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RESEARCH PAPER

A Novel Integrated SWARA-MARCOS Model for Inventory Classification

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ABSTRACT
In the field of logistics, there is a daily need for decision making, i.e. the need to solve business problems by selecting an appropriate solution. During the implementation of decision-making processes, it is necessary to find an optimal solution that will best meet the needs of companies. The selection of an optimal solution is crucial for the profitability, cost-effectiveness and long-term development of companies. The decision-making process in logistics is facilitated by applying various tools such as multi-criteria decision-making methods. In this paper, an integrated SWARA (Step-wise Weight Assessment Ratio Analysis) – MARCOS (Measurement Alternatives and Ranking according to Compromise Solution) model was developed and applied in order to classify products. Fifty alternatives, i.e. products were evaluated based on three criteria. The first criterion is the quantity of purchased products, the second criterion is the unit price of products and the third criterion is the annual value of purchase. The SWARA method was applied to determine the significance of the criteria, while the classification of products was performed using the MARCOS method. According to the results of the originally created MCDM model, the products were grouped into three categories A, B, and C. Then, a sensitivity analysis was performed using a model involving the integration of SWARA method and ABC analysis. Using this model, the classification of products into three groups was performed on the basis of the aforementioned criteria, and then a comparative analysis was conducted.

KEYWORDS: *SWARA method; MARCOS method; ABC analysis; MCDM; Inventory classification.*

1. Introduction

The need for decision making in logistics arises on a daily basis. Decision making is one of the most important processes in business activities. The results of decision-making process can have a short-term or long-term positive or negative impact on business operations. The selection of an optimal decision, i.e. solution greatly affects the further company's development and growth, business efficiency and cost-effectiveness, competitiveness in the market and many other important factors of business activities. The decision-making process is greatly facilitated by applying various decision-making methods and techniques, especially in terms of complex multi-criteria decision-making (MCDM). Multi-criteria decision-making is decision-making based on different criteria that are used to evaluate different variants of problem solving. Multi-criteria decision-making methods not only serve to highlight one, the best alternative from a set of observed ones, but can also be used to rank alternatives or to separate acceptable alternatives from unacceptable ones. Therefore, it should be found a solution that is the best according to all considered criteria at the same time, although the criteria considered are partially or completely conflicting in most cases.

Inventory means stored material used to ensure normal production and meet customer needs. One of the most important tasks of logistics management is inventory management. When managing inventory, we strive to keep them as small as possible, but sufficient to meet the needs of customers, i.e. consumers. Too much

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inventory leads to high inventory costs, while too little inventory implies a number of problems and consequences in overall business operations.

Various methods, techniques and analyzes are used to determine the optimal quantity of inventory and to classify existing inventory. An indispensable tool in inventory classification is ABC analysis, the basic function of which is to rationalize purchasing and inventory management. The aim of this paper is to create an integrated SWARA – MARCOS model for the first time in order to classify inventory into three different groups. In this paper, it is necessary to classify 50 products on the basis of several criteria in order to obtain precise data on the significance of products in inventory management processes. The first criterion is the quantity of purchased products, the second criterion is the unit price of products and the third criterion is the annual value of purchase. In order to solve this problem, it is used a combination of MCDM methods, more precisely the SWARA method and the MARCOS method. The SWARA method was applied to obtain the weight values of the criteria, and then the MARCOS method was used to rank the products.

In addition to the introductory notes on the importance of the research field in Section 1, the paper is structured through five other sections. In Section 2 of the paper, a review of literature is provided with a review of the previous application of the methods used in this paper. Section 3 presents the methodology of the paper which, as already mentioned, consists of SWARA method, MARCOS method and ABC analysis. Application procedures and basic features of the stated methods and ABC analysis are explained in detail. So far, the SWARA method has found its application for solving various problems precisely due to the simplicity of its application. The MARCOS method is a very flexible and simple method that can be applied to solve problems from different business areas and logistics. The main advantage of ABC analysis is to focus on important processes in a supply chain, i.e. to classify products based on the ratio of consumption/inventory/sales. In Section 4, the problem is solved, i.e. the weight values of the criteria are first determined applying the SWARA method, and they are further used when applying the MARCOS method and ABC analysis. Then, an initial matrix for the MARCOS method is formed on the basis of determined values of the stated products, and the products are ranked on the basis of the values obtained by applying the MARCOS method. In addition, in Section 5, a sensitivity analysis of the results obtained is performed applying a model that includes the integration of SWARA method and ABC analysis, and single-criterion ABC analysis. More precisely, it is performed the ABC analysis which enables the grouping of products into group A, B or C, i.e. enables the classification of products into important and more important, and those less important, which leads to the most profitable products.

2. Literature Review

The aforementioned multi-criteria decision-making methods, i.e. the SWARA method and the MARCOS method, have found their application for solving various problems. Below, it will be mentioned some of the papers related to the application of the following: SWARA method, MARCOS method and ABC analysis. Stević et al. [1] developed the MARCOS method and evaluated and ranked suppliers in the healthcare sector. It has been concluded that the MARCOS method is a very useful tool for everyday decision making in different fields since it allows considering a large number of criteria and alternatives while maintaining the stability of the method. The MARCOS method is based on examining the reference values of alternatives in relation to ideal values and a comprehensive rational and reasonable application methodology [1]. The model is very flexible and simple, so it can be applied to other problems of multi-criteria analysis, which is confirmed by Stević and Brković [2] in their research where the MARCOS method was applied to evaluate human resources. Ulutaş et al. [3] apply the MARCOS method for ranking alternatives, i.e. in order to rank and select the optimal equipment for performing logistics activities in a warehouse. Based on the paper, it has been concluded that the MARCOS method is easy to use and facilitates the decision-making process, and that in combination with other multi-criteria decision-making methods further contributes to increasing the reliability of assessment. Puška et al. [4] apply the MARCOS method in order to evaluate project management software. It has been noticed that the results obtained by applying the MARCOS method can be used to further define long-term strategies for growth and development of enterprises. According to Ajalli et al. [5], SWARA is a multi-criteria decision-making method in which experts, i.e. decision-makers have the most significant role in calculating and finally assessing the weights of criteria defined. According to the authors, the stated decision model can be used in various areas of management when making decisions such as project selection, site and technology selection, supply chain selection, etc. Durmaz et al. [6] point out the importance of integrating the SWARA method and other stochastic methods in order to increase the efficiency of decision making. The application of this model enables decision-makers to implement a decision-making process outside their fields of expertise, which is confirmed by Vesković et al. [7] in their research where the integrated model Delphi – SWARA – MABAC (multiattributive border approximation area comparison) was applied. Stanujkic et al. [8] point out the advantages of applying the SWARA method in comparison to the AHP method (Analytical Hierarchy Process). The advantages of the application refers to a significantly smaller number of pairwise comparisons compared to the AHP method, therefore, the SWARA method is also much easier for application. Radović and Stević [9] evaluated and selected key performance indicators in transportation using the SWARA method. The authors have concluded that it is possible to create scenarios that will increase the productivity of the company and fully meet the transportation requirements of users of their services, relying on ranking by experts and the use of the SWARA method. Singh et al. [10] applied the integrated SWARA – WASPAS (Weighted aggregated sum product assessment) model to assess suppliers in the cement industry where it is shown the great importance of applying the SWARA method in a decision-making process, i.e. the impact of selecting an optimal solution on business efficiency. A similar study was conducted by Yazdani et al. [11] where it was emphasized the advantage of the SWARA method, which enables all experts or decision-makers to determine the significance of each criterion by themselves.

