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PROCUREMENT OPTIMIZATION BY SELECTING EFFICIENT SUPPLIERS USING DEA-FUCOM-COCOSO APPROACH AND SOLVING ORDER ALLOCATION PROBLEM

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Abstract. *Procurement logistics is one of the most important segments of the supply chain and one of the key factors of a company's competitiveness. For that reason, many companies strive for constant optimization of this segment of the supply chain, both in terms of costs and in terms of time, reliability, etc. The aim of this paper is to develop a new approach based on DEA-FUCOM-CoCoSo methods that aim to select efficient suppliers. The developed model was tested on the data of one trading company. The DEA method was used in order to select only efficient ones from 29 observed in this paper. The FUCOM method was used to determine the weights of the 9 observed criteria used in the CoCoSo method for evaluation of 6 efficient suppliers. The results of the application of this method determined the final rank of suppliers, after which only the first 3 suppliers were considered. At the very end, a model for solving the problem of order allocation is defined in order to determine from which supplier it is necessary to order goods and in what quantity. By applying the defined model, the quantities that need to be ordered from certain suppliers in order to meet the demand on the market are obtained. Based on the results, the developed approach showed the possibility of large application not only on the observed example but also on a larger problem.*

Key words: *Procurement logistics, Supplier selection, Order allocation problem, FUCOM, CoCoSo*

1. INTRODUCTION

Procurement logistics is a segment of the supply chain that deals with the procurement of raw materials (products), inventory management, demand forecasting, selection of suppliers, tenders, etc. Procurement starts a whole series of other activities that are realized in order to deliver a certain product to the end-user. Also, procurement conditions all further activities and processes regardless of the type and size of the company. Having in

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mind all these tasks, it can be concluded that efficient procurement logistics can achieve significant savings in the business. In order to achieve these savings, it is necessary to manage procurement processes, which is especially important if it is known that procurement costs can be up to 70% of the costs of the final product [1]. In addition, the share of procurement in the total turnover can range from 50-90% [2]. Inventory management is just one of the places to achieve savings, where it is necessary to find the optimum between the quantity of goods in stock and the cost of purchasing new products. In addition to inventory, another place where savings can be made is when selecting suppliers. When selecting a supplier, it is necessary to take care to select a supplier who can follow the demand in the market, but also who has the necessary flexibility for sudden changes in demand. On that occasion, it is necessary to apply certain tools in order to facilitate the process of selecting a supplier. This problem has been recognized a long time ago in the literature where there are a large number of multi-criteria decision-making (MCDM) methods that can be applied to facilitate this problem. After selecting an adequate supplier, procurement logistics faces the next problem, which is the problem of order allocation, where it is now necessary to determine the quantities that need to be ordered from the supplier at the lowest possible cost. This problem is particularly complex given the many limitations that may arise on that occasion. Like the previous one, this problem has also been recognized in the literature where there are a large number of papers proposing numerous models to facilitate solving this problem [3-7].

The aim of this paper is to define the procedure of procurement optimization by selecting efficient suppliers, as well as to define a model for solving the order allocation problem. To the best of the authors' knowledge, there are no papers that simultaneously solve both problems in the way described in this paper (using MCDM methods and model for solving the problem of order allocation). This is exactly the gap that this paper deals with, which will enable managers to get a complete solution on the one hand, while on the other hand, it lays the foundation for an integrated solution for two groups of problems for future research in the literature. In order to achieve this, a hybrid Data Envelopment Analysis-Full Consistency Method-Combined Compromise Solution (DEA-FUCOM-CoCoSo) approach was applied in this paper. The DEA method is a mathematical method using linear programming techniques to convert inputs to outputs with the purpose of evaluating the performance of comparable products. The aim is to determine relative efficiency which represents the ratio of the total weighted output to the total weighted input. The FUCOM method reduces the subjectivity of decision-makers, which leads to consistency in the weight values of the criteria. For this reason, this method was applied in this paper to determine the weights of the criteria. Deviation from Full Consistency (DFC) was also obtained by applying this method. After determining the weights of the criteria, the CoCoSo method was applied in order to obtain the final rank of the suppliers. The CoCoSo method uses three aggregation strategies to generate measures of the overall utility of the alternatives. This method is characterized by an innovative structure based on the integration of compromise decision-making algorithms. In addition, the CoCoSo method is more reliable and stable than the available methods [8]. For this reason, this method has been applied in this paper in order to obtain the final rank of the suppliers. In addition, another reason for the application of this method is the fact that there are only a few papers in the field of logistics that applied this method.

The paper is organized as follows. After an introductory discussion, a description of the problem discussed in this paper was made as well as a review of the literature. The third chapter describes the formulations of the methods used in this paper, i.e., DEA method, FUCOM, CoCoSo, and order allocation model. The next chapter presents the results and discussion of applying the described methodology on the example of a trading company. At the very end, concluding remarks are given as well as directions for future research.

