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AN INTEGRATED DECISION-MAKING MODEL FOR EFFICIENCY ANALYSIS OF THE FORKLIFTS IN WAREHOUSING SYSTEMS

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Abstract*. In the logistics world, special attention should be given to warehousing systems, cost rationalization, and improvement of all the factors that affect efficiency and contribute to smooth functioning of logistics subsystems. In real time industrial practice, the issue of evaluating and selecting the most appropriate forklift involves a complex decision-making problem that should be formulated through an efficient analytical model. The forklifts efficiency plays a very important role in the company. The forklifts are being used on a daily basis and no logistical processes could be done without them. Therefore, it has been decided to determine their efficiency, which will contribute to the optimization of the process in this logistics subsystem. This study puts forward an integrated forklift selection model using Data Envelopment Analysis (DEA), Full Consistency Method (FUCOM) and Measurement Alternatives and Ranking According to the Compromise Solution (MARCOS) methods. Five input parameters (regular servicing costs, fuel costs, exceptional servicing costs, total number of all minor accidents and damage caused by forklifts) and one output parameter (number of operating hours) were first identified to assess efficiency of eight forklifts in a warehousing system of the Natron-Hayat company using the DEA model. This step allows sorting of efficient forklifts which are subsequently evaluated and ranked using FUCOM and MARCOS methods. A sensitivity analysis is also performed in order to check reliability and accuracy of the results. The findings of this research clearly show that the proposed decision-making model can significantly contribute to all spheres of business applications.*

Key Words*: DEA, FUCOM, MARCOS, Warehouse, Forklifts*

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1. INTRODUCTION

The warehouse, in addition to being one of the basic subsystems of logistics, is an important part in every organization for which it deserves special attention in terms of monitoring and analyzing its associated processes and activities. When planning, building and using any warehouse, the greatest attention is paid to size of the warehouse, layout, and training of employees who manage the warehousing system. On the other hand, enough attention is generally not given to selecting the most appropriate forklift which is one of the most important items that can greatly affect the entire warehousing system, optimization of vehicles' waiting for loading and unloading, efficiency and overall effectiveness of the entire organization. Considering that the Natron-Hayat company is one of the leading ones in the region of Bosnia and Herzegovina, optimization of parameters in the warehousing system can bring superior results which finally lead to business success. There are currently eight forklifts in the warehouse of the considered company and it is necessary to analyze efficiency of these forklifts in order to justify those procurement investments that will contribute to the business success of the company. Data Envelopment Analysis (DEA), which is a linear programming-based method, is here adopted in order to analyze efficiency of forklifts which are currently operating at the considered warehouse. DEA is primarily used to determine relative efficiencies of decision-making units (DMUs) or alternatives. Major reasons for a rapid increase in the use of the DEA method lie in the fact that this model is interdisciplinary in applications; it is also suitable in the cases where other approaches do not provide satisfactory results due to their complex or unknown nature of the links between multiple inputs and outputs [1]. The main benefit of this method is its competence to quarter a variety of input-output combinations. Another advantage of the DEA method is that there is no requirement of clearly stipulating mathematical form for the considered functions which enables it to be used for any input-output measurement. Based on the collected data for all the forklifts that serve in the warehousing system of the case company, the DEA method has identified the forklifts which are not efficient enough, and they are excluded from further considerations. Based on the DEA-based results, two popular multi-criteria decision-making (MCDM) methods, called Full Consistency Method (FUCOM) and Measurement Alternatives and Ranking According to the Compromise Solution (MARCOS) are further applied to derivation of a complete ranking of the efficient forklifts in order to identify the most efficient forklift alternative. The FUCOM method is used here to obtain criteria weights, whereas the rankings of forklift alternatives are derived using the MARCOS method. The contribution of this paper is reflected in the fact that based on the DEA-MCDM model applied to the warehousing system and handling equipment; it can significantly improve the decision-making process, reduce costs and increase work efficiency. Based on the recommendations of the proposed model, procurement of handling and transportation equipment can be planned efficiently. The contribution of this research in scientific terms can be observed through the original integration of DEA and two MCDM methods for handling efficiency estimation problems when solo application of the DEA method is unable to provide for a complete ranking order of alternatives in multi-criteria environment. There are different places and ways of determining efficiency in the company. However, due to many parameters, the DEA method proved to be a good method, whose results will show efficient as well as less efficient forklifts. The results of the DEA method can help managers with the selection and purchasing of forklifts in the future. However, after the DEA method, it has been decided to use multi-criteria methods to obtain the best and most realistic results. The main reason for the combination and development of the DEA-FUCOM-MARCOS model is that any company that faces decision-making challenges can get comprehensive and as realistic results as possible through this model.

In addition to introductory considerations, the paper is structured through other five sections. Section 2 presents an overview of the literature used throughout the research. Section 3 presents the methods used to select the most efficient forklift in the warehousing system, namely DEA, FUCOM and MARCOS methods. Section 4 presents application of DEA method, while Section 5 provides selection of the most efficient forklift using FUCOM and MARCOS methods. Section 6 refers to sensitivity analysis of the obtained results and Section 7 concludes the paper.