According to Dujmović [12], the application of ABC analysis leads to establishing an efficient system of control and management of purchasing, sales and warehousing operations. Kampf et al. [13] applied ABC analysis in the automotive industry with the aim of using the cost saving effect. It has been concluded that ABC analysis is one of the tools that enable companies to control their costs. It provides management with the ability to evaluate and control the resources used within the company. It allows management to assess whether costs are in line with the purpose of their spending. Yu [14] proved that multi-criteria ABC analysis together with ERP systems (Enterprise Resource Planning) have a great impact on increasing the efficiency of inventory management, i.e. increasing the efficiency and cost effectiveness of business operations.

3. Methodology

The methodology of the paper is shown in Figure 1 where it is easiest to see what procedures are implemented in the paper, and the way of applying ABC analysis and the integration of SWARA and MARCOS methods. Product characteristics are systematized according to: quantity of purchased products, unit price and annual value of purchase. The total number of products is 50, and three criteria are defined. The first criterion is the quantity of purchased products, the second criterion is the unit price of products and the third criterion is the annual value of purchase. It is first necessary to determine the significance of the criteria they have in the classification of inventory. This can be done by applying multi-criteria decision-making methods. In this case, the SWARA method is applied to determine the weights of the criteria. Each step of the method is explained clearly and in detail. After determining the weight of the criteria, it is further applied the MARCOS method, which is implemented through seven steps, which are explained in detail in the paper. Based on the results of the applied MARCOS method, the products are ranked. At the end of the paper, a sensitivity analysis of the results obtained is performed using a model that includes the integration of the SWARA method and ABC analysis. The products are grouped into three groups: A, B and C. The most important products are classified into group A, while group B consists of moderately important products. Group C includes relatively insignificant products whose share by type increases and share by value decreases.

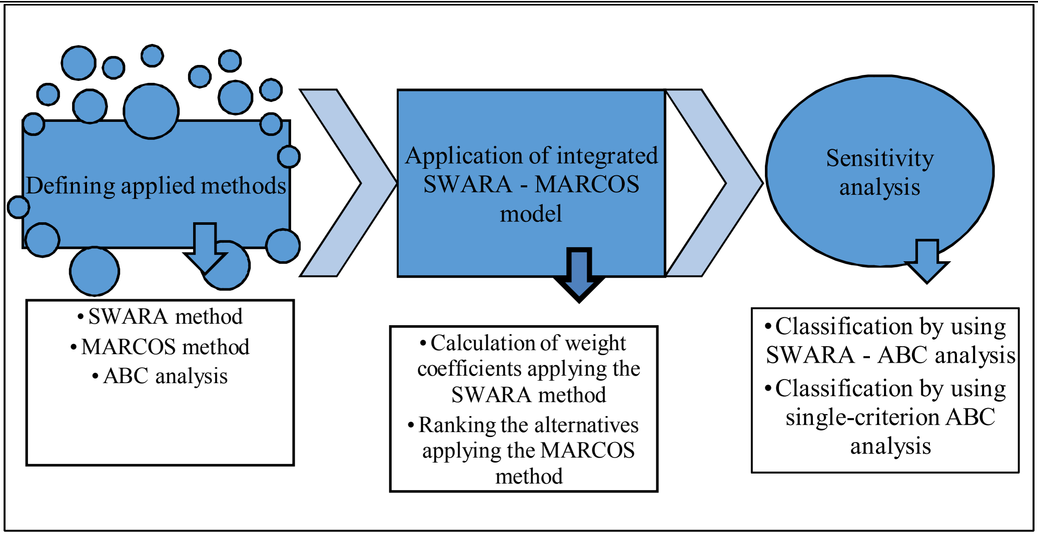

Fig. 1. Applied methodology

3.1. SWARA method

The method of weight assessment ratio analysis or the SWARA method is a widely applied method that has been commonly used in combination with other MCDM methods in determining the weight of criteria so far. Keršulienė et al. [15] have proposed the SWARA method that allows the inclusion of experts' opinion in the process of rational decision making. The way in which the SWARA method is manifested is the facilitated approach and process of finding a solution. Stanujkic et al. [8] especially emphasize the advantages of applying the SWARA method in comparison to the AHP method. The advantages of the application refer to a significantly smaller number of pairwise comparisons compared to the AHP method, therefore, the SWARA method is also much easier for application. Although SWARA is one of newer methods, so far it has found its application for solving various problems, such as: ranking companies according to indicators of corporate social responsibility [16], selection of packaging design [8], personnel selection problems [17], evaluation of key performance indicators in transportation [9], etc. The mathematical overview of determining the weights of criteria using the SWARA method can also be presented as follows [15]:

Step 1: The criteria need to be sorted in descending order based on their expected significance. For example, the most significant criterion is in the first position, and the least significant criterion is in the last position.

Step 2: Starting from the previously determined rank, the relative significance of that criterion (criterion Cj) is determined in relation to the subsequent one (Cj+1), and this is repeated for each subsequent criterion. This relation, i.e. ratio, is also called the comparative significance of the average value sj.

Step 3: Determining the coefficient kj as in (1):

$$kj = \begin{Bmatrix} 1 & j = 1 \\ sj + 1 & j > 1 \end{Bmatrix} \tag{1}$$

Step 4: Determining the calculated weights qj as in (2):

$$qj = \begin{Bmatrix} 1 & j = 1 \\ \frac{qj-1}{kj} & j > 1 \end{Bmatrix} \tag{2}$$

Step 5: Calculation of weight coefficients using the following equation as in (3):

$$wj = \frac{qj}{\sum_{k=1}^{n} qk} \tag{3}$$

where wj represents the relative weight of criterion j, and n represents the number of criteria.