2. PROBLEM DESCRIPTION AND LITERATURE REVIEW

As previously mentioned, procurement logistics is one of the factors of a company's competitiveness. This is due to the fact that procurement logistics is directly responsible for procuring the necessary raw materials or finished products in order to meet market demand. The inability to meet market demand in addition to a bad reputation has an impact on the creation of additional costs. For this reason, it is very important to effectively manage these processes. However, this is quite complicated given that a number of problems arise on this occasion. Namely, it is first necessary to determine the need for procurement, then define the quantities as well as the type of product that needs to be procured. In practice, this is often done on the basis of forecasts that are determined on the basis of data from the previous period. It is then necessary to identify potential suppliers from whom products can be procured. Once established, it is necessary to define the criteria in order to evaluate and rank them. These criteria are mainly financial and logistical. Once the criteria are determined, the suppliers are evaluated according to them, after which the selection is made. After that, a tender is usually announced and negotiations are conducted. Based on this procedure, the complexity of this problem faced by procurement logistics can be seen. However, even after selecting a supplier, it is necessary to constantly monitor and measure the results in order to achieve efficient business. Monitoring of results is usually realized by applying certain key performance indicators (KPIs) that are defined [9]. In order to increase business efficiency, as well as reduce costs, it is necessary to optimize procurement. This optimization is reflected either through an increase in the value of the defined KPIs or through a decrease in the number of suppliers, i.e., cessation of work with inefficient suppliers. This problem has been recognized both in practice and in the literature where there is a large number of papers that relate only to the problem of supplier selection using various MCDM methods [10, 11].

MCDM methods are often used in solving various problems in logistics. These problems are most often related to the location of facilities (logistics centers, warehouses, etc.), the selection of suppliers, the selection of 3PL providers, etc. Thus, Ulutas et al. [12] in their paper applied the fuzzy SWARA and CoCoSo method to solve the problem of selecting the location of the logistics center. Finally, the obtained results were compared with other MCDM methods. A similar problem was addressed by Yazdani et al. [13] who developed a two-stage decision-making model consisting of the application of the DEA method in the first phase, and the application of rough full consistency (R-FUCOM) and R-CoCoSo method. The DEA method was applied to identify efficient and inefficient alternatives, while in the second phase the methods were applied to perform a ranking of efficient alternatives. Principal Component Analysis (PCA) was combined with the DEA method in the paper [14] for measuring global logistics efficiency. In the paper [15] the DEA method was used to measure transport efficiency and to identify the main factors that affect transport efficiency. Andrejić et al. [16] applied the DEA method in their paper as well as the Malmquist productivity index for measuring efficiency change in time for distribution centers. Ayadi et al. [17] applied the fuzzy FUCOM method for determining the weights of criteria and sub-criteria, and then applied fuzzy multi-attribute ideal-real comparative analysis (F-MAIRCA) and fuzzy preference ranking organization method for enrichment evaluation (F-PROMETHEE) for ranking the locations of the logistics platform. The problem of selecting a 3PL provider was addressed by Wen et al. [18] who applied the CoCoSo method in a hesitant fuzzy linguistic environment to solve the multi-expert problem of selecting a 3PL provider. Ecer and Pamucar [5] applied the fuzzy best-worst method (F-BWM) and fuzzy CoCoSo with the Bonferroni method to select a sustainable supplier. Mishra et al. [19] in their paper proposed a hesitant fuzzy CoCoSo framework based on discrimination measure for ranking sustainable 3PL reverse logistics provider. A review of the literature showed that in addition to MCDM methods, mathematical programming models based on genetic algorithm (GA), particle swarm optimization (PSO), etc. are used in the selection and optimization. Pan [4] proposed an optimization model of vendor selection based on fuzzy GA. The results of the application of the proposed model showed that it is possible to reduce the total procurement costs. The problem of supplier selection and order allocation was solved in the paper [3] in a closed-loop supply chain using Monte Carlo simulation and goal programming. Rosyidi et al. [20] proposed a model for concurrent supplier selection model to minimize the purchasing cost and fuzzy quality loss considering process capability and assembled product specification. Gheidar-Kheljani et al. [21] solved the problem of supply chain optimization policy for supplier selection by applying a mathematical programming approach. In their model, the authors assumed that after ordering, the supplier divides the order into smaller lot sizes and delivers them over a period of time. Masi et al. [22] developed a meta-model for choosing a supplier selection technique within an engineering, procurement, and construction (EPC) company. Choudhary and Shankar [23] proposed an integer linear programming model to determine ordering times, lot-sizes, suppliers, and carriers to be selected at minimal costs. Firouzi and Jadidi [24] developed a multi-objective model for supplier selection and order allocation problem with fuzzy parameters in their paper. As the literature review found that there are not enough papers dealing with the described issues in the way described in this paper, the authors decided to apply DEA-FUCOM-CoCoSo methods for supplier selection as well as the Pure Integer Conic Program (PICONE) model to solve the problem of order allocation.

