Future research should include an analysis of the operation of the selected forklift with a focus on its efficiency.

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