3.2. MARCOS method

In this sections of the paper, the algorithm of the MARCOS method is presented. The MARCOS method is based on defining the relations between alternatives and reference values (ideal and anti-ideal alternatives). On the basis of defined relations, the utility functions of alternatives are determined and it is made a compromise ranking in relation to ideal and anti-ideal solutions [18]. Decision preferences are defined on the basis of utility functions. Utility functions represent the position of an alternative in relation to an ideal and anti-ideal solution. The best alternative is the one that is closest to an

ideal and at the same time the furthest from an anti-ideal reference point. The MARCOS method is implemented through the following steps [1]:
Step 1: Forming an initial decision matrix. Multi-criteria models involve defining a set of n criteria and m alternatives. In the case of group decision-making, it is necessary to form a set of r experts who will evaluate the alternatives according to the criteria. In the case of group decision making, expert correspondent matrices are aggregated into an initial aggregated decision matrix.
Step 2: Forming an extended initial matrix as in (4). In this step, the initial matrix is extended by defining an ideal (AI) and anti-ideal (AAI) solution.

$$X = \begin{array}{c} \\ AAI \\ A_1 \\ A_2 \\ \cdots \\ A_m \\ AI \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{aa1} & x_{aa2} & \cdots & x_{aan} \\ x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \\ x_{ai1} & x_{ai2} & \cdots & x_{ain} \end{bmatrix} \end{array} \quad (4)$$

The anti-ideal solution (AAI) represents the worst alternative while the ideal solution (AI) represents an alternative with the best characteristics. Depending on the nature of the criteria, AAI and AI are defined by applying Expressions (5) and (6):

$$AAI = \min x_{ij} \ if\ j \in B \ and\ max\ x_{ij}\ if\ j \in C \quad (5)$$

$$AI = \max x_{ij} \ if\ j \in B \ and\ min\ x_{ij}\ if\ j \in C \quad (6)$$

where B represents a benefit group of criteria, while C represents a non-benefit group of criteria.
Step 3: Normalization of the extended initial matrix (X). The elements of the normalized matrix $N = [n_{ij}]_{m\times n}$ are obtained by applying Expressions (7) and (8):

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \quad if\ j \in C \quad (7)$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \quad if\ j \in B \quad (8)$$

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

Step 4: Determining the weighted matrix $V = [v_{ij}]_{mxn}$. The weighted matrix V is obtained by multiplying the normalized matrix N by the weight coefficients of the criterion w_j, Expression (9).

$$v_{ij} = n_{ij} \times w_j \quad (9)$$

Step 5: Calculation of the utility degree of the alternative K_i. By applying Expressions (10) and (11), the utility degrees of the alternative in relation to an anti-ideal and ideal solution are calculated.

$$K_i^- = \frac{S_i}{S_{aai}} \quad (10)$$

$$K_i^+ = \frac{S_i}{S_{ai}} \quad (11)$$

where S_i (i=1,2,..,m) represents the sum of the elements of the weighted matrix V, Expression (12)

$$S_i = \sum_{i=1}^{n} v_{ij} \quad (12)$$

Step 6: Determining the utility function of alternatives $f(Ki)$. The utility function represents a compromise of the observed alternative in relation to an ideal and anti-ideal solution. The utility function of alternatives is defined by applying Expression (13)

$$f(K_i) = \frac{K_i^+ + K_i^-}{\frac{1-f(K_i^+)}{f(K_i^+)} + \frac{1-f(K_i^-)}{f(K_i^-)}} \quad (13)$$

where $f(K_i^-)$ represents the utility function in relation to an anti-ideal solution, while $f(K_i^+)$ represents the utility function in relation to an ideal solution. The utility functions in relation to an ideal and anti-ideal solution are determined by applying Expressions (14) and (15).

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \quad (14)$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \quad (15)$$

Step 7: Ranking the alternatives. The ranking of alternatives is done on the basis of the final values of utility functions. It is preferable that the alternative has as higher value of the utility function as possible.

3.3. ABC analysis

ABC analysis in inventory management is an almost unavoidable tool since efficient inventory classification can be a vital activity for companies, especially in terms of a large amount of inventory. ABC analysis is a simple stochastic method [20]. The main advantage of ABC analysis is to focus on essential processes in a supply chain, i.e. to classify products based on the ratio of consumption/inventory/sales. ABC analysis enables the classification of products into three groups, i.e. it enables the classification of products into important and more important, and those less important, which leads to the most profitable products, i.e. cost reduction. The most important products are classified into group A, while groups B and C consist of products whose share by type increases and share by value decreases. In other words, the most attention is paid to group A, less to group B, and the least to group C [12]. The procedure for conducting ABC analysis can be described through the following stages [12]:

- Collecting data on annual needs or consumption of materials in the last 12 months by types and calculating the value of needs/consumption by multiplying the quantities of individual materials with their planned or average purchase prices
- Sorting materials in descending order according to the value of annual needs/consumption and calculating the percentage share of the value of individual materials in the total value of annual needs/consumption and cumulation of percentage shares
- Comparison of cumulative percentage shares of the value of annual demand/consumption and percentage share of the number of types, on the basis of which we can determine groups A, B and C and for each material to which group it belongs.

During the implementation of the third stage of ABC analysis, i.e. when sorting materials into groups A, B and C, it is necessary to meet the following conditions [18]:

The percentage share of costs or number of individual product categories in relation to total purchese costs/total number should satisfy the condition shown by Equation (16):

$$A = 40 - 80\%\,, B = 15 - 40\%\,, C = 5 - 20\% \tag{16}$$

The percentage of individual product categories out of the total number of all product types should satisfy the condition shown by Equation (17):

$$A = 5 - 25\%, B = 20 - 40\%, C = 40 - 75\% \tag{17}$$

The relation of the number of products to the category should satisfy the following condition (18):

$$A < B < C \tag{18}$$

Group A requires the utmost attention and control by management. The trend of this group was important in the past, but future trends are also important, and they are determined by forecasting demand and production. In order to achieve the above, it is necessary to devote attention to inventory management at all levels of the company. Group B is most often managed by computer, thus creating the preconditions for the maximum attention of management to product group A. In group C, it is important to emphasize the large portion of the products of this group in the total number, but of small value. For this group, the goal is to increase safety stock, and minimize the number of orders [12].

Classical ABC analysis that takes into account only one criterion is the most applicable analysis in the process of determining the state of inventory due to its simplicity. However, the biggest disadvantage of classical ABC analysis is exactly that consideration of one-criterion function [19], therefore there are significant papers in the literature that take into account several criteria. Compared to classical analysis, the ABC analysis based on a multi-criteria function achieves significant savings. Quantitative and value analysis are most often used as criteria. When applying the ABC analysis based on a multi-criteria function, two problems can arise: how to select relevant criteria and how to determine their significance [20].