Based on the above, it can be concluded that there is a significant number of papers dealing with the issue of supplier selection and the problem of order allocation, by applying various models. However, a review of the literature did not establish that there are papers dealing with the application of the MCDM methods for supplier selection and the model for solving order allocation problem. In order to select only efficient ones from the total number of suppliers, which will be later considered and evaluated using the FUCOM and CoCoSo methods, the DEA method was applied in this paper. When implementing this method, it is necessary to define inputs and outputs. The procured quantities and purchase value were defined as inputs, while revenue, sales value, number of stores where the goods of that supplier are sold, write-off, costs of excessive stocks, and service level are defined as outputs. The procured quantity represents the total quantity of goods ordered from a particular expressed in tons (t). The purchase value represents the value (price) paid by the retailer to the supplier, expressed in the monetary unit (m.u). Revenue represents the amount obtained when the value-added tax (VAT) is deducted from the sales price, expressed in the m.u. Sales value is obtained by adding the retailer’s margin and the amount of VAT to the purchase price also expressed in the m.u. The number of stores represents the total number of stores in which the goods of that supplier are sold (since the retailer has stores across the country). Write-off represents all breaks, damages, expiration of the goods, etc., which is expressed in the m.u. Excessive inventory costs occur due to poor inventory planning, which is expressed also in the m.u. The service level represents the accuracy of the supplier's delivery (in terms of the completeness of the order and the timeliness of delivery), which is expressed in percentage (%). Some of these indicators were also observed as criteria for evaluating suppliers in the FUCOM method. However, in addition to them, other logistical criteria have been defined. The reason for that lies in the fact that the observed company, when selecting a supplier, first contracts and defines financial indicators, and only after that the logistics ones. This is one of the main problems in practice, and in future models it is necessary to observe the financial and logistical criteria at the same time. For this reason, the FUCOM method considered the following criteria used to evaluate suppliers:

- Quality
- Price
- Revenue
- Excess inventory costs
- Service level
- Reliability
- Flexibility
- Write-off
- Quality certification

In order to quantify the quality of the product, sales volume (t) in the past were observed (for a period of 3 months) and suppliers were evaluated on that basis. The price of the product is obtained by subtracting the purchase value from the sales value, expressed in the m.u. Reliability was also obtained on the basis of historical data (how often the supplier complied with the agreed deadline, required quantity, and service level), expressed in %. Flexibility represents the time needed and the ability to react to sudden changes in demand. In this paper, flexibility was determined based on the data from the retailer and represents the number of additional deliveries from the supplier needed in order to satisfy the demand. Finally, the last criterion was the number of quality certifications that the supplier has, given that the quality of the considered company is an important parameter when selecting a supplier.

3. METHODOLOGY

In order to select the efficient suppliers a combination of DEA-FUCOM-CoCoSo methods was used in this paper while to solve the order allocation problem, a model for order quantity allocation was used. The methodological steps of the application of these methods are presented below (Fig. 1).

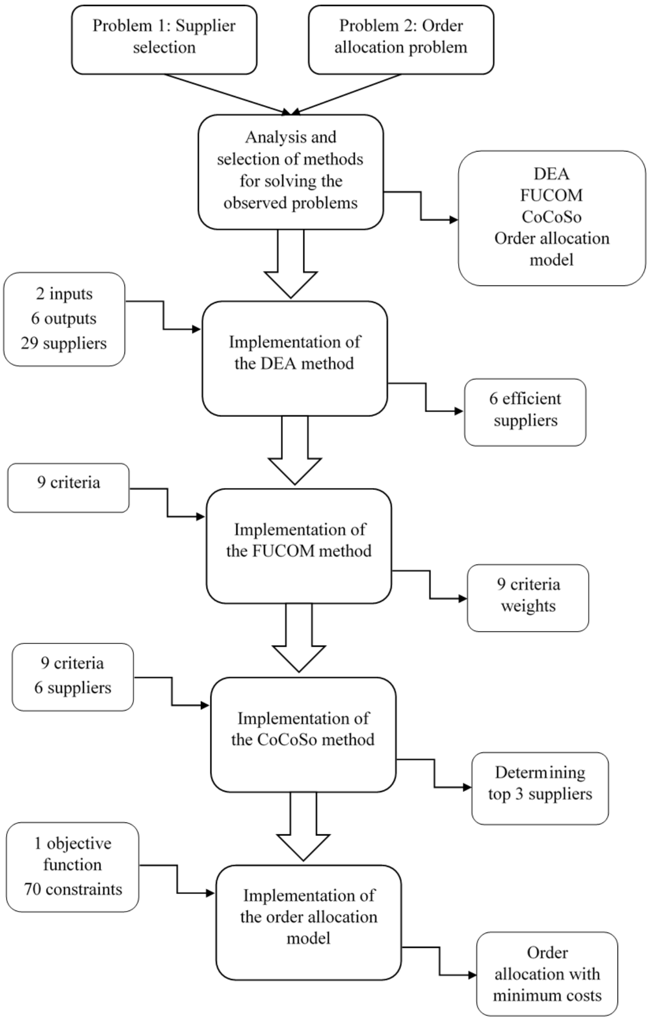

Fig. 1 Methodology

3.1 DEA method for selecting efficient suppliers

In order to single out only the efficient ones from the total number of suppliers, which will then be analyzed, the DEA CCR output-oriented model was applied, which is presented below [25]:

$$\min \sum_r v_{ri} x_{ij0} \tag{1}$$

s.t.

