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MULTI-CRITERIA APPROACH FOR SELECTING THE SUPPLIER FOR SUPPLYING HEAVY LIFTING EQUIPMENT BY USING INTEGRATED FUCOM AND MARCOS METHOD

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Abstract: The paper presents the way of selecting the most appropriate suppliers. The process of the optimum selection of the supplier has a long-term nature. The selection process plays an important role in reducing the cost and time to market and also improves the quality of the products. The paper considers the choice of supplier due to the most significant criteria for producer. It includes several stages for ensuring the effectiveness final cooperation, with using different tools improvement of outcomes. The application of different evaluation approaches in logistics requires considering many factors with different significance for making the final decision. Multi-criteria decision-making (MCDM) methods are often applied in logistics to create different strategies and evaluations. The Full Consistency Method (FUCOM) was applied to determine the significance of the criteria, while the evaluation of potential suppliers was performed using Measurement Alternatives and Ranking according to Compromise Solution (MARCOS)

***Key Words* – FUCOM, MARCOS, MCDM, multi-criteria decision making, supplier selection process, selection criteria of supplier.**

I. INTRODUCTION

During the last decade, many organizations in the industrial area have faced a sharp competition due to the fact of globalization which has pushed them to choose the outsourcing strategy as a right solution to produce products at minimal cost. This strategy has participated in controlling the costs of sourced raw materials and products that are very often qualified to cover organization requirements and increase at the same time their competitiveness in the market (Steven et al., 2014). Currently, many organizations heavily rely on outsourcing trends and have become more dependent on suppliers to achieve their business tasks. Consequently, outsourcing in developing countries may have entailed some certain side-effects, e.g., the procedure of treatment with the suppliers has become more complex and the supply chain foundations turned into fragments, which would undoubtedly impact on the products quality and the organization’s performance (Steven et al., 2014). In fact, the supply chain and suppliers’ performance have become more serious for the organizations’ goals achievement (Handfield et al., 2002).

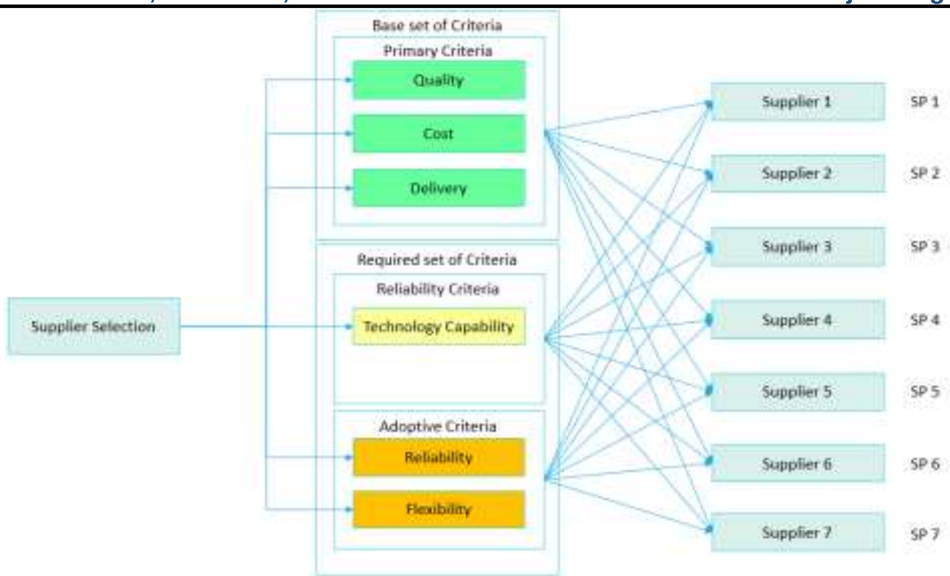

Fig. 1 – Supplier selection criteria

Selecting the most appropriate supplier not only relies on investigating some price list but, also it also relies on a broader range of criteria such as quality, delivery, technological capability, technical support. Reducing the suppliers' number in selection pool and narrow the supplier field. To empirically explore the relationship between supplier selection and business process improvement and aims to fill the gaps. Finding the qualified suppliers to award the business. Objective is to develop a method using Full Consistency Method (FUCOM) and Measurement Alternatives and Ranking according to Compromise Solution (MARCOS) methods for the ranking of alternatives on the basis of multi criteria. The objective of this paper is to change the traditional supplier selection methods by shifting the emphasis from using a single model to using multiple models in the unstructured decision-making context and to provide a tool for decision makers to make informed decisions of supplier selection in the multiple perspectives