4. Numerical Example of Applying an Integrated SWARA – MARCOS Model

This section presents the procedure for applying an integrated SWARA – MARCOS model with the aim of determining the weight values of criteria and ranking the alternatives. As already mentioned, the characteristics of the products are systematized according to: the quantity of purchased products, unit price and the annual value of purchase. Based on the stated product characteristics, three criteria are defined. The first criterion is the quantity of purchased products, the second criterion is the unit price of products and the third criterion is the annual value of purchase. All three criteria need to be maximized. Quantity is the amount of products ordered on an annual basis and can be expressed in the following units: pieces, bags, tons… Unit price is an individual monetary expression of costing of the above products. The annual value of purchase is obtained by multiplying the unit price for each product individually by the quantity of a particular product.

4.1. Application of SWARA method for determining the significance of criteria for product classification

In this section of the paper, it is used the SWARA method, which is applied to determine the value of weight coefficients. The first step is to rank the criteria according to their significance. The most significant criterion is in the first position, and the least significant criterion is in the last position. In this case, criterion C3 is in the first position, criterion C2 is in the second position and criterion C1 is in the third position. After the ranking in the second step, it is necessary to determine the relative significance of criterion Cj in relation to the subsequent criterion (Cj+1). The first criterion always has a value of 1.00, while the other values indicate the dominance of one criterion over the subsequent one. In this case, criterion C3 is 0.25 more significant than C2, while C2 is 0.13 more significant than C1. Applying the third step of the SWARA method, i.e. Equation (1), the values of the coefficient Kj are obtained, which is shown in the third column of Table 1. In the fourth step, applying Equation (2), the calculated weights *qj* are obtained. The example of calculation is: q2 = 1/1.25 = 0.8, etc. In the fifth step, applying Equation (3), we calculate the final values of the criteria, which is also shown in Table 1. For example: w1 = 1/2.5 = 0.40, etc. Thus, the weight value of the first criterion is 0.28, of the second criterion 0.32 and of the third criterion 0.40. The obtained values of weight coefficients will be further used when applying the MARCOS method and ABC analysis.

Tab. 1. Weight values of criteria

	Sj	Kj= Sj+1	qj	Wj
C3	1.00	1.00	1.00	0.40
C2	0.25	1.25	0.80	0.32
C1	0.13	1.13	0.71	0.28
$\sum$			2.51	

4.2. Ranking the alternatives using the MARCOS method

Applying the MARCOS method, it is necessary to rank the alternatives, i.e. ranking of 50 products based on three previously defined criteria. At the very beginning, it is necessary to form an initial decision matrix, and then to form an extended initial matrix by defining an ideal (AI) and anti-ideal solution (AAI). The ideal and anti-ideal solution are defined depending on the nature of the criteria by applying Equations (5) and (6). In this case, all the criteria are of benefit type, and the least value is taken as an anti-ideal solution. For the first criterion it is 5, for the second criterion 7 and for the third criterion 35. An ideal solution is determined by applying Equation (6) and in this case it is necessary to choose the highest values. The ideal solution for the first criterion is 147, for the second criterion 50 and for the third criterion 6762. The extended initial decision matrix is shown in Table 2.

Tab. 2. Extended initial decision matrix

Alternatives	C1	C2	C3
AAI	5	7	35
A1	25	17	425
A2	106	29	3074
A3	38	10	380
A4	125	34	4250
A5	141	21	2961
A6	37	46	1702
A7	83	34	2822
A8	74	8	592
A9	100	45	4500

A10	87	35	3045
A11	142	14	1988
A12	126	17	2142
A13	147	46	6762
A14	41	22	902
A15	85	49	4165
	…		
A40	90	16	1440
A41	32	50	1600
A42	132	11	1452
A43	106	34	3604
A44	95	25	2375
A45	92	8	736
A46	114	12	1368
A47	98	42	4116
A48	106	16	1696
A49	139	35	4865
A50	89	27	2403
AI	147	50	6762

The next step is to normalize the initial matrix by applying Equation (7) for cost criteria and (8) for benefit criteria. So, we apply Equation (8) because all the criteria are of benefit type in this case. The values of the normalized decision matrix are shown in Table 3. The example of normalization is as follows:

$$n_{11} = \frac{25}{149} = 0.17\ ;\ n_{12} = \frac{17}{50} = 0.34$$

Tab. 3. Normalized matrix

Alternatives	C1	C2	C3
AAI	0.034	0.14	0.005
A1	0.170	0.34	0.063
A2	0.721	0.58	0.455
A3	0.259	0.20	0.056
A4	0.850	0.68	0.629
A5	0.959	0.42	0.438
A6	0.252	0.92	0.252
A7	0.565	0.68	0.417
A8	0503	0.16	0.088
A9	0.680	0.90	0.665
A10	0.592	0.70	0.450
A11	0.966	0.28	0.294
A12	0.857	0.34	0.317
A13	1.000	0.92	1.000
A14	0.279	0.44	0.133
A15	0.578	0.98	0.616
	…		
A40	0.612	0.32	0.213
A41	0.218	1.00	0.237
A42	0.898	0.22	0.215
A43	0.721	0.68	0.533
A44	0.646	0.50	0.351
A45	0.626	0.16	0.109
A46	0.776	0.24	0.202
A47	0.667	0.84	0.609
A48	0.721	0.32	0.251
A49	0.946	0.70	0.719
A50	0.605	0.54	0.355
AI	1.000	1.00	1.000

After the normalization of the extended initial matrix, it is necessary to calculate the values of the weighted normalized matrix by applying Equation (9), i.e. it is necessary to multiply the previously normalized matrix with the values of the criteria obtained by applying the SWARA method: C1=0.28, C2=0.32, C3=0.40. The weighted normalized matrix is shown in Table 4.