2. Literature Review

A large number of modern studies in which they are used prove the application of DEA and MCDM methods in logistics and transport. The Charnes, Cooper and Rhodes (CCR) model is considered as the most primary and vastly applied DEA model. The CCR model was first conceptualized and formulated by Charnes, Cooper and Rhodes in 1978 [2]. The basic theme of this model actually originated from earlier work on the basic theory of productivity measurement using single output and single input ratio concept. Applications of the DEA method are now found in many areas, and DEA has become a central technique in productivity and efficiency analyses for comparing organizations, enterprises, regions and countries. The DEA method has also made its contribution to logistics [3, 4, 5], warehousing [6] and transportation [7] as its subsystems and supply chains [8, 9].

The paper [4] presents an overview of DEA models for measuring the efficiency of supply chains. The process of measuring efficiency in production companies differs greatly from the process of measuring efficiency in service companies. It was concluded that in order to successfully measure efficiency in logistics, it is necessary to consider a large number of inputs and outputs that are heterogeneous (financial, technical, environmental, energy, social, etc.) and are expressed in different units of measurement. In this sense, it is possible to measure energy, environmental, cost and other types of efficiency in logistics. In the paper [10], the DEA model was applied in order to analyze the efficiency of the bus subsystem of public passenger transport in Belgrade, on a sample of five small, three medium, and two large companies. The subject of the research in [11] is the analysis of the efficiency of airlines in the European Union in 2012, where the application of the DEA model assessed the individual efficiency of each airline; besides, it also identified inefficient elements of business that could be improved. The paper [12] deals with the analysis of the efficiency of intermodal terminals with the aim of identifying terminals that would serve as models for the improvement of existing and development of new terminals. The DEA method was used to determine the efficiency of the terminals, and the research was conducted on a sample of 35 real land trimodal terminals in Europe. The results of the research showed that for the defined sample, the parameters storage capacity and length of railway tracks had the greatest influence on achieving the efficiency of the terminal.

In addition to assessing efficiency, this method is also used to define degree of safety, i.e. to evaluate risk in transportation and traffic systems [13, 14]. The DEA method has also found application in military organization [15, 16, 17]. This is shown in Ref. [15] presenting the application of the DEA and SFA methods for evaluating the efficiency of the work of the selected ten military transport units and 173 military motor vehicles used in cargo transportation tasks for the needs of supply and special needs of the army, individually and within six defined classes. We also see the application of the DEA method and the determination of the efficiency of the Liaoning port logistics [16]. This paper used DEA to analyze the logistics efficiency of four major ports in the Liaoning Province. Then based on the results of DEA analysis, the relationship between logistics efficiency and its influencing factors is studied. The results show that the overall pure technical efficiency of port logistics in the Liaoning Province has been maintained at a high level and the state is stable. Also, there is an increasing number of papers related to solving logistics problems using MCDM methods. This research [17] created the hybrid BWM-COPRAS model for the assessment of off-road vehicles.

3. METHOD

In this section, Fig. 1 presents the methodology which includes application of the DEA method for assessing relative efficiencies of the alternative of forklifts and the FUCOM and MARCOS methods application to identifying the most efficient forklift.

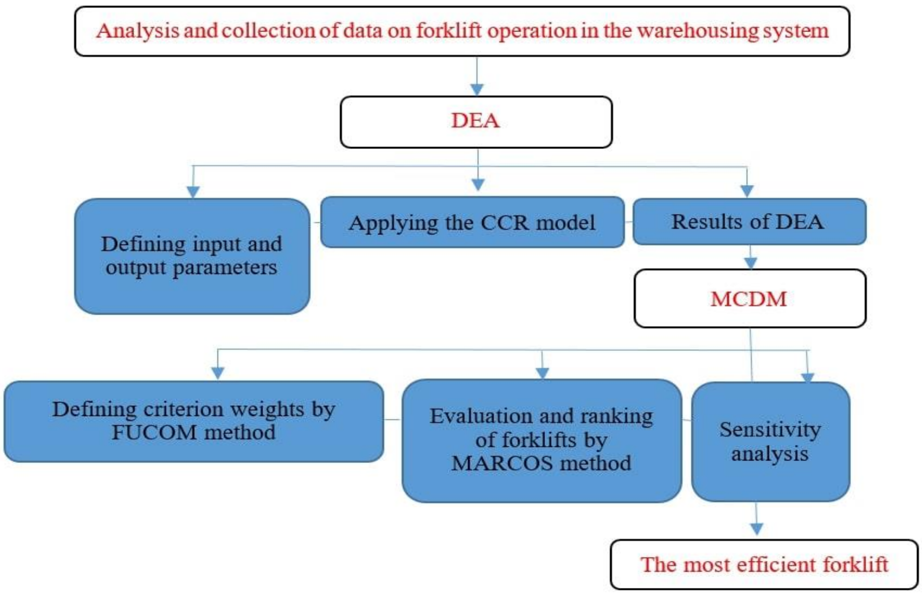

Fig. 1 Research methodology

The research methodology in this paper consists of four phases. The first phase refers to the analysis and collection of necessary data on the operation of forklifts in the warehousing system. In the second phase, the DEA method is applied which is presented through three steps, namely: defining input and output parameters, applying CCR model and results of DEA method. After obtaining results of the DEA CCR model, the third phase starts in which the FUCOM and MARCOS methods are applied to selecting the most efficient forklift. The last step of the third phase is a sensitivity analysis of the obtained results. Finally, at the end of the paper, the results of all the applied steps aim at determining the most efficient forklift.