II. History

During the last two decades, multi-criteria decision-making MCDM methods have become one of the most valuable approaches applied in the different research areas (Jato-Espino et al., 2014). During this period, numerous models have been developed and reformulated in order to overcome the complexity discovered through the process of the supplier selection but, the majority of researchers have mostly focused on decision-making methods, with complex mathematical models, to resolve the supplier selection problem. In literature, however, various studies have tackled and proposed different techniques in a variety of ways for overcoming the issue of complexity in supplier selections. Successfully performing the supplier selection strategy in the supply chain, researchers have to take into consideration a wide range of criteria. In other words, the selection of accurate criteria represents a basic step in the decision-making procedure for assessing and prioritizing suppliers (Buyukozkan & Cifci 2011). Weber et al. (1991) stated that the price is an essential indicator in decision making for evaluating and selecting the right supplier. Ho et al. (2010) declared that the basic set of criteria for selecting the resilient supplier entails price, quality, and delivery. While Chang et al. (2011) conducted research that encompasses ten essential criteria which paid, later on, attention by numerous researchers from different fields of study. This set of criteria is as follows: 'quality, delivery reliability, lead time, cost, capacity, flexibility, technology capability, environmental control, service level, and reduction on demand'. Sen et al., 2009 has described the supplier selection by using three determinants i.e., Quality, Socio-economic, and technology.

The FUCOM method is widely used as proved by numerous scientific papers where the method has been used. The FUCOM method assists managers in prioritizing criteria using simple algorithms, as well as in assessing phenomena according to current requirements of decision-makers. Sofuoglu notes that the FUCOM method in combination with other methods provided successful results when making decisions in a manufacturing company engaged in the manufacture and processing of newly developed high strength parts. Durmic uses the FUCOM method to evaluate the criteria when selecting suppliers. Prentkovskis et al., use the FUCOM method to determine the weight coefficients of quality dimensions when measuring service quality. The FUCOM method is used in various decision-making fields and when evaluating certain alternatives

MARCOS represents a new multi-criteria technique developed by Stević et al. The advantages of the MARCOS methodology were confirmed through a case study in which the evaluation of sustainable supplier selection in healthcare industries was performed. After the initial study, in just a few months, several studies have appeared in the exploit the advantages of the MARCOS methodology.

III. Research Methodology

a. Full Consistency Method (FUCOM)

The Full Consistency Method (FUCOM) method is based on the principles of pairwise comparison and validation of results through deviation from maximum consistency (Pamucˇar et al., 2018) Benefits that are determinative for the application of Full Consistency Method (FUCOM) are a small number of pairwise comparisons of criteria (only $n - 1$ comparison), the ability to validate the results by defining the deviation from maximum consistency (DMC) of comparison and appreciating transitivity in pairwise comparisons of criteria. The Full Consistency Method (FUCOM) model also has a subjective influence of a decision-maker on the final values of the weights of criteria. This particularly refers to the first and second steps of Full Consistency Method (FUCOM) in which decision-makers rank the criteria according to their personal preferences and perform pairwise comparisons of ranked criteria.