Tab. 4. Weighted decision matrix

Alternatives	C1	C2	C3
AAI	0.010	0.045	0.002
A1	0.048	0.109	0.025
A2	0.202	0.186	0.182
A3	0.072	0.064	0.022
A4	0.238	0.218	0.251
A5	0.269	0.134	0.175
A6	0.070	0.294	0.101
A7	0.158	0.218	0.167
A8	0.141	0.051	0.035
A9	0.190	0.288	0.266
A10	0.166	0.224	0.180
A11	0.270	0.090	0.118
A12	0.240	0.109	0.127
A13	0.280	0.294	0.400
A14	0.078	0.141	0.053
A15	0.162	0.314	0.246
	…		
A40	0.171	0.102	0.085
A41	0.061	0.320	0.095
A42	0.251	0.070	0.086
A43	0.202	0.218	0.213
A44	0.181	0.160	0.140
A45	0.175	0.051	0.044
A46	0.217	0.077	0.081
A47	0.187	0.269	0.243
A48	0.202	0.102	0.100
A49	0.265	0.224	0.288
A50	0.170	0.173	0.142
AI	0.280	0.320	0.400

The next step is to calculate the utility degree of alternatives K_i applying Equations (10) and (11). First of all, it is necessary to summarize all values by rows for all alternatives as follows: S_{AAI} = 0.010+0.045+0.002 = 0.056, etc. Then, we calculate the degree of utility in relation to the anti-ideal solution by applying Equation (10). The example of calculation is as follows:

$$K_1^- = \frac{0.182}{0.056} = 3.219$$

After that, by applying Equation (11), we obtain the degree of utility in relation to the ideal solution, e.g.

$$K_1^+ = \frac{0.182}{1.00} = 0.182$$

All other utility degree values for all alternatives are shown in Table 5. The next step is to calculate the utility function of alternatives. The utility function according to the anti-ideal solution by applying Equation (14) is obtained as follows:

$$f(K_1^-) = \frac{K_1^+}{K_1^+ + K_1^-} = \frac{0.182}{0.182 + 3.219} = 0.053$$

While the utility function according to the ideal solution is obtained by applying Equation (15):

$$f(K_1^+) = \frac{K_1^-}{K_1^+ + K_1^-} = \frac{3.219}{0.182 + 3.219} = 0.947$$

The finally obtained utility functions of the alternatives are obtained by applying Equation (13) as follows:

$$f(K_1) = \frac{0.182 + 3.129}{\frac{1-0.947}{0.947} + \frac{1-0.053}{0.053}} = 0.181$$

In the same way, other values of the utility function of alternatives are obtained, which are shown in Table 5. Finally, it is necessary to rank the alternatives according to the value of the utility function.

Table 5. Results obtained by applying the MARCOS method

Alternatives	S_i	K_i^-	K_i^+	fK^-	fK^+	fK_i	Rank
AAI	0.056						
A1	0.182	3.219	0.182	0.053	0.947	0.181	45
A2	0.569	10.096	0.569	0.053	0.947	0.568	22
A3	0.159	2.817	0.159	0.053	0.947	0.158	46
A4	0.707	12.539	0.707	0.053	0.947	0.705	11
A5	0.578	10.252	0.578	0.053	0.947	0.576	20
A6	0.466	8.255	0.466	0.053	0.947	0.464	31
A7	0.543	9.622	0.543	0.053	0.947	0.541	24
A8	0.227	4.028	0.227	0.053	0.947	0.226	44
A9	0.745	13.205	0.745	0.053	0.947	0.742	8
A10	0.570	10.105	0.570	0.053	0.947	0.568	21
A11	0.478	8.470	0.478	0.053	0.947	0.476	28
A12	0.476	8.432	0.476	0.053	0.947	0.474	30
A13	0.974	17.278	0.974	0.053	0.947	0.971	1
A14	0.272	4.828	0.272	0.053	0.947	0.271	40
A15	0.722	12.801	0.722	0.053	0.947	0.720	10
			…				
A40	0.359	6.366	0.359	0.053	0.947	0.358	37
A41	0.476	8.433	0.476	0.053	0.947	0.474	29
A42	0.408	7.230	0.408	0.053	0.947	0.406	33
A43	0.633	11.219	0.633	0.053	0.947	0.631	15
A44	0.481	8.537	0.481	0.053	0.947	0.480	27
A45	0.270	4.787	0.270	0.053	0.947	0.269	41
A46	0.375	6.647	0.375	0.053	0.947	0.374	36
A47	0.699	12.394	0.699	0.053	0.947	0.697	12
A48	0.405	7.175	0.405	0.053	0.947	0.403	34
A49	0.777	13.770	0.777	0.053	0.947	0.774	5
A50	0.484	8.591	0.484	0.053	0.947	0.483	26
AI	1.000		1.000				

According to the results obtained, alternative, i.e. product 13 is the best product according to all defined criteria. Then, the second position is taken by product 16, while product 27 takes the third position in the overall ranking. Product 34 is in the last position in the ranking. Setting the following restriction, the products are classified into three groups: 0.00-0.500=C, 0.500-0.700=B and >0.700=A. According to the given restriction, 26 products are classified into group C, 13 into group B and 11 into group A.

5. Sensitivity Analysis

5.1. Classification of products by applying an integrated SWARA – ABC analysis model

At the very beginning, it is necessary to calculate the annual value of purchase (AVP) by multiplying the quantity of individual products (Q) and the unit price (UP) for each product individually, e.g. $AVP = Q * UP \rightarrow AVP_{(P1)} = 25 * 17 = 425$. Then, we calculate the percentage share for each product and for all criteria. The percentage share, i.e. share for the first criterion, i.e. the quantity, is obtained as the quotient of the quantity of individual products and the total quantity of all products. The example of the calculation is as follows:

$$S_Q = \frac{Q}{\sum Q} \rightarrow S_{Q(P1)} = \frac{25}{4235} * 100 = 0.59\%$$

In the same way, the share by products for other criteria is obtained, i.e. the share for the unit price (unit price for a certain product/total value of unit prices) and the share in the annual value of purchase (annual value of purchase for each product individually/total value of annual purchase). The exampe of calculation is as follows:

$$S_{UP} = \frac{UP}{\sum UP} \rightarrow S_{UP(P1)} = \frac{17}{14701} * 100 = 1.16\%$$

$$S_{AVP} = \frac{AVP}{\sum AVP} \rightarrow S_{AVP(P1)} = \frac{425}{127027} * 100 = 0.33\%$$

Then, it is calculated the percentage share by products for the defined criteria, i.e. for quantity, unit price and annual value of purchase that we multiply with the corresponding values of weight coefficients obtained by applying the SWARA method. Therefore, the percentage share by products related to quantity is multiplied by 0.28, the percentage share of individual products in the total unit price is multiplied by 0.32 and the percentage share of individual products in the total annual value of purchase is multiplied by 0.40.

The values obtained in this way are summarized by products, and thus we obtain the final value of the percentage share by products on the basis of which it is necessary to sort the products in descending order. The final value of the percentage share by products is shown in Figure 2. After that, we cumulate the values of the final percentage shares and sort the products into groups A, B and C. When sorting products into groups, it is necessary to meet conditions (16), (17) and (18). By applying all the conditions that need to be met when sorting products into groups, we obtain the following results:

- Group A includes 13 products;
- Group B includes 17 products;
- Group C includes 20 products.