3.1 DEA method

This section presents two DEA CCR models [2] that have been applied to obtaining the values of alternatives, i.e. DMUs according to an input-oriented model (min) and an output-oriented model (max). The DEA CCR input oriented model (min) is as follows:

$$\begin{gathered} DEA_{input} = \min \sum_{i=1}^{m} w_i\, x_{i-input} \\ st: \\ \sum_{i=1}^{m} w_i\, x_{ij} - \sum_{i=m+1}^{m+s} w_i\, y_{ij} \geq 0, \quad j = 1, \dots, n \\ \sum_{i=m+1}^{m+s} w_i\, y_{i-output} = 1 \\ w_i \geq 0, \quad i = 1, \dots, m+s \end{gathered} \tag{1}$$

DMUs consist of m input parameters for each alternative x_{ij}, while s represents the output parameters for each alternative y_{ij}, taking into account weights of the parameters denoted by w_i,n represents total number of DMUs. The DEA CCR output oriented model (max) is as follows:

$$\begin{gathered} DEA_{output} = \max \sum_{i=m+1}^{m+s} w_i\, y_{i-output} \\ st: \\ -\left(\sum_{i=1}^{m} w_i\, x_{ij}\right) + \sum_{i=m+1}^{m+s} w_i\, y_{ij} \leq 0, \quad j = 1, \dots, n \\ \sum_{i=1}^{m} w_i\, x_{i-input} = 1 \\ w_i \geq 0, \quad i = 1, \dots, m+s \end{gathered} \tag{2}$$

3.2 FUCOM method

FUCOM method was developed by Pamučar, Stević and Sremac [18] to determine the criteria weights in mutually conflicting MCDM environment. FUCOM provides the possibility to perform model validation by calculating error size for the obtained weight vectors by determining degree of consistency [18-21]. Fig. 2 presents FUCOM algorithm including steps of this method.

3.3 MARCOS method

The MARCOS method (Fig. 3) is based on defining relations between an alternative and reference values (ideal and anti-ideal alternatives). Based on these defined relations, utility functions of the alternatives are determined and a compromise ranking is made in relation to ideal and anti-ideal solutions. Decision preferences are defined based on utility functions. Utility functions represent position of an alternative in relation to an ideal and anti-ideal solution. The best alternative is the one which is closest to an ideal as well as furthest from an anti-ideal reference point. The MARCOS method is implemented through the following simple steps [22-24] presented in Fig. 3.

Algorithm: FUCOM

Input: Expert pairwise comparison of criteria

Output: Optimal values of the weight coefficients of criteria/sub-criteria

Step 1: Expert ranking of criteria/sub-criteria.

Step 2: Determining the vectors of the comparative significance of evaluation criteria.

Step 3: Defining the restrictions of a non-linear optimization model.

Restriction 1: The ratio of the weight coefficients of criteria is equal to the comparative significance among the observed criteria, i.e. $w_k / w_{k+1} = \varphi_{k/(k+1)}$.

Restriction 2: The values of weight coefficients should satisfy the condition of mathematical transitivity, i.e. $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$.

Step 4: Defining a model for determining the final values of the weight coefficients of evaluation criteria:

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

Step 5: Calculating the final values of evaluation criteria/sub-criteria $(w_1, w_2, ..., w_n)^T$.

Fig. 2 Overview of FUCOM method and its steps

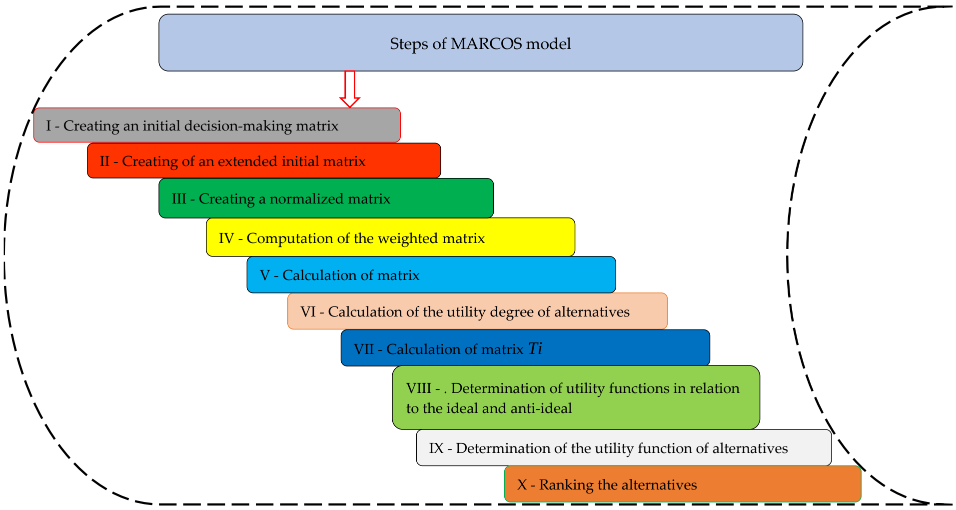

Fig. 3 Algorithm of the MARCOS method

4. Application of the DEA Method for Evaluation of Forklift Efficiency

Natron-Hayat Ltd. is a highly recognized and reputable European company in the field of manufacturing paper and paper packaging applications. In this company, the method of storage is decentralized, and includes four warehouses for storage of finished products (warehouse of Paper machine PM_4, warehouse of Paper machines PM_3-PM_1, warehouse of production plant Paper Products and customs warehouse). It is clear that the main handling equipment in the warehouses is a forklift, so it is the reason for conducting this research in order to determine how efficiency of a forklift affects the entire warehousing process. The collected data from the analysis of forklift efficiency and application of the integrated DEA-MCDM model cover one calendar year (2019). Most of the data were recorded in previous years; however, special attention was paid to some parameters for getting precise and comprehensive data for the considered case study.