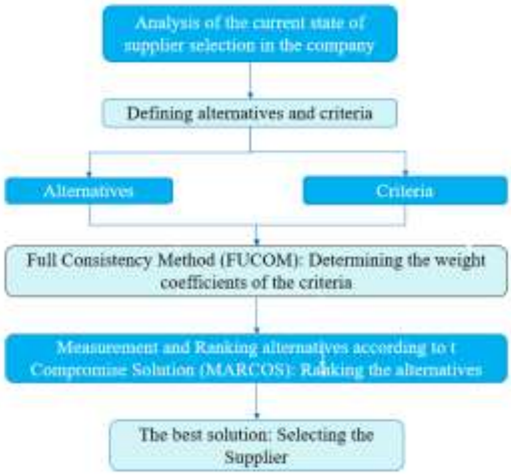

Fig. 2 – Methodology for deciding on selecting a Supplier

However, unlike other subjective models, Full Consistency Method (FUCOM) has shown minor deviations in the obtained values of the weights of criteria from optimal values. Additionally, the methodological procedure of Full Consistency Method (FUCOM) eliminates the problem of redundancy of pairwise comparisons of criteria, which exists in some subjective models for determining the weights of criteria.

The procedure for obtaining the weight coefficients of criteria by using Full Consistency Method (FUCOM) is

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

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

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

Step 3:

In the third step, the final values of the weight coefficients of the evaluation criteria

$(w_1, w_2, ..., w_n)$ are calculated. The final values of the weight coefficients should satisfy the two conditions 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 conditionis met $W_k / W_{k+1} = \varphi_{(k/k+1)}$

In addition to the condition (3), the final values of the weight coefficientsshould satisfy the condition of mathematical transitivity i.e. that

$\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$.

Based on the defined settings, the final model for determining the final values ofthe weight coefficients of the evaluation criteria can be defined

min χ

subject to

$|(W_k / W_{k+1}) - \varphi_{(\kappa/\kappa+1)}| \leq \chi, \ \forall j$

$|(W_k / W_{k+1}) - \varphi_{(\kappa/\kappa+1)}) \otimes \varphi_{(\kappa+1/\kappa+2)}| \leq, \ \forall j$

$\sum w_j = 1, \ \forall j$

$w_j \geq 0, \ \forall j$y solving model (5), the final values of the evaluation criteria $(w_1, w_2, ..., w_n)^T$ and degree of DFC (χ) are generated

b. Measurement Alternatives and Ranking According to Compromise Solution (MARCOS) method

The Measurement Alternatives and Ranking According to Compromise Solution (MARCOS) method is based on defining the relationship between alternatives and reference values (ideal and anti-ideal alternatives). On the basis of the defined relationships, the utility functions of alternatives are determined, and compromise ranking is made in relation to ideal and anti-ideal solutions. Decision preferences are defined on the basis of utility functions. Utility functions represent the position of an alternative with regard to an ideal and anti-ideal solution. The best alternative is the one that is closest to the ideal and at the same time furthest from the anti-ideal reference point. The Measurement Alternatives and Ranking According to Compromise Solution (MARCOS) method is performed through the following steps

Step 1 - Formation of an initial decision-making matrix:

Multi-criteria models include the definition of a set of n criteria and m alternatives. In the case of group decision-making, a set of r experts should be formed to evaluate alternatives according to the criteria

Step 2 - Formation of an extended initial matrix:

In this step, the extension of the initial matrix is performed by defining the ideal (AI) and anti-ideal (AAI) solution.

$$X = \begin{array}{c} \\ AAI \\ A_1 \\ A_2 \\ \vdots \\ A_m \\ AI \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{aa1} & x_{aa2} & \cdots & x_{aan} \\ x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{22} & \cdots & x_{mn} \\ x_{ai1} & x_{ai2} & \cdots & x_{ain} \end{bmatrix} \end{array} \quad (1)$$

The anti-ideal solution (*AAI*) is the worst alternative, while the ideal solution (*AI*) is an alternative with the best characteristic

Step 3 - Normalization of the extended initial matrix (*X*):

The elements of the normalized matrix $N = [n_{ij}]_{m\times n}$ are obtained by applying Eqs. (4) and (5).

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \text{ if } j \in C \quad (4)$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \text{ if } j \in B \quad (5)$$

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

Step 4 - Determination of the weighted matrix:

$V = [v_{ij}]_{m\times n}$.