The values obtained by applying the above steps of ABC analysis are shown in Tables 6 and 7.

Tab. 6. Percentage share of products by criteria

Product	Quantity	Share	MCDM-Q	Unit price	Share	MCDM-UP	AVP	Share	MCDM-AVP
P1	25	0.59%	0.17%	17	1.16%	0.37%	425	0.33%	0.13%
P2	106	2.50%	0.71%	29	1.97%	0.63%	3074	2.42%	0.96%
P3	38	0.90%	0.25%	10	0.68%	0.22%	380	0.30%	0.12%
P4	125	2.95%	0.83%	34	2.31%	0.74%	4250	3.35%	1.33%
P5	141	3.33%	0.94%	21	1.43%	0.46%	2961	2.33%	0.93%
P6	37	0.87%	0.25%	46	3.13%	1.00%	1702	1.34%	0.53%
P7	83	1.96%	0.55%	34	2.31%	0.74%	2822	2.22%	0.89%
P8	74	1.75%	0.49%	8	0.54%	0.17%	592	0.47%	0.19%
P9	100	2.36%	0.67%	45	3.06%	0.98%	4500	3.54%	1.41%
P10	87	2.05%	0.58%	35	2.38%	0.76%	3045	2.40%	0.96%
P11	142	3.35%	0.95%	14	0.95%	0.30%	1988	1.57%	0.62%
P12	126	2.98%	0.84%	17	1.16%	0.37%	2142	1.69%	0.67%
P13	147	3.47%	0.98%	46	3.13%	1.00%	6762	5.32%	2.12%
P14	41	0.97%	0.27%	22	1.50%	0.48%	902	0.71%	0.28%
P15	85	2.01%	0.57%	49	3.33%	1.06%	4165	3.28%	1.31%
				…					
P40	90	2.13%	0.60%	16	1.09%	0.35%	1440	1.13%	0.45%
P41	32	0.76%	0.21%	50	3.40%	1.08%	1600	1.26%	0.50%
P42	132	3.12%	0.88%	11	0.75%	0.24%	1452	1.14%	0.46%
P43	106	2.50%	0.71%	34	2.31%	0.74%	3604	2.84%	1.13%
P44	95	2.24%	0.63%	25	1.70%	0.54%	2375	1.87%	0.75%
P45	92	2.17%	0.61%	8	0.54%	0.17%	736	0.58%	0.23%
P46	114	2.69%	0.76%	12	0.82%	0.26%	1368	1.08%	0.43%
P47	98	2.31%	0.65%	42	2.86%	0.91%	4116	3.24%	1.29%
P48	106	2.50%	0.71%	16	1.09%	0.35%	1696	1.34%	0.53%
P49	139	3.28%	0.93%	35	2.38%	0.76%	4865	3.83%	1.53%
P50	89	2.10%	0.59%	27	1.84%	0.59%	2403	1.89%	0.75%

Tab. 7. Cumulative calculation and product grouping applying ABC analysis

Product	Final	Product-sort.	Final-sort.	Cumulative	Group
P1	0.67%	P13	4.10%	4.10%	A
P2	2.30%	P16	3.49%	7.59%	A
P3	0.59%	P27	3.47%	11.07%	A
P4	2.91%	P49	3.21%	14.28%	A
P5	2.32%	P28	3.20%	17.48%	A
P6	1.78%	P23	3.18%	20.66%	A
P7	2.18%	P33	3.18%	23.84%	A

P8	0.85%	P17	3.06%	26.90%	A
P9	3.06%	P9	3.06%	29.96%	A
P10	2.30%	P15	2.94%	32.90%	A
P11	1.87%	P4	2.91%	35.80%	A
P12	1.88%	P47	2.86%	38.66%	A
P13	4.10%	P18	2.80%	41.45%	A
P14	1.03%	P35	2.71%	44.16%	B
P15	2.94%	P43	2.58%	46.74%	B
			…		
P40	1.40%	P14	1.03%	93.23%	C
P41	1.80%	P45	1.02%	94.24%	C
P42	1.57%	P32	0.97%	95.22%	C
P43	2.58%	P31	0.92%	96.13%	C
P44	1.92%	P8	0.85%	96.99%	C
P45	1.02%	P1	0.67%	97.66%	C
P46	1.45%	P3	0.59%	98.25%	C
P47	2.86%	P20	0.58%	98.83%	C
P48	1.59%	P22	0.55%	99.38%	C
P49	3.21%	P29	0.43%	99.80%	C
P50	1.93%	P34	0.20%	100.00%	C

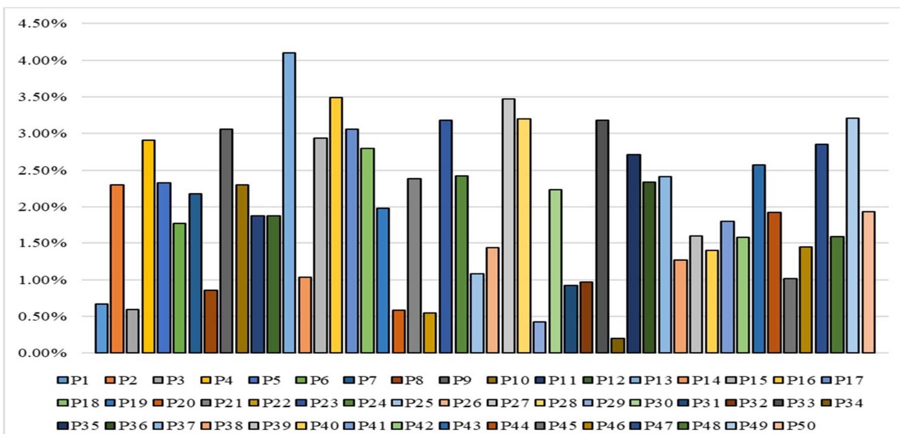

Fig. 2. Final value of percentage shares by products

5.2. Single-criterion ABC analysis

In this section of the paper, we will present the results of single-criterion analysis based on the values of one criterion. Three single-criterion ABC analyses have been performed. The criterion on which the first ABC analysis is based is the quantity of products and its results are shown in Table 8.

By applying the single-criterion ABC analysis that takes into account the quantity of products, we have obtained the following results:

- Group A includes 13 products;
- Group B includes 17 products;
- Group C includes 20 products.

It means that the greatest attention in business operations should be focused on 13 products in group A, and then on 17 products in group B. Although the largest share of products in the total number of products is in group C, these products have low value. For group C, the goal is to increase safety stock for the 20 products that the group covers, and to minimize the number of orders.