The data that form the basis for the DEA method in this paper are presented in Fig. 4.

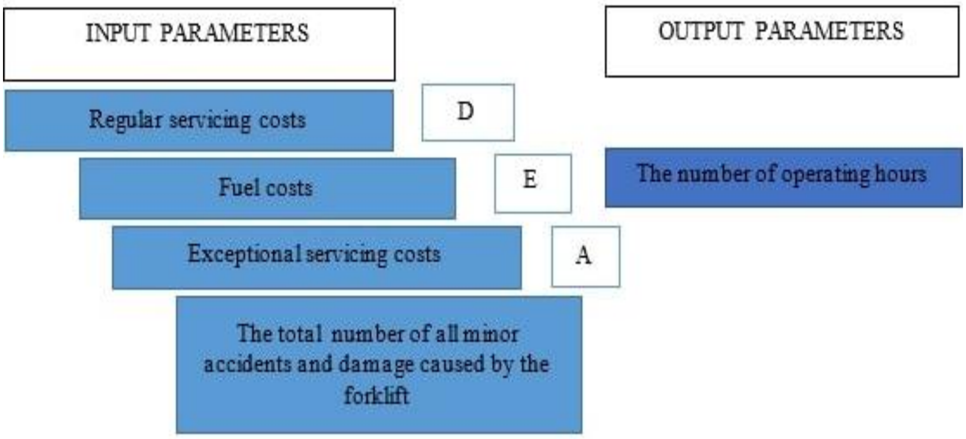

Fig. 4 Input and output parameters required to determine efficiency of forklifts

In order to determine efficiencies of the considered forklifts, data were collected for all forklifts, currently in operation. Table 1 shows input and output parameters for all eight forklifts. Input parameters for each of the eight forklifts are difficult to be determined, but the most important input parameters on the basis of which the efficiency can be determined using the DEA method are: regular servicing costs, fuel costs, exceptional servicing costs, and the total number of minor accidents and damage caused by the forklift. Output parameter, i.e. the result of forklift operation is the number of operating hours for each forklift individually.

Table 1 Input and output parameters for all forklifts

Parameters	Regular servicing costs (BAM)	Fuel costs (BAM)	Exceptional servicing costs (BAM)	The total number of all minor accidents and damage caused by the forklift	The number of operating hours (h)
Forklift 1	870	483	562.5	12	864
Forklift 2	1820	5622	562.5	36	4320
Forklift 3	2534	14806	2,222.11	36	5184
Forklift 4	3503	13706	5,094.27	36	5184
Forklift 5	1500	6097	1,363.85	36	2400
Forklift 6	1890	7593	2,887.89	60	3240
Forklift 7	1800	4046	562.5	60	2640
Forklift 8	2700	8856	562.5	36	3840

Table 1 shows all input as well as output parameters for forklifts currently in operation. Each of these forklifts caused certain costs as stated, and also a certain number of minor accidents and damage. The number of operating hours is an output parameter that is very important for determining efficiency, and from this table, we can see that forklifts 3 and 4 have the highest number of operating hours, which does not mean that they are the most efficient as there are other forklifts as well with lower costs, fewer accidents and less damage.

The input and output DEA models are given below by Eqs. (1) and (2).

By solving the DEA models for all the considered forklifts, the obtained values are shown in Table 2. This table also presents the final DEA values, obtained by comparing the two input and output oriented DEA models. The DEA final values are being derived from: DEA-final$_n$ = DEA-output$_n$ / DEA-input$_n$.

Table 2 Results of DEA method

	DEA-input	DEA-output	DEA-final
Forklift 1	1.000	1.000	1.000
Forklift 2	1.000	1.000	1.000
Forklift 3	1.000	1.000	1.000
Forklift 4	1.000	1.000	1.000
Forklift 5	1.483	0.674	0.454
Forklift 6	1.384	0.722	0.521
Forklift 7	1.234	0.809	0.655
Forklift 8	1.125	0.888	0.789

From Table 2, it is clear that forklifts 5, 6, 7 and 8 have values less than 1. They are not considered further into the model since they are neither efficient enough nor do they contribute to the Natron-Hayat company like other forklifts. After obtaining the results of the DEA method, it is observed that the first four forklifts have efficiency values of 1, indicating them as efficient alternatives; the most efficient of these four forklifts will now be selected in the next phase using FUCOM-MARCOS methods.

5. Ranking Efficient Forklifts by Applying the FUCOM and MARCOS Methods

The DEA model results indicate that the first four forklifts are efficient alternatives, fulfilling their tasks satisfactorily. This section of the paper presents results of MCDM methods as applied for these four forklifts. Criteria weights are determined by the FUCOM method, while the MARCOS method is used to determine the most efficient forklift, i.e. ranking of these four forklifts is derived according to their efficiency.

Calculation of criteria weights by the FUCOM method is performed as follows.

The first step is an activity in which the criteria are ranked as follows:

$$C_2 > C_5 > C_1 > C_4 > C_3$$

After ranking the criteria, they are compared, so the values of comparative priorities are defined according to the second step, which can be seen in Table 3.