The weighted matrix *V* is obtained by multiplying the normalized matrix *N* with the weight coefficients of the criterion w_j, Eq.(6).

$$v_{ij} = n_{ij} \times w_j \quad (6)$$

Step 5 - Calculation of the utility degree of alternatives *Ki*:

By applying Eqs.(7) and (8), the utility degrees of an alternative in relation to the anti-ideal and ideal solution are calculated.

$$K_i^- = \frac{S_i}{S_{aai}} \quad (7)$$

$$K_i^+ = \frac{S_i}{S_{ai}} \quad (8)$$

where S_i ($i = 1, 2, \ldots\ldots m$) represents the sum of the elements of the weighted matrix *V*, Eq.(9).

$$S_i = \sum_{i=1}^{n} v_{ij} \quad (9)$$

Step 6 - Determination of the utility function of alternatives $f(K_i)$:

The utility function is the compromise of the observed alternative in relation to the ideal and anti-ideal solution. The utility function of alternatives is defined by Eq.(10).

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}} \quad (10)$$

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

Utility functions in relation to the ideal and anti-ideal solution are determined by applying Eqs. (11) and (12).

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \quad (11)$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \quad (12)$$

Step 7 - Ranking the alternatives:

This is based on the final values of utility functions. It is desirable that an alternative has the highest possible value of the utility function.

IV. Case Study

In the present study considers making the best decision on selecting a supplier for a particular company. The research for the purpose of this paper has been carried out in a company classified as a supply chain industry. The company carries out container handling operations and they are facilitating the container handling from / to the ship and rail. The company have plan to expand the handling capacity from 0.6 million container per year to 1.2 million per year. For this reason, the company intends to buy a new container handling equipment i.e., rail mounted quay crane, rubber tyre gantry crane, reach stacker and heavy fork lift. The present study focuses on selecting the supplier for supplying heavy fork lift with six main criteria with regard to the supplier selection strategy requirements

Table 1- The criteria for selecting a supplier

Code	Criteria	Characteristics and description of the criteria
C1	Product Quality	Product quality means to incorporate features that have a capacity to meet consumer needs
C2	Cost	Direct and indirect costs for buying a product and service
C3	Delivery	On-time delivery with the exact quantity of products ordered
C4	Technological Capability	Firm's ability to design and develop new process, product and upgrade knowledge and skills about the physical environment in unique way
C5	Flexibility	The possibility to respond to short term changes in demand or supply situations. of other external disruptions together
C6	Reliability	the ability of a company to consistently supply an acceptable product at the required time

Table 2 - Defining the alternatives

Code	Alternatives (make)	Characteristics and description of the alternatives
A1	Make A	ACE one of the lowest price fork lifts in the Market. ACE is the only company to provide the heaviest weight lifting forklift in India. Good range of service available through dealer & spare parts also cheap
A2	Make B	Follow the best process management for customer service. Toyota pricing is so competitive
A3	Make C	Products Combine Innovative Design with State-Of-The-Art Manufacturing & Testing, Environmentally Friendly, Designed to Perform, Highest Quality, Wide Variety of Solutions
A4	Make D	Experts in People, Products & Productivity. Features That Deliver. Environmentally Friendly. Adaptable Application. Best Customer Service
A5	Make E	Ergonomic, Efficient and Innovative Design.
A6	Make F	Very durable, dependable and great customer service
A7	Make G	Quality of the fork lift is good, but comparatively the cost is higher

Data collection sheet :

Table 3 - Ratings of the alternatives by the criteria using the scale from 1 to 5