Tab. 8. ABC analysis based on quantity

			Sorted				
Product	Quantity	Share	Product	Quantity	Share	Cumulative	Group
P1	25	0.59%	P13	147	3.47%	3.47%	A
P2	106	2.50%	P11	142	3.35%	6.82%	A
P3	38	0.90%	P5	141	3.33%	10.15%	A
P4	125	2.95%	P49	139	3.28%	13.44%	A
P5	141	3.33%	P35	136	3.21%	16.65%	A
P6	37	0.87%	P17	134	3.16%	19.81%	A

P7	83	1.96%	P42	132	3.12%	22.93%	A
P8	74	1.75%	P27	129	3.05%	25.97%	A
P9	100	2.36%	P12	126	2.98%	28.95%	A
P10	87	2.05%	P38	126	2.98%	31.92%	A
P11	142	3.35%	P4	125	2.95%	34.88%	A
P12	126	2.98%	P16	124	2.93%	37.80%	A
P13	147	3.47%	P46	114	2.69%	40.50%	A
P14	41	0.97%	P2	106	2.50%	43.00%	B
P15	85	2.01%	P18	106	2.50%	45.50%	B
			...				
P40	90	2.13%	P3	38	0.90%	94.52%	C
P41	32	0.76%	P6	37	0.87%	95.40%	C
P42	132	3.12%	P26	33	0.78%	96.17%	C
P43	106	2.50%	P39	33	0.78%	96.95%	C
P44	95	2.24%	P41	32	0.76%	97.71%	C
P45	92	2.17%	P25	27	0.64%	98.35%	C
P46	114	2.69%	P1	25	0.59%	98.94%	C
P47	98	2.31%	P31	22	0.52%	99.46%	C
P48	106	2.50%	P29	11	0.26%	99.72%	C
P49	139	3.28%	P22	7	0.17%	99.88%	C
P50	89	2.10%	P34	5	0.12%	100.00%	C

The criterion on which the second ABC analysis is based is the unit price of products and the results of this ABC analysis are shown in Table 9. According to the results of this ABC analysis, group A includes 13 products, group B includes 17 products and there are 20 products in group C.

Tab. 9. ABC analysis based on the unit price of products

			Sorted				
Product	Unit price	Share	Product	Unit price	Share	Cumulative	Group
P1	17	1.16%	P21	50	3.40%	3.40%	A
P2	29	1.97%	P41	50	3.40%	6.80%	A
P3	10	0.68%	P15	49	3.33%	10.14%	A
P4	34	2.31%	P28	49	3.33%	13.47%	A
P5	21	1.43%	P33	49	3.33%	16.80%	A
P6	46	3.13%	P6	46	3.13%	19.93%	A
P7	34	2.31%	P13	46	3.13%	23.06%	A
P8	8	0.54%	P9	45	3.06%	26.12%	A
P9	45	3.06%	P23	45	3.06%	29.18%	A
P10	35	2.38%	P16	44	2.99%	32.18%	A
P11	14	0.95%	P39	43	2.93%	35.10%	A
P12	17	1.16%	P27	42	2.86%	37.96%	A
P13	46	3.13%	P36	42	2.86%	40.82%	A
P14	22	1.50%	P47	42	2.86%	43.67%	B
P15	49	3.33%	P18	38	2.59%	46.26%	B
			...				
P40	16	1.09%	P11	14	0.95%	93.61%	C
P41	50	3.40%	P29	14	0.95%	94.56%	C
P42	11	0.75%	P46	12	0.82%	95.37%	C
P43	34	2.31%	P42	11	0.75%	96.12%	C
P44	25	1.70%	P3	10	0.68%	96.80%	C
P45	8	0.54%	P20	9	0.61%	97.41%	C
P46	12	0.82%	P8	8	0.54%	97.96%	C
P47	42	2.86%	P32	8	0.54%	98.50%	C
P48	16	1.09%	P45	8	0.54%	99.05%	C
P49	35	2.38%	P34	7	0.48%	99.52%	C
P50	27	1.84%	P38	7	0.48%	100.00%	C

In addition to the aforementioned analyses, it has been performed the ABC analysis which considers the annual value of purchase. According to the results of this analysis, group A includes 11 products, group B contains 15 products and there are 24 products in group C. Table 10 shows the results of the ABC analysis based on the annual value of purchase.

Tab. 10. ABC analysis based on the annual value of purchase

			Sorted				
Product	AVP	Share	Product	AVP	Share	Cumulative	Group
P1	425	0.33%	P13	6762	5.32%	5.32%	A
P2	3074	2.42%	P16	5456	4.30%	9.62%	A
P3	380	0.30%	P27	5418	4.27%	13.88%	A
P4	4250	3.35%	P49	4865	3.83%	17.71%	A
P5	2961	2.33%	P23	4770	3.76%	21.47%	A
P6	1702	1.34%	P28	4753	3.74%	25.21%	A
P7	2822	2.22%	P33	4704	3.70%	28.91%	A
P8	592	0.47%	P17	4556	3.59%	32.50%	A
P9	4500	3.54%	P9	4500	3.54%	36.04%	A
P10	3045	2.40%	P4	4250	3.35%	39.39%	A
P11	1988	1.57%	P15	4165	3.28%	42.67%	A
P12	2142	1.69%	P47	4116	3.24%	45.91%	B
P13	6762	5.32%	P18	4028	3.17%	49.08%	B
P14	902	0.71%	P35	3808	3.00%	52.08%	B
P15	4165	3.28%	P43	3604	2.84%	54.91%	B
			...				
P40	1440	1.13%	P25	810	0.64%	96.75%	C
P41	1600	1.26%	P45	736	0.58%	97.33%	C
P42	1452	1.14%	P32	696	0.55%	97.88%	C
P43	3604	2.84%	P31	594	0.47%	98.35%	C
P44	2375	1.87%	P8	592	0.47%	98.81%	C
P45	736	0.58%	P1	425	0.33%	99.15%	C
P46	1368	1.08%	P3	380	0.30%	99.44%	C
P47	4116	3.24%	P20	369	0.29%	99.74%	C
P48	1696	1.34%	P29	154	0.12%	99.86%	C
P49	4865	3.83%	P22	147	0.12%	99.97%	C
P50	2403	1.89%	P34	35	0.03%	100.00%	C

5.3. Comparative analysis

In this section of the paper, it is performed a comparison of the product classification results obtained by applying the integrated SWARA – MARCOS model which includes the integration of the SWARA method and ABC analysis with the results of single-criterion ABC analyses. When comparing the results of the integrated SWARA – MARCOS model with the results of the model that includes the integration of the SWARA method and ABC analysis, we can notice several minor deviations. Based on the results of the integrated SWARA – MARCOS model, group A includes 11 products, group B includes 13 and group C includes 26 products, while the results of the SWARA – ABC model show that 13 products are classified into group A, 17 into group B and 20 into group C.