Table 3 Overview of comparative priorities for comparing criteria

Criterion name (in accordance with ranking)	C_2	C_5	C_1	C_4	C_3
Comparison of criteria	1	1.15	1.3	1.6	2.1

It is then necessary to apply the third, fourth and fifth steps of the FUCOM method in order to obtain final values of criteria weights. The final results of the FUCOM method, i.e. significance of the criteria on the basis of which final evaluation of the forklift efficiency is performed, are shown in Fig. 5.

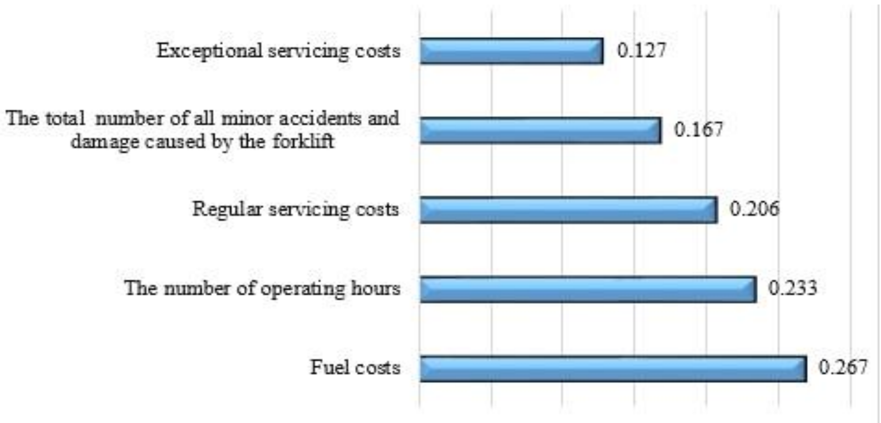

Fig. 5 Criteria weights as given by FUCOM method

According to the results of the FUCOM method, as shown in Fig. 5, we can see that out of five criteria, the criterion related to fuel costs is the most significant (C_2). It is then subsequently followed by criterion C_5 (number of operating hours) and C_1 (regular servicing costs). The last two and the least significant criteria are those relating to the total number of all minor accidents and damage caused by the forklift (C_4) and exceptional servicing costs (C_3).

After determining the criteria weights, the MARCOS method is applied in order to derive a complete ranking order of the four forklifts. Table 4 presents an extended initial matrix formed according to the second step of the MARCOS method. Essence of forming this matrix is to consider the initial decision matrix while taking into account orientation of the criteria themselves, i.e. the need to minimize or maximize the criteria. It should be emphasized that the first four criteria: regular servicing costs, fuel costs, exceptional servicing costs and the total number of all minor accidents and damage caused by the forklift are minimized, and the total number of operating hours needs to be maximized. Accordingly, for the first four criteria, the ideal solution that enters the extended initial decision matrix is the minimum value, while for the fifth criterion, the highest value is the ideal solution. When forming an anti-ideal solution, which is also an integral part of the aforementioned matrix, opposite values are taken.

Table 4 Extended initial matrix

	C1	C2	C3	C4	C5
AII	3503	14806	5094.3	36.0	864
A1	870	483	562.5	12	864
A2	1820	5622	562.5	36	4320
A3	2534	14806	2222.11	36	5184
A4	3503	13706	5094.27	36	5184
AI	870	483	562.50	12.00	5184
max/min	min	min	min	min	max

Normalization of the extended initial matrix is performed according to step 3, and values of the normalized matrix can be seen in Table 5:

$$n_{ij} = \frac{x_{ai}}{x_{ij}}; x_{21} = \frac{870}{1820} = 0.478$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}}; n_{15} = \frac{864}{5184} = 0.167$$

Table 5 Normalized matrix

	C1	C2	C3	C4	C5
AII	0.248	0.033	0.110	0.333	0.167
A1	1.000	1.000	1.000	1.000	0.167
A2	0.478	0.086	1.000	0.333	0.833
A3	0.343	0.033	0.253	0.333	1.000
A4	0.248	0.035	0.110	0.333	1.000
AI	1.000	1.000	1.000	1.000	1.000

Weighted normalized matrix is then obtained according to the fourth step of the MARCOS method by multiplying the values from the normalized matrix by weight coefficients of the criteria, which were previously obtained using the FUCOM method, as shown in Table 6.

$$v_{ij} = n_{ij} \times w_j; v_{11} = 1.000 \times 0.206 = 0.206$$

Table 6 Weighted normalized matrix

	C1	C2	C3	C4	C5
AII	0.051	0.009	0.014	0.056	0.039
A1	0.206	0.267	0.127	0.167	0.039
A2	0.098	0.023	0.127	0.056	0.194
A3	0.071	0.009	0.032	0.056	0.233
A4	0.051	0.009	0.014	0.056	0.233
AI	0.206	0.267	0.127	0.167	0.233

Calculation of utility degree of K_i alternative: according to step 5, utility degrees of the alternatives in relation to an anti-ideal and ideal solution are calculated as follows.

$$K_I^- = \frac{S_i}{S_{aai}} = \frac{0.806}{0.168} = 4.790, \qquad K_I^+ = \frac{S_i}{S_{ai}} = \frac{0.806}{1} = 0.806$$

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

$$S_i = \sum_{i=1}^{n} v_{ij} = S_1 = 0.206 + 0.267 + 0.127 + 0.167 + 0.039 = 0.806$$