Evaluation 1 - E1							Evaluation 2 - E2						
	C1	C2	C3	C4	C5	C6		C1	C2	C3	C4	C5	C6
A1	4	3	3	4	3	3	A1	4	2	2	2	3	2
A2	3	2	3	3	2	3	A2	4	4	5	4	3	4
A3	4	3	2	2	3	4	A3	5	4	3	5	4	3
A4	3	2	3	2	3	2	A4	3	3	2	2	2	2
A5	5	4	4	4	4	4	A5	2	3	1	4	3	4
A6	5	5	3	4	3	5	A6	3	2	2	4	2	4
A7	5	5	4	5	5	5	A7	2	2	1	3	3	3
Evaluation 3 - E3							Evaluation 4 - E4						
	C1	C2	C3	C4	C5	C6		C1	C2	C3	C4	C5	C6
A1	3	1	1	1	2	1	A1	5	4	1	3	5	2
A2	3	4	5	4	4	5	A2	3	5	2	4	3	2
A3	4	4	4	5	3	4	A3	4	5	2	5	2	2
A4	2	2	1	2	2	2	A4	4	5	3	5	2	3
A5	3	2	1	4	2	3	A5	4	5	3	5	2	3
A6	2	2	1	4	2	3	A6	5	4	3	5	1	2
A7	3	2	1	4	2	3	A7	4	4	2	5	1	3
Evaluation 5 - E5							Evaluation 6 - E6						
	C1	C2	C3	C4	C5	C6		C1	C2	C3	C4	C5	C6
A1	3	5	1	4	2	3	A1	4	5	2	4	3	1
A2	3	3	4	3	4	2	A2	4	4	2	5	2	3
A3	4	3	1	3	4	5	A3	3	4	1	5	1	2
A4	2	5	4	5	2	1	A4	3	4	2	5	1	2
A5	2	5	4	5	1	3	A5	3	4	1	5	2	2
A6	4	4	3	4	1	4	A6	4	5	2	5	2	3
A7	4	4	4	4	3	3	A7	3	5	3	5	2	1

Evaluation of the Criteria by the Steps of the Full Consistency Method (FUCOM):

Table 4 – Evaluation of criteria

M l	**C2**	**Cl**	**C4**	**C6**	**C3**	**C5**
	1	2	2.1	3	4	4.3
DM 2	C2	C4	C6	Cl	C3	C5
	1	1.2	2	2.6	3	3
DM 3	Cl	C6	C2	C4	C5	C3
	1	1.5	2.2	2.2	4.3	6.8
DM 4	C2	C4	Cl	C3	C6	C5
	1	1.5	2	3	4	4.6
DM 5	C4	C2	Cl	C3	C6	C5
	1	1	3	3.1	4	5
DM 6	C4	C2	Cl	C6	C3	C5
	1	2	4	4.5	5	6

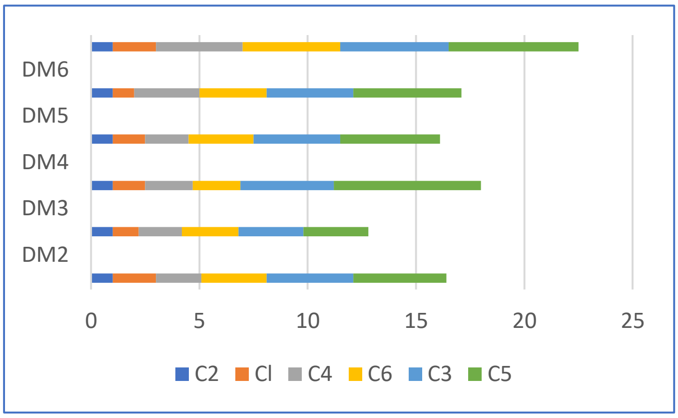

Fig. 3 - **A graphic representation of the evaluation results of the criteria**

Table shows that the first decision-maker identified criterion C2, i.e., the cost of the product, as the most significant criterion, and criterion C5, i.e., Flexibility, as the least significant

Table 5 - Results of the evaluation of the criteria by the FUCOM method

Code	Criteria	DM1	DM2	DM3	DM4	DM5	DM6	Wj
C1	Product Quality	0.1701	0.1083	0.3245	0.1764	0.1124	0.1124	0.1673
C2	Cost	0.3401	0.2803	0.1478	0.3539	0.3381	0.2247	0.2808
C3	Delivery	0.0855	0.0931	0.0480	0.1176	0.1092	0.0903	0.0906
C4	Technological Capability	0.1625	0.2337	0.1478	0.2363	0.3381	0.4494	0.2613
C5	Flexibility	0.0789	0.0931	0.0758	0.0767	0.0672	0.0746	0.0777
C6	Reliability	0.1131	0.1406	0.2170	0.0882	0.0853	0.0903	0.1223
							Sum	1.0000

The table and the graph show that, according to the decision-makers, cost of the product is the most significant criterion when selecting a supplier, four decision makers (DMI, DM2, DM4 and DM5) rated this criterion as the most important (0.2808). The technological capability as a criterion are in the second position with a slightly lower score (0.2613).