Differences between the results of the aforementioned models occur in products 47 and 18, which are classified into group B using the first integrated model, and into group A using multi-criteria ABC analysis. In addition, products 19, 50, 44, 11, 41 and 12 are classified into group C using the integrated SWARA – MARCOS model, i.e. into group B using the SWARA – ABC model. Larger differences appear when comparing the results of the integrated SWARA – MARCOS model with single-criterion ABC analyses, of which the first ABC analysis takes into account the unit price of products, the second one considers the quantity of products and the third ABC analysis is based on the annual value of purchase. According to the results of ABC analysis based on the unit price of products and ABC analysis based on quantity, 13 products are classified into group A, 17 into group B and 20 into group C, while in the ABC analysis based on the annual value of purchase, 11 products are classified into group A, 15 into group B and 24 into group C.

For example, product 49 belongs to group B using the ABC analysis based on the unit price of products, while using model SWARA – MARCOS, using the ABC analysis based on quantity and the ABC analysis based on the annual value of purchase belongs to group A. Product 33 and product 23 belong to group A by applying all the aforementioned classification models, except when applying the ABC analysis based on quantity where they belong to group B. Product 50 is classified into group B using the ABC analysis based on the annual value of purchase, while applying all other classification models it is classified into group C. Product 19 is in group C using the SWARA – MARCOS model, i.e. in group B using the ABC analysis based on the unit price of products and the ABC analysis based on the annual value of purchase. Product 6 is classified into group C using all classification models except for the application of ABC analysis which takes into account the unit price of products. In addition, product 44 belongs to group C using all models except for the application of single-criterion ABC analysis which takes into account the quantity of products where it belongs to group B. Another example of difference is product 12 which is classified into group A using the ABC analysis based on quantity, while using the integrated SWARA – MARCOS model and the remaining single-criterion ABC analyses, it is classified into group C. Table 11 shows a comparison of the results of integrated SWARA – MARCOS models with the results of SWARA – ABC models and the results of single-criterion ABC analyses. Based on the conducted comparative analysis, it can be proved the previously given statement, which refers to the shortcomings of one-criterion ABC analysis. Therefore, the creation of an integrated SWARA – MARCOS model and its application for inventory classification has its justification.

Tab. 11. Comparison of the results of applied product classification models

SWARA - MARCOS			SWARA - ABC		ABC (UP)		ABC (Q)		ABC (AVP)	
Product	Rank	Group	Product	Group	Product	Group	Product	Group	Product	Group
P13	1	A	P13	A	P21	A	P13	A	P13	A
P16	2	A	P16	A	P41	A	P11	A	P16	A
P27	3	A	P27	A	P15	A	P5	A	P27	A
P28	4	A	P49	A	P28	A	P49	A	P49	A
P49	5	A	P28	A	P33	A	P35	A	P23	A
P33	6	A	P23	A	P6	A	P17	A	P28	A
P23	7	A	P33	A	P13	A	P42	A	P33	A
P9	8	A	P17	A	P9	A	P27	A	P17	A
P17	9	A	P9	A	P23	A	P12	A	P9	A
P15	10	A	P15	A	P16	A	P38	A	P4	A
P4	11	A	P4	A	P39	A	P4	A	P15	A
P47	12	B	P47	A	P27	A	P16	A	P47	B
P18	13	B	P18	A	P36	A	P46	A	P18	B
P35	14	B	P35	B	P47	B	P2	B	P35	B
P43	15	B	P43	B	P18	B	P18	B	P43	B
					…					
P14	40	C	P14	C	P11	C	P3	C	P25	C
P45	41	C	P45	C	P29	C	P6	C	P45	C
P32	42	C	P32	C	P46	C	P26	C	P32	C
P31	43	C	P31	C	P42	C	P39	C	P31	C
P8	44	C	P8	C	P3	C	P41	C	P8	C
P1	45	C	P1	C	P20	C	P25	C	P1	C
P3	46	C	P3	C	P8	C	P1	C	P3	C
P20	47	C	P20	C	P32	C	P31	C	P20	C
P22	48	C	P22	C	P45	C	P29	C	P29	C
P29	49	C	P29	C	P34	C	P22	C	P22	C
P34	50	C	P34	C	P38	C	P34	C	P34	C

5.4. Managerial implications

Today, many companies face certain problems that can significantly impede the optimality of inventory management due to uncertain deliveries. Therefore, it is necessary to form adequate models of inventory classification as a prerequisite for their optimal management. Taking into account the obtained results, managers can create different policies of procurement and storage of the considered products. This means that the greatest focus should be on products 13, 16 and 27 that are ranked as best. Setting the following restriction, the products are classified into three groups: 0.00-0.500=C, 0.500-0.700=B and >0.700=A. All products from group A should be constantly monitored and perform procurement through more frequent deliveries, while products from group C should be grouped into as large orders as possible.

6. Discussion and Conclusion

Through this paper, it has been determined the importance of multi-criteria decision-making methods and their influence on inventory management and ordering processes. The paper uses an integrated SWARA – MARCOS model with the aim of determining the weight values of criteria and ranking the alternatives. The biggest advantage of the SWARA method is the simplicity of its application, i.e. obtaining required results by applying a small number of steps. Using the SWARA method, we have obtained that the weight value of the first criterion is 0.28, the weight value of the second criterion is 0.32 and the weight value of the third criterion is 0.40. Using the MARCOS method, 50 products have been ranked. Based on the results obtained by applying the MARCOS method, the product with the best characteristics, according to the defined criteria, is product 13. Then, the second position is taken by product 16, while product 34 is in the last position in the overall ranking. The formation of such an integrated multi-criteria model creates benefits for managers. This is reflected through simple application of an integrated model that provides accurate results. In this way, complex calculations and incomprehensibility for managers as decision makers are avoided. The combined SWARA-MARCOS model can be applied to any data set within the ABC analysis.

Classical ABC analysis takes into account only one criterion, which is its biggest disadvantage. ABC analysis that considers several different criteria contributes to the optimization of logistics processes to a greater extent, which ultimately leads to reduction in operating costs. The multi-criteria ABC analysis applied to solving the given problem shows that the greatest attention should be paid to 13 products that are in group A. The trends regarding these products need to be regularly controlled and monitored. Group B includes 17 products that are moderately important products. In group B, it is tried to automate all routine decisions and thus save time. There are 20 products in group C and these products are relatively insignificant products. For this group, the goal is to increase safety stocks and minimize the number of orders. The key benefit of ABC analysis is the rationalization of inventory procurement and management.

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