$$\sum_r u_r y_{rj} - \sum_r v_i x_{ij} \leq 0, \qquad \forall j \tag{2}$$

$$\sum_i u_i y_{ij0} = 1 \tag{3}$$

$$u_r, v_i \geq 0, \forall \mathrm{r}, \forall \mathrm{i} \tag{4}$$

where j represents the number of DMUs ($j=1, 2, \ldots, n$), m represents the number of inputs ($x_{ij} = 1, 2, \ldots, m$) and s represents the number of outputs ($y_{rj} = 1, 2, \ldots, s$). y_{rj} represents the amount of the r^{th} output from DMU_j; u_r represents the weight given to the r^{th} output; x_{ij} represents the amount of the i^{th} input used by DMU_j; v_i represents the weight given to the i^{th} input.

3.2 FUCOM method for determining criteria weights

The procedure for determining the weight coefficients of criteria is comprised of three steps presented below [26, 27]:

Step 1 – all evaluation criteria are ranked according to the significance (from the most significant to the least significant).

$$Cj(1) > Cj(2) > \ldots > Cj(k) \tag{5}$$

where k represents the rank of the observed criterion.

Step 2 – ranked criteria are compared in order to determine the comparative priority $\varphi_{k/(k+1)}$, where k represents the rank of the criteria.

$$\Phi = (\varphi 1/2, \varphi 2/3, \ldots, \varphi k/(k+1)) \tag{6}$$

where $\varphi_{k/(k+1)}$ represents the significance that the criterion of the $C_{j(k)}$ rank has compared to the criterion of the $C_{j(k+1)}$ rank.

Step 3 – the final values of the weight coefficients of the evaluation criteria are determined. In order to determine these values two conditions must be met:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{7}$$

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{8}$$

After these two conditions are met, the final model for determining the final values of the weight coefficients of the evaluation criteria can be defined as:

$$\mathrm{Min}\ \chi \tag{9}$$

s.t.

$$\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{\frac{k}{k+1}}\right| \leq \chi, \forall \mathrm{j} \tag{10}$$

$$\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \leq \chi, \forall \mathrm{j} \tag{11}$$

$$\sum_{j=1}^{n} w_j = 1, \forall \mathrm{j} \tag{12}$$

$$w_j \geq 0, \forall \mathrm{j} \tag{13}$$

After solving this model the final values of the evaluation criteria weights are determined $(w_1, w_2, \ldots, w_n)^T$ as well as the degree of $DFC\ (\chi)$.

3.3 CoCoSo method for supplier ranking

The procedure for the determination of final ranking by CoCoSo method includes the following steps [28]:

Step 1 – Determine the initial decision-making matrix.

Step 2 – The normalization of criteria values is accomplished based on compromise normalization equation:

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}; for\ benefit\ criterion \tag{14}$$

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}; for\ cost\ criterion \tag{15}$$

Step 3 – The total of the weighted comparability sequence and the whole of the power weight of comparability sequences for each alternative sum of the weighted comparability sequence and also an amount of the power weight of comparability sequences for each alternative as S_i and P_i respectively are calculated:

$$S_i = \sum_{j=1}^{n} \left(w_j r_{ij}\right) \tag{16}$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \tag{17}$$

Step 4 – Relative weights of the alternatives using the following aggregation strategies are computed:

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m}(P_i + S_i)} \tag{18}$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \tag{19}$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{\left(\lambda \max_i S_i + (1-\lambda) \max_i P_i\right)}; 0 \leq \lambda \leq 1 \tag{20}$$

In Eq. (20), λ is chosen by decision-makers and is usually $\lambda = 0.5$.

Step 5 – The final ranking of the alternatives is determined based on k_i values (the higher the value the better):

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \tag{21}$$

3.4 Order allocation model

In order to solve the problem of order allocation, the PICONE model was applied in this paper. The model presented is based on Anna and Fhiliantie [29] with the model being further complicated by the introduction of new constraints and the inclusion of transport costs in the objective function. The model notation which was used is shown below in Table 1.