Also, we have that

$$S_{aai} = 0.051 + 0.009 + 0.014 + 0.056 + 0.039 = 0.168$$

Determining utility function of alternative $f(K_i)$. The utility function represents a compromise of the observed alternative in relation to an ideal and anti-ideal solution. Utility functions of alternatives are defined according to the sixth step:

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1-f(K_i^+)}{f(K_i^+)} + \frac{1-f(K_i^-)}{f(K_I^-)}} = \frac{0.806 + 4.790}{1 + \frac{1-0.856}{0.856} + \frac{1-0.144}{0.144}} = 0.787$$

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

The utility functions in relation to an ideal and anti-ideal solution are determined by applying step 8 as follows

$$f(K_I^-) = \frac{K_i^+}{K_i^+ + K_i^-} = \frac{0.806}{0.806 + 4.790} = 0.144$$

$$f(K_I^+) = \frac{K_i^-}{K_i^+ + K_i^-} = \frac{4.790}{0.806 + 4.790} = 0.856$$

The ninth and tenth steps represent ranking of alternatives on the basis of utility functions. It is always preferable when an alternative has the highest possible value of utility function.

Table 7 Results of MARCOS method

	Si	Ki-	Ki+	fK-	fK+	Ki	Rank
A1	0.806	4.790	0.806	0.144	0.856	0.787	1
A2	0.498	2.959	0.498	0.144	0.856	0.486	2
A3	0.400	2.375	0.400	0.144	0.856	0.390	3
A4	0.363	2.155	0.363	0.144	0.856	0.354	4

Results of the MARCOS method of Table 7 show that the most efficient forklift is A1, i.e. alternative 1. From Table 7, it is observed that utility function of forklift A1 is significantly higher than the obtained values of other forklifts. Forklift A2 is less efficient as compared to the forklift A1, and the next position in terms of efficiency is occupied by forklift A3. The least efficient among these four forklifts is forklift A4, i.e. alternative 4 due to its lowest utility function value.

6. Sensitivity Analysis

In order to test accuracy of the obtained results, a sensitivity analysis has been performed. In this paper, the sensitivity analysis has been done in two parts. The first part involves changing criteria weights to determine how the criteria weights affect the results. The second part is a comparison of the obtained results with those of seven other well established MCDM methods.

6.1 Changes in weight values of criteria

In this part of the sensitivity analysis, impact of changes in criteria weights is analyzed. Criteria weights are changed in a range of 15-90%, starting from the most significant criterion C_2, followed by criteria C_5, C_1, C_4 to criterion C_3. By applying Eq. (3), a total of 30 scenarios are formed.

$$W_{n\beta} = (1 - W_{n\alpha})\frac{W_\beta}{(1-W_n)} \quad (3)$$

In scenarios S_1-S_6, weight of the most significant criterion C_2 was changed, while in scenarios S_7-S_{12}, weight of criterion C_5 was changed, followed by subsequent weight changes in criterion C_1 for scenarios S_{13}-S_{18}, criterion C_4 for scenarios S_{19}-S_{24} and criterion C_3 for scenarios S_{25}-S_{30}, respectively. $W_{n\beta}$ represents a new value of criteria C_1, C_3, C_4, C_5, $W_{n\alpha}$ represents a reduced value of criterion C_2, W_β is an original value of the observed criterion and W_n represents an original value of the criterion whose value is reduced – C_2 (for the first group of scenarios, S_1-S_6). $W_{n\beta}$ represents a new value of criteria C_1, C_2, C_3, C_4, $W_{n\alpha}$ represents a reduced value of criterion C_5, W_β is an original value of the observed criterion and W_n represents an original value of the criterion whose value is reduced –C_5 (for the second group of scenarios, S_7-S_{12}). $W_{n\beta}$ represents a new value of criteria C_2, C_3, C_4, C_5, $W_{n\alpha}$ represents a reduced value of criterion C_1, W_β is an original value of the observed criterion and W_n represents an original value of the criterion whose value is reduced –C_1 (for the third group of scenarios, S_{13}-S_{18}). $W_{n\beta}$ represents a new value of criteria C_1, C_2, C_3, C_5, $W_{n\alpha}$ represents a reduced value of criterion C_4, W_β is an original value of the observed criterion and W_n represents an original value of the criterion whose value is reduced - C_4 (for the fourth group of scenarios, S_{19}-S_{24}). $W_{n\beta}$ represents a new value of criteria C_1, C_2, C_4, C_5, $W_{n\alpha}$ represents a reduced value of criterion C_3, W_β is an original value of the observed criterion and W_n represents an original value of the criterion whose value is reduced - C_3 (for the fifth group of scenarios, S_{25}-S_{30}).

All simulated values of the criteria through the newly formed 30 scenarios are presented in Table 8.