The least significant criterion, when considering the overall score, is flexibility, and even five members of the expert team (DMl, DM2, DM4, DM5 and DM6) rated it as the least significant (0.077)

Table 6 - Extended initial decision matrix

Criteria	C1	C2	C3	C4	C5	C6
Anti-ideal	2.612	2.759	1.452	1.485	1.783	1.908
A1	3.583	2.759	1.452	2.938	2.997	1.908
A2	3.137	3.349	3.130	2.142	3.028	3.144
A3	3.759	3.583	1.830	1.589	2.699	3.298
A4	2.612	3.097	2.197	2.100	2.001	2.001
A5	2.844	3.476	1.830	1.485	2.247	3.240
A6	3.476	3.249	2.095	1.666	1.783	3.528
A7	3.192	3.249	2.054	1.589	2.495	2.856
Ideal	3.759	3.583	3.130	2.938	3.028	3.528

Table 7 – Normalized Matrix

Criteria	C1	C2	C3	C4	C5	C6
Anti-ideal	0.111	0.205	0.040	0.137	0.048	0.071
A1	0.153	0.205	0.040	0.137	0.081	0.071
A2	0.134	0.249	0.086	0.188	0.082	0.118
A3	0.161	0.266	0.051	0.253	0.074	0.123
A4	0.111	0.230	0.060	0.191	0.055	0.075
A5	0.122	0.258	0.051	0.270	0.061	0.121
A6	0.148	0.241	0.058	0.240	0.048	0.131
A7	0.136	0.241	0.057	0.253	0.067	0.107
Ideal	0.161	0.266	0.086	0.270	0.082	0.131

Ranking the alternatives:

The final results obtained by the MARCOS method are shown in the table

Table 8 – Final results

Ai	Si						
AAI	0.613	**Ki-**	**Ki+**	**f(K)**	**f(K+)**	**f(Ki)**	**Rank**
A1	0.659	1.110	0.687	0.378	0.612	0.555	7
A2	0.818	1.378	0.852	0.378	0.612	0.689	5
A3	0.883	1.487	0.920	0.378	0.612	0.743	1
A4	0.691	1.164	0.720	0.378	0.612	0.582	6
As	0.839	1.413	0.874	0.378	0.612	0.707	2
A6	0.827	1.394	0.862	0.378	0.612	0.698	3
A1	0.820	1.381	0.854	0.378	0.612	0.691	4
AI	1						

Ideal and anti-ideal solutions are obtained, the values of 1.000 and 0.613, respectively. The alternative with the utility function value closest to the ideal solution value is the best alternative and is ranked first.
In this study, it is alternative A3, i.e., Make C, with the utility function value of 0.743. The worst-ranked alternative is the alternative with the utility function value closest to the value of the anti-ideal solution, and here it is alternative Al, i.e., Make A, with the utility function value of 0.555

Sensitivity analysis:
In order to verify the results, we compared the results obtained by the Measuring of Alternative and Ranking according to Compromise Solution (MARCOS) method with the results obtained by other multi-criteria decision-making methods.