Table 1 Model notation

Indexes	
i (i = 1,2,...,m)	Index of period (month)
j (j = 1,2,..., n)	Index of supplier
Sets	
M	Number of periods
N	Number of suppliers
Parameters	
P_{ij}	The price of raw material in the period *i* from supplier *j* (m.u./kg)
TC_{ij}	Transportation cost in period *i* for supplier *j* (m.u./kg)
OC_{ij}	The ordering cost of goods during the period *i* from supplier *j* (m.u./order)
HC_i	The holding cost of goods in period *i* (m.u./kg)
D_i	Demand of goods in period *i* (kg)
SC_{ij}	Supplier's capacity in the period *i* from supplier *j* (kg)
SS_i	Safety stock in period *i* (kg)
DT_{ij}	Delivery time in period *i* from supplier *j* (days)
DT_{max}	The maximum delivery time (days)
DQij	Discount quantity (quantity for which discount is granted) in period *i* from supplier *j* (kg)
DAij	Discount amount granted if DQ is achieved (%)
DCcap	Distribution center capacity (kg)
Decision variables	
X_{ij}	The amount of goods ordered in the period *i* from supplier *j* (kg)
Y_{ij}	Binary variable (takes value 1 if order allocation will be carried out to a supplier and 0 otherwise)
I_i	The quantity of goods stored in period *i* (kg)

The model formulation (objective function and constraints) used in this paper is shown below.

$$Min\ C = \sum_{i=1}^{m}\sum_{j=1}^{n} p_{ij}X_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n} OC_{ij}Y_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n} TC_{ij}X_{ij} + \sum_{i=1}^{m} HC_i I_i \quad (22)$$

s.t.

$$X_{ij} \leq SC_{ij} \qquad \forall i,j \quad (23)$$

$$X_{ij} \leq MSC_{ij}Y_{ij} \qquad \forall i,j \quad (24)$$

$$\sum_{j=1}^{n} X_{ij} + I_i \geq D_i \qquad \forall i \quad (25)$$

$$I_i = I_{i-1} + \sum_{j=1}^{n} X_{ij} - D_i \qquad \forall i \quad (26)$$

$$I_1 = I_0 + \sum_{j=1}^{n} X_{1j} - D_1 \quad (27)$$

$$I_i \geq SS_i, \qquad \forall i \quad (28)$$

$$SS_i = 0{,}15 * D_i \qquad \forall i \tag{29}$$

$$DT_{ij}Y_{ij} \leq DT_{max} \qquad \forall i,j \tag{30}$$

$$X_{ij}Y_{ij} \geq DQ_{ij} \qquad \forall i,j \tag{31}$$

$$OC_{ij} = DA_{ij} * OC_{i-1j} \qquad \forall i,j \tag{32}$$

$$X_{ij} + I_i + SS_i \leq DC_{cap} \qquad \forall i,j \tag{33}$$

$$Y_{ij} \in (0{,}1), \qquad \forall i,j \tag{34}$$

$$X_{ij}, I_i \geq 0 \; and \; integer, \qquad \forall i,j \tag{35}$$

$$O_{ij} \geq 0, \qquad \forall i,j \tag{36}$$

In the developed model, the objective function has the task to minimize the total costs, i.e., costs of procurement, ordering, inventory, and transportation. Constraint (23) refers to the capacity of a supplier which must be greater than the quantity ordered from that supplier. Constraint (24) refers to order quantity allocation where that quantity must be less than the total capacity of the supplier for all periods. In order to meet the demand, the constraint (25) is set. The next two constraints (26) and (27) relate to inventory balance. Since the lack of products can cause the inability to meet demand on the one hand, and on the other hand too much stock can generate excessive costs, it is necessary to find a balance in the quantity of goods in stock. When managing inventory, it is necessary to define a safety stock so that the company does not run out of products. Constraints (28) and (29) refer to this issue. Delivery time (which is the time that elapses from the moment of ordering to the moment of delivery) is also important for the ability to respond quickly to current demand. For this reason, a constraint (30) has been set. Suppliers often grant discounts on certain quantities when ordering (thus stimulating customers to order from them). For this reason, the constraints (31) and (32) are included in the model developed in this paper. Namely, if the ordered quantity is higher than the quantity for which the discount is granted, then the discount will be granted when ordering in the following period ($i+1$). Constraint (33) refers to the capacity of the retailer's distribution center which must not be exceeded. Finally, constraints (34), (35), and (36) define the variables used in this paper.

4. RESULTS AND DISCUSSION

As already mentioned, the DEA method was first used in this paper in order to single out only the efficient ones from the observed 29 suppliers. On that occasion, procured quantities and purchase value are defined as inputs, while revenue, sales value, number of stores where the goods of that supplier are sold, write-off, costs of excessive stocks and service level are defined as outputs. Based on the data obtained from the analyzed company, the previously described output-oriented CCR model was applied. After solving the set model, it was concluded that only 6 suppliers are efficient out of the total number, which is shown in Table 2.