Table 8 Simulated values of criteria through newly formed 30 scenarios

	W1	W2	W3	W4	W5		W1	W2	W3	W4	W5
S1	0.217	0.227	0.134	0.176	0.245	S16	0.082	0.309	0.147	0.193	0.269
S2	0.228	0.187	0.141	0.185	0.258	S17	0.051	0.319	0.152	0.200	0.278
S3	0.239	0.147	0.148	0.195	0.271	S18	0.021	0.330	0.157	0.206	0.287
S4	0.251	0.107	0.155	0.204	0.283	S19	0.212	0.275	0.131	0.142	0.240
S5	0.262	0.067	0.162	0.213	0.296	S20	0.218	0.283	0.135	0.117	0.247
S6	0.273	0.027	0.169	0.222	0.309	S21	0.224	0.292	0.139	0.092	0.253
S7	0.215	0.280	0.133	0.175	0.198	S22	0.230	0.300	0.143	0.067	0.260
S8	0.224	0.292	0.139	0.182	0.163	S23	0.237	0.308	0.146	0.042	0.267
S9	0.234	0.304	0.145	0.190	0.128	S24	0.243	0.316	0.150	0.017	0.274
S10	0.243	0.316	0.150	0.197	0.093	S25	0.210	0.273	0.108	0.171	0.238
S11	0.252	0.328	0.156	0.205	0.058	S26	0.215	0.279	0.089	0.174	0.243
S12	0.262	0.340	0.162	0.213	0.023	S27	0.219	0.285	0.070	0.178	0.248
S13	0.175	0.278	0.132	0.174	0.242	S28	0.224	0.291	0.051	0.182	0.253
S14	0.144	0.288	0.137	0.180	0.251	S29	0.228	0.297	0.032	0.185	0.258
S15	0.113	0.299	0.142	0.187	0.260	S30	0.233	0.302	0.013	0.189	0.263

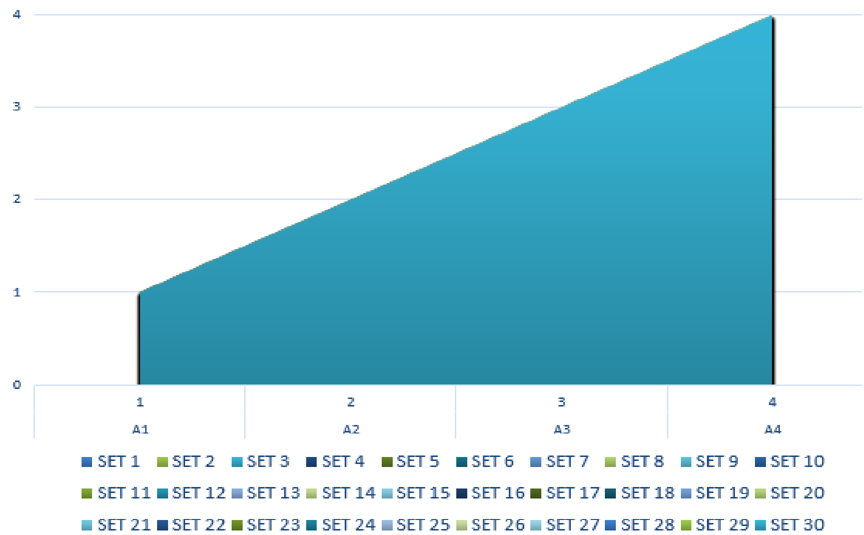

Fig. 6 Results of the sensitivity analysis for new criterion values

Fig. 6 clearly shows that the initially obtained results do not change with changes in criteria weights which is a clear indicator of invariability of the obtained results. Forklift A1 remains the most efficient alternative, followed by forklifts A2, A3 and A4.

6.2 Comparative analysis

In this section, a comparative analysis is performed with seven other MCDM methods, namely ARAS - additive ratio assessment [25], MABAC - Multi-Attributive Border Approximation area Comparison [26, 27], SAW - Simple Additive Weighting method [28], WASPAS - weighted aggregated sum product assessment [29], EDAS - evaluation based on distance from average solution [30], CoCoSo - Combined Compromise Solution [31] and TOPSIS - Technique for Order of Preference by Similarity to Ideal Solution [32].

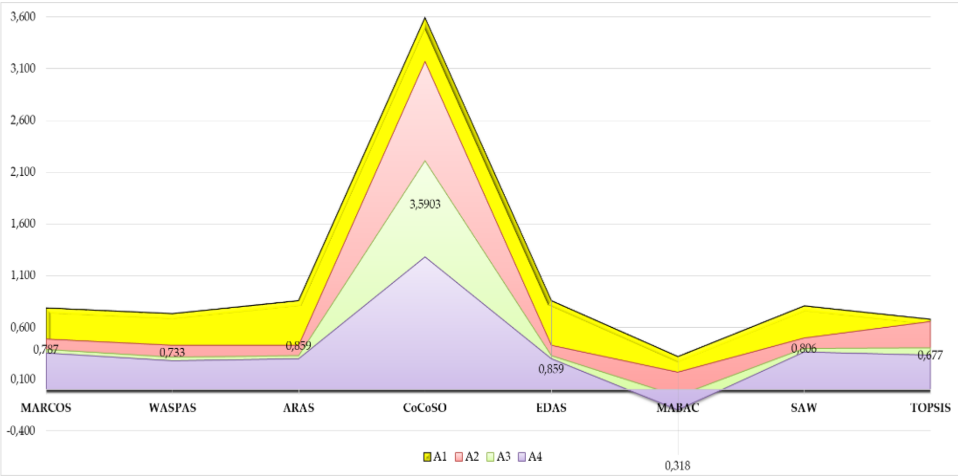

Fig. 7 Results of comparative analysis with seven other MCDM methods

Based on the results of comparative analysis with seven other MCDM methods, we can conclude that no changes are observed in terms of forklift ranking. Fig. 7 clearly shows that in all the considered MCDM methods, forklift A1 retains its first position, i.e. it is the most efficient forklift; with respect to efficiency, it is followed by forklifts A2, A3 and A4. Based on the performed comparative analysis and the applied integrated DEA-FUCOM-MARCOS model, it can be concluded that the proposed methodology is quite reliable, and any changes in parameters do not affect stability of alternative rankings.