- Simple Additive Weighing (SAW) used by MacCrimmon,
- Additive Ratio Assessment (ARAS) has been incorporated by Zavadskas & Turskis and
- Weighted Aggregates Sum Product Assessment (WASPAS) was introduced by Zavadskas et al.,

Table 9 - A sensitivity analysis of the results obtained by the MARCOS / SAW / ARAS / WASPAS method

	MARCOS		SAW		ARAS		WASPAS	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Al	0.555	7	0.687	7	0.679	7	0.674	7
A2	0.689	5	0.852	5	0.853	4	0.848	5
A3	0.743	1	0.920	1	0.912	1	0.916	1
A4	0.582	6	0.720	6	0.717	6	0.717	6
AS	0.707	2	0.874	2	0.868	2	0.868	2
A6	0.698	3	0.862	3	0.858	3	0.858	3
A7	0.691	4	0.854	4	0.850	5	0.852	4

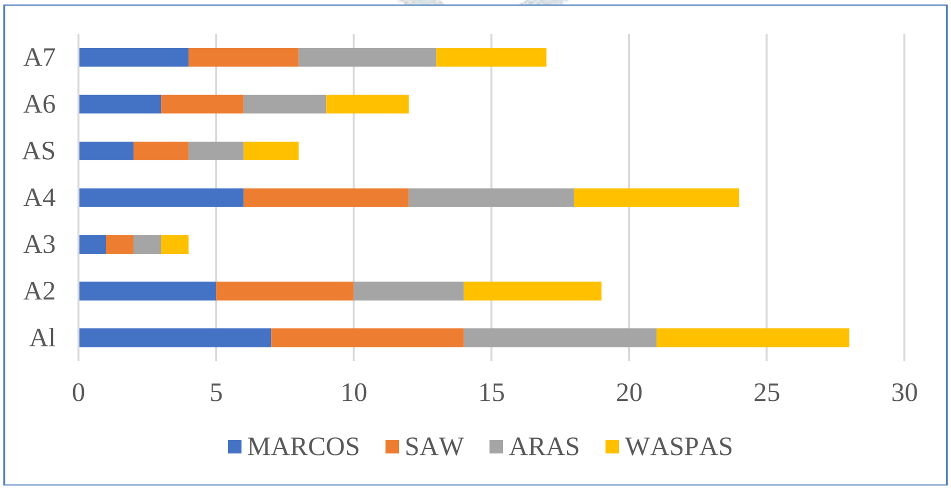

Fig. 4 - A graphic representation of the sensitivity analysis of the results obtained by the MARCOS / SAW / ARAS / WASPAS method

Comparing the results obtained by the last three methods it can be noticed that the results are generally the same, which means that we can with high probability claim that the results obtained are accurate.
The table and figure show that there is a slight deviation in ranking by the Additive Ratio Assessment (ARAS) method compared to the other three methods. By this method, alternatives A2 and A7 has changed their positions, i.e., alternative A2 is ranked fourth

by this method and alternative A7 as fifth. It is the only difference we can see using all four methods. All other methods show identical ranking results. Thus, by applying all four methods, **alternative Al,** is ranked as the worst alternative, i.e., it is in the seventh place. **Alternative A3,** is the best alternative according to the results obtained by all four methods. That is, **alternative A3** is ranked first according to all the methods. Therefore, the results obtained by the Measuring of Alternative and Ranking according to Compromise Solution (MARCOS) method represent accurate and reliable results. If the company wants to make the best decision about selecting a supplier, it can rely on the results obtained by this method. According to the results of this study, the best decision of the company on selecting a Fork lift supplier would be the decision to use **alternative A3** as the supplier.

V. Conclusion

In this study, a new integrated Full consistency method (FUCOM) - Measuring of Alternative and Ranking according to Compromise Solution (MARCOS) model for the evaluation of suppliers has been formed. The integration of the two methods has been performed in this research, which is one of the major contributions.

Unlike other subjective models, Full consistency method (FUCOM) has shown minor deviations in the obtained values of the weights of criteria from optimal values. Measuring of Alternative and Ranking according to Compromise Solution (MARCOS) method is based on testing the reference values of alternatives in relation to ideal values and on a comprehensive rational and reasonable application methodology. The model is very flexible and simple so it can also be applied to other problems of multi-criteria analysis.

Applying the method, the **worst-ranked alternative** was **alternative Al,**. The method showed that **alternative A3,** is the **best-ranked supplier**. This supplier would be a much better alternative than the current other equipment which are considered for this study

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