Table 2 Results of the DEA method

DMU Name	Objective Value	DMU Name	Objective Value
Supplier 1	0.830178741	Supplier 16	1
Supplier 2	0.993094408	Supplier 17	0.912238298
Supplier 3	0.894018835	Supplier 18	0.762394285
Supplier 4	0.653831891	Supplier 19	0.935567367
Supplier 5	0.952766145	Supplier 20	0.839325219
Supplier 6	0.850352713	Supplier 21	0.727809542
Supplier 7	1	Supplier 22	0.653232181
Supplier 8	1	Supplier 23	0.852216565
Supplier 9	1	Supplier 24	0.731280219
Supplier 10	0.716469484	Supplier 25	0.85044203
Supplier 11	0.938969404	Supplier 26	0.697173369
Supplier 12	1	Supplier 27	1
Supplier 13	0.973693036	Supplier 28	0.716652258
Supplier 14	0.856429161	Supplier 29	0.985050685
Supplier 15	0.812191691		

Since the application of the DEA method separated efficient from inefficient suppliers, in the following parts of the paper only efficient suppliers were observed and analyzed. Following the application of the DEA method, the FUCOM method was applied to determine the weights of the criteria that were later used in the CoCoSo method for the final ranking of suppliers. Criteria used in this paper for evaluation are product quality (C1), price (C2), revenue (C3), excess inventory costs (C4), service level (C5), reliability (C6), flexibility (C7), write-off (C8) and quality certification (C9). The first step in applying the FUCOM method is to rank the criteria from the most significant to the least significant, which is shown below.

$$C1 > C2 > C3 > C4 > C5 > C6 > C7 > C8 > C9$$

After ranking the criteria by importance, the second step was conducted in order to determine the significance of the criteria ($\omega_{Cj(k)}$). The comparison is made with respect to the first-ranked (C1) criterion. The presented values were obtained based on the assessment of 5 experts in the field of procurement of the analyzed company. The results of the comparison are shown in Table 3.

Table 3 Priorities of criteria

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
$\omega_{Cj(k)}$	1	1.5	2.1	3.7	4.2	5	5	7	9

Based on the value of $\omega_{Cj(k)}$ from Table 3, it is possible to define a model in order to determine the weights of the criteria. The model used in this paper is presented below.

$$\text{Min } \chi$$

s.t.

$$\left|\frac{w_1}{w_2} - 1.5\right| \leq \chi, \left|\frac{w_2}{w_3} - 1.4\right| \leq \chi, \left|\frac{w_3}{w_4} - 1.76\right| \leq \chi, \left|\frac{w_4}{w_5} - 1.13\right| \leq \chi, \left|\frac{w_5}{w_6} - 1.19\right| \\ \leq \chi, \left|\frac{w_6}{w_7} - 1\right| \leq \chi, \left|\frac{w_7}{w_8} - 1.4\right| \leq \chi, \left|\frac{w_8}{w_9} - 1.28\right| \leq \chi,$$

$$\left|\frac{w_1}{w_3} - 2.1\right| \leq \chi, \left|\frac{w_2}{w_4} - 2.46\right| \leq \chi, \left|\frac{w_3}{w_5} - 1.99\right| \leq \chi, \left|\frac{w_4}{w_6} - 1.34\right| \leq \chi, \left|\frac{w_5}{w_7} - 1.19\right| \\ \leq \chi, \left|\frac{w_6}{w_8} - 1.4\right| \leq \chi, \left|\frac{w_7}{w_9} - 1.79\right| \leq \chi,$$

$$\sum_{j=1}^{9} w_j = 1,$$

$$w_j \geq 0, \forall j$$

LINGO software was used to solve the presented model. By solving the model, the values of the criteria weights were obtained *(0.3015, 0.2010, 0.1438, 0.0817, 0.0724, 0.0610, 0.0610, 0.0436, 0.0341)T* as well as the *DFC* of the results $\chi = 0.00$. After determining the weights of the criteria, the CoCoSo method was applied in order to obtain the final rank of the suppliers. The first step in applying this method involves defining an initial decision matrix, which is shown in Table 4.

Table 4 Initial decision-making matrix

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
Optimal value	**max**	**min**	**max**	**min**	**max**	**max**	**max**	**min**	**max**
S1	6.207	5.119.942	12.441.184	13.278	99	98.8	651	379.872	1
S2	4.141	2.656.669	9.070.183	121.953	96	98.3	1521	468.742	3
S3	9	1.333	4.454	0	67	99.6	25	176	4
S4	9.561	4.437.933	7.802.354	45.416	45	97.9	671	631.287	2
S5	21.116	4.576.211	11.061.054	118.626	62	99.2	1518	326.144	1
S6	148	29.337	116.760	37.059	100	98.5	32	61.294	3

After determining the initial matrix, the second step was performed, i.e., normalization according to the type of criteria. Based on Table 4 it can be concluded that in this paper, 6 criteria that are max type and 3 criteria that are min type were observed. Normalization was performed using Eqs. (14) and (15). The results of normalization are shown in Table 5.