6.3 Changing the number of inputs and the creation of the PCA-DEA model

In this part of the sensitivity analysis, the number of inputs was changed, forming four scenarios (S) in which one input was eliminated, starting from the first. Subsequently, the Principal Component Analysis PCA-DEA [33] was applied with 85% of the information retained. The results of this part of the sensitivity analysis are shown in Fig. 8.

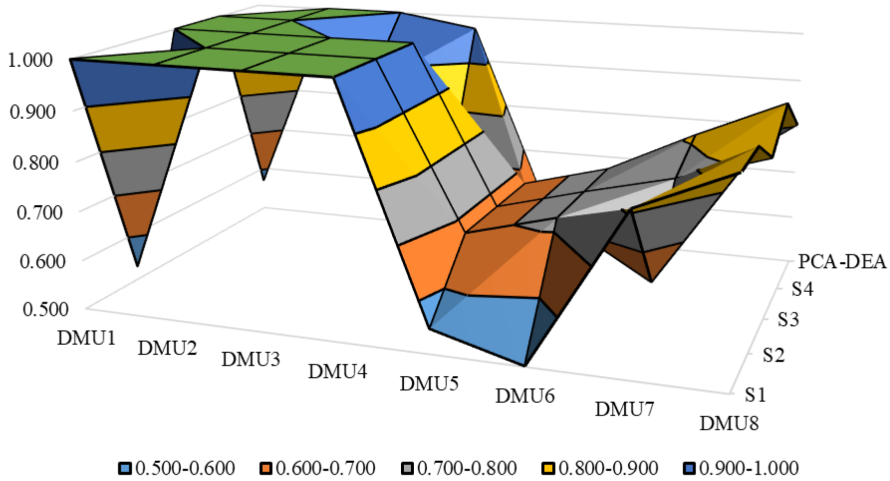

Fig. 8 Results of the sensitivity analysis with PCA-DEA and a reduced number of inputs

The results shown in Fig. 8 show that if we eliminate the first input (regular servicing costs) or third input (exceptional servicing costs), the results do not change, i. e. V1-V4 forklifts are efficient, while the others are not. In the second scenario, when we eliminate the second input (fuel costs), the efficiency of forklifts V2-V4 does not change (1.000). In contrast, the efficiency of the first forklift V1 changes drastically because it gets inefficient and the lowest value. This means that the efficiency of the first forklift is strictly related to the second input. In the fourth scenario, when the total number of all minor accidents and damage caused by the forklift is eliminated, the V1 and V2 forklifts are efficient, which is the final rank by applying the integrated DEA-FUCOM-MARCOS model. Finally, by applying the PCA-DEA model, the results tend to the second scenario.

7. Conclusions

This paper presents the way of dealing with determining the efficiency of handling and transportation equipment in each company. Based on the efficiency analysis (DEA), it has been determined which forklifts currently operating in this warehousing system are efficient and which of them do not contribute to work to the extent they should. Based on the data (regular servicing costs, fuel costs, exceptional servicing costs, total number of all minor accidents and damage caused by the forklift, number of operating hours) for all eight forklifts operating in the warehousing system of the Natron-Hayat company, it has been determined that four out of eight forklifts are not efficient enough and do not contribute to work in this company (A5-A8) like other forklifts. After that, using multi-criteria decision-making methods, the ranking and selection of the most efficient forklift out of the remaining four ones are carried out. After determining the weight coefficients of the criteria using the FUCOM method, the MARCOS method is presented, step by step, and its final results.

Based on the results of the applied MARCOS method, it has been determined that forklift A1 is currently the most efficient forklift serving in this system. Also, a sensitivity analysis has been performed in order to determine the stability of the final results. After changing the weight values of the criteria, it has been determined that these changes do not affect the final result. Then a comparative analysis is carried out, i.e. testing the stability of the results with seven other MCDM methods. After applying all these methods, we have come to the conclusion that there are no changes in terms of determining the efficiency of forklifts, forklift A1 is still the most efficient forklift, followed by forklifts A2, A3 and A4.

The contribution of this paper is evident in forming an original integrated model for determining efficiency, which can be applied to other fields as well. Specifically in this paper, the significance of the applied model is that the warehousing system managers are provided with a quantified analysis based on which they can make further decisions in order to increase the overall efficiency of warehousing systems of the company that is the object of the research. By applying this model, it is possible to easily determine the efficiency of both forklifts and other equipment, and pay more attention to identifying and monitoring input and output parameters. Regarding the obtained results, it is necessary that the managers in warehousing systems perform adequate monitoring of all activities done by forklifts, and to rationalize all unnecessary movements and pointless operation of forklifts. The issues with previous works in determining the efficiency are that only one of the above methods was used, but their combination was not applied.

From all said above, we can conclude that the decentralized warehousing system of the company is very complex, that there are great opportunities for savings and possibilities to improve all activities and processes in it. This paper has shown that the DEA analysis can be applied in this segment and that in combination with multi-criteria decision-making methods it can provide significant results just as it can direct companies‘ business operations in the right direction in terms of future plans. Future research could focus on ensuring that inefficient forklifts are no longer in use, and that additional funds are invested in the forklifts which contribute to a successful business. Also, this model can be applied to determine the efficiency of other means of transport handling.

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