Table 5 Normalized matrix

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
Weight	**0.3015**	**0.2010**	**0.1438**	**0.0817**	**0.0724**	**0.0610**	**0.0610**	**0.0436**	**0.0341**
S1	0.29	0.00	1.00	0.89	0.98	0.53	0.42	0.40	0.00
S2	0.20	0.48	0.73	0.00	0.93	0.24	1.00	0.26	0.67
S3	0.00	1.00	0.00	1.00	0.40	1.00	0.00	1.00	1.00
S4	0.45	0.13	0.63	0.63	0.00	0.00	0.43	0.00	0.33
S5	1.00	0.11	0.89	0.03	0.31	0.76	1.00	0.48	0.00
S6	0.01	0.99	0.01	0.70	1.00	0.35	0.00	0.90	0.67

The next step involves determining the values of S_i and P_i for each alternative (supplier) using Eqs. (16) and (17). The results of this step are shown in Tables 6 and 7.

Table 6 Weighted comparability sequence and S_i

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**S_i**
S1	0.09	0.00	0.14	0.07	0.07	0.03	0.03	0.02	0.00	0.45
S2	0.06	0.10	0.10	0.00	0.07	0.01	0.06	0.01	0.02	0.44
S3	0.00	0.20	0.00	0.08	0.03	0.06	0.00	0.04	0.03	0.45
S4	0.14	0.03	0.09	0.05	0.00	0.00	0.03	0.00	0.01	0.34
S5	0.30	0.02	0.13	0.00	0.02	0.05	0.06	0.02	0.00	0.60
S6	0.00	0.20	0.00	0.06	0.07	0.02	0.00	0.04	0.02	0.42

Table 7 Exponentially weighted comparability sequence and *Pi*

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**P_i**
S1	0.69	0.00	1.00	0.99	1.00	0.96	0.95	0.96	0.00	6.55
S2	0.61	0.86	0.96	0.00	0.99	0.92	1.00	0.94	0.99	7.27
S3	0.00	1.00	0.00	1.00	0.94	1.00	0.00	1.00	1.00	5.94
S4	0.79	0.67	0.94	0.96	0.00	0.00	0.95	0.00	0.96	5.27
S5	1.00	0.64	0.98	0.75	0.92	0.98	1.00	0.97	0.00	7.24
S6	0.22	1.00	0.51	0.97	1.00	0.94	0.72	1.00	0.99	7.34

Finally, the last step in the application of the CoCoSo method involves determining three aggregate strategies as well as the value of k_i in order to determine the final rank of the suppliers. These coefficients were determined using Eqs. (18)-(21). The obtained results are shown in Table 8.

Table 8 Final aggregation and CoCoSo ranking of the alternatives

Supplier	K_{ia}	K_{ib}	K_{ic}	K_i	Rank
S1	0.166	2.563	0.882	1.924	4
S2	0.182	2.658	0.970	2.048	2
S3	0.151	2.443	0.804	1.799	5
S4	0.133	2.000	0.706	1.518	6
S5	0.185	3.137	0.987	2.268	1
S6	0.183	2.610	0.976	2.033	3

Based on the results of Table 8, it can be concluded that suppliers S5, S2, and S6 stood out as the first three most favorable solutions. These three suppliers are then further analyzed in the second part of the paper, which deals with solving the problem of allocating quantities during ordering. To solve this problem, the previously described model in Chapter 3 was applied. The input data of the model used in this paper are shown in Table 9. The model was used to allocate orders for 3 suppliers in the next 3 months.

Table 9 Input data of the model

Parameter	Period (month)	Supplier 1	Supplier 2	Supplier 3
P_{ij}	M1	430	450	440
	M2	430	450	440
	M3	430	450	440
TC_{ij}	M1	0.58	0.56	0.60
	M2	0.58	0.56	0.60
	M3	0.58	0.56	0.60
OC_{ij}	M0	1450	1425	1500
HC_{ij}	M1	25	25	25
	M2	25	25	25
	M3	25	25	25
SC_{ij}	M1	9000	11000	8500
	M2	9000	11000	8500
	M3	9000	11000	8500
DT_{ij}	M1	2	3	2
	M2	2	3	2
	M3	2	3	2
DQ_{ij}	M1	7000	8500	6000
	M2	7200	8500	6100
	M3	7400	8800	6500
DA_{ij}	M1	10	9	10
	M2	12	12	11
	M3	13	15	14

Based on the data of the analyzed company, it was concluded that in the previous month the stock level was 5.000 kg (I_0). Also, based on the forecasts made in the company, the demand for the observed goods in the next period (for the next 3 months) is defined D_1 = 15.000 kg, D_2 = 17.500 kg, and D_3 = 19.000 kg. In order to calculate the cost of ordering (OC_{ij}) it is necessary to define the cost of ordering in the previous period, which is defined on the basis of data from the company and whose amount can be seen in Table 9 (M_0). The maximum delivery time (DT_{max}) is the time prescribed by the contracts (which are signed annually) and is 4 days for all suppliers. The last data required for the model is the capacity of the distribution center which in this case is 50.000 kg (DC_{cap}). It should be noted here that the displayed capacity refers only to the analyzed goods, and not to the capacity of the entire DC, which is significantly higher. Based on these data, a PICONE model was formed, which was solved using LINGO software. The output results of the model are shown in Table 10.

Table 10 Output results of the model

Objective function	Value	Variable	Value
C	30.304.800	O13	1.350
Variable	**Value**	O21	1.148,4
X11	7.000	O22	1.141,14
X12	8.500	O23	1.201,5
X13	6.000	O31	999,108
X21	7.200	O32	969,969
X22	8.500	O33	1033,29
X23	6.100	I1	11.500
X31	7.400	I2	15.800
X32	8.800	I3	19.500
X33	6.500	SS1	2.250
O11	1.305	SS2	2.625
O12	1.296,75	SS3	2.850

Based on the results from Table 10, it can be concluded that the total costs for the observed period are 30.304.800 m.u. In addition, it can be seen that all suppliers are engaged in all months. In the first month, it is necessary to order 7.000 kg of goods from supplier 1, 8.500 kg of goods from the second and 6.000 kg from the third. Since the quantities shown are equal to the quantities necessary to grant a discount, based on the values of the variables *O11*, *O12* and *O13*, it can be seen that the discount has been calculated and that the ordering costs amount to 1.305 m.u. for supplier 1, 1.296,75 m.u. for supplier 2 and 1.350 m.u. for supplier 3. The values of the quantity of goods in stock (11.500 kg) and safety stocks (2.250 kg) can also be seen for the first month. For the second month, according to the results of Table 10, it is necessary to order 7.200 kg of goods from supplier 1, 8.500 kg from supplier 2 and 6.100 kg of goods from supplier 3. The costs of ordering are 1.148,4 m.u.; 1.141,14 m.u.; 1.201,5 m.u. respectively. At the end of the second month, it can be seen that there are 15.800 kg of goods left in stock, and 2.625 kg of safety stocks. In the third month, it is necessary to order 7.400 kg of goods from supplier 1, 8.800 kg of goods from supplier 2 and 6.500 kg of goods from supplier 3, where the ordering costs are 999,108 m.u.; 969,969 m.u. and 1033,29 m.u. respectively. Based on these data, it can be seen that the ordering costs are the lowest for this month. At the end of the third month 19.500 kg of goods are left in stock and 2.850 kg of safety stocks.

The results of the implementation showed that the proposed approach can provide significant decision support. Also, the analyzed data in this paper refers to only 1 of the over 30 categories that exist within the analyzed company. This approach contributes because it observes all aspects of the real problem that has been solved. In addition, the proposed approach is fully applicable in practice and suitable for real-time problem solving (decision-support tool). The selection of financial and logistical criteria in the selection of suppliers as well as the costs of procurement, ordering, inventory and transport with certain constraints fully covered all real cases. One of the more significant constraint implemented in the model is the one related to the discount that is granted in case of ordering a certain quantity of products. The advantage of the proposed model is reflected in the applicability for other categories of goods, but also other types and sizes of companies, product types, etc. with minimal changes. The developed model represents a new integrated (hybrid approach) that solves two problems at once and which can be a goods basis for future research.

5. CONCLUSION

The aim of this paper was to present the complexities and problems faced by procurement logistics. The selection of suppliers, as well as the order allocation problem stand out as one of the most significant problems of procurement logistics that are recognized both in practice and in the literature. The problem of supplier selection is a frequent topic of papers in the literature where there are numerous MCDM methods used in solving this problem. On the other hand, the order allocation problem is often solved by applying numerous models and algorithms. However, a review of the literature found that there are no papers that combine these two approaches to solve the problems of supplier selection and order allocation. For this reason, a combination of DEA-FUCOM-CoCoSo methods for the selection of efficient suppliers was applied in this paper, after which a model for solving the order allocation problem was defined. The DEA method was applied in this paper in order to single out efficient from inefficient suppliers. In the example of a trading company, 6 efficient suppliers were identified, out of 29, which were then further analyzed in the paper. According to the data from the company, and also on the basis of a review of the literature, 9 criteria for evaluating suppliers have been defined. As the weights of these criteria are not the same, the FUCOM method for determining weights was applied. After solving the FUCOM model, the weights of the criteria were obtained which were then applied in the CoCoSo method to obtain the final ranking of suppliers, since the goal was to determine the 3 best suppliers (according to the observed criteria) to then determine the quantities to be ordered from them, for the next 3 months. This problem is solved in the second part of the paper where a model is defined that aims to minimize the costs of procurement, ordering, inventory, and transport with certain constraints. After solving the developed model, the results showed that it is necessary to engage all 3 suppliers each month in order to meet the demand in the market.

The limitation of this research is reflected in the application of a described methodology on a relatively small example, i.e., one product segment. The results of the analyzed example showed that the proposed approach can provide significant decision support, not only in the observed example but also beyond. Namely, the developed approach can be applied to other problems, and not only to those related to procurement, with certain changes in the model. The application of the developed approach to the problems that occur in other segments of the supply chain stands out as one of the future directions of research. In addition, the application of algorithms, such as PSO and GA, to optimize the amount of procurement also stands out as one of the directions of future research.

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