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Multi-Criteria Decision-Making Methods in Green Logistics

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ABSTRACT

Due to the increased demands of the world community in accordance with the goals of the concept of sustainable development, supply chain management requires complex decision-making models that consider many environmental, economic, and social constraints when implementing various environmentally friendly, green methods and technologies. An effective tool in such conditions is the use of MCDM, multi-criteria decision-making methods.

The objective of the research, the results of which are provided in the article, is to analyse the application of MCDM in green logistics and management of green supply chains. The work used a set of methods including system and structural-functional analysis, methods of the theory of fuzzy sets, mathematical statistics, and expert assessments.

A general scheme of MCDM implementation is offered and a combined MCDM model is developed for assessing decisions on the choice of green technologies, including a system of indicators for logistics flows, a model for managing logistics flows and a system of tools for green logistics.

In the MCDM model, a fuzzy analytical hierarchical process (fuzzy AHP) is used to establish the weight of indicators of logistics flows, eleven MCDM methods are used to rank green logistics tools: SAW, TOPSIS, PROMETHEE, COPRAS, ARAS, WASPAS, MAIRCA, EDAS, MABAC, CODAS, MARCOS. Comparison of the use of various MCDM methods showed a high convergence of the ranking results (Spearman's rank correlation coefficient is of 0.949). The most consistent are SAW, MARCOS and WASPAS methods, the least consistent are CODAS methods.

The results of the design example showed that the most preferable solution is the «use of intermodal technologies and multimodal transportation» (ranked first within all eleven methods), the least preferable solution is the «use of environmentally friendly fuels and lubricants (fuels)» (ranked 12th within 10 methods of 11).

Keywords: *multi-criteria decision-making methods, sustainable development, green logistics, green supply chain management.*

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INTRODUCTION

In the modern world, the decision-making process in an organisation is carried out in the context of the concept of sustainable development [1] and must simultaneously consider economic, social and environmental consequences of decision-making in the long term [2]. The effective implementation of the concept of sustainable development in logistics activities and supply chain management is based on the use of methods of making managerial decisions to change the parameters of logistics flows, improve the elements of the logistics system and their functions [3]. The complexity of decision-making is associated with participation of many stakeholders in the supply chain, pursuing goals of varying complexity [4]; with uncertainty and dynamism of the logistics environment; as well as with the need to consider the influence of many factors (economic, technical, technological, infrastructural, social and environmental ones) [3]; with the presence of a wide variety of managerial decisions at different levels of management; with an increase in the number of criteria for evaluating managerial decisions related, in particular, to achievement of sustainable development goals [3; 5].

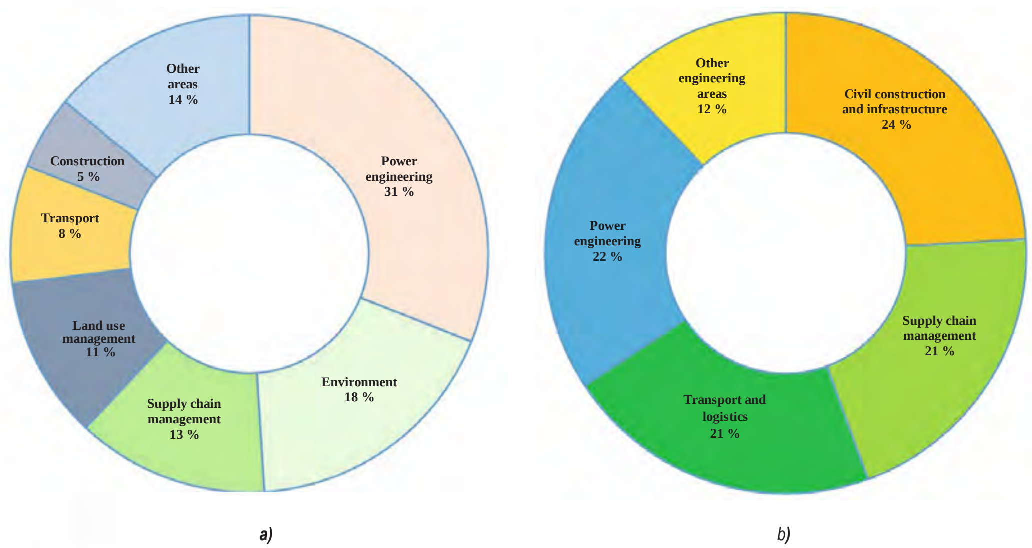
The need to consider the listed constraints when making a decision has led to the active development of the scientific area in multi-criteria decision analysis (MCDA) or multi-criteria decision making (MCDM).

The *objective* of the article is to analyse the application of multi-criteria decision-making methods in green logistics and management of green supply chains. Achieving this goal is based on the use of systemic and structural-functional analysis in the development of an MCDM model for choosing green logistics tools, expert assessment methods and fuzzy set theory for assessing the indicators of logistics flows, as well as on mathematical statistics for calculating the Spearman rank correlation coefficient when comparing various MCDM methods.

LITERATURE REVIEW

MCDM methods are an important part of decision theory and analysis. The main purpose of their use is reduced to solving four types of problems [6]: choosing the best solution from the set, ranking and sorting of solutions, describing and systematising solutions and the consequences of their implementation for assessment and further management. Currently, MCDMs are actively used in the field of climate change [7], sustainable development [2], economics [8], sustainable engineering [9], supply chain management [10–12], energy consumption [13], reverse logistics [14], corporate sustainability [15], in transport [16; 17], in green logistics [18] and management of green supply chains [19; 20].

MCDM methods fall into two categories: Multi-Objective Decision Making (MODM) [21] and Multi-Attribute Decision Making (MADM)



Pic. 1. Using MCDM methods:
a – in the field of sustainable development; b – in sustainable engineering (compiled by the author based on [2; 9]).

[22]. MODM models include an infinite or very large number of alternative solutions, and the purpose while considering the stated problem is to determine the optimal alternative given a set of well-defined constraints by solving a mathematical model. MADM models are discrete and are applied for ranking, where a finite number of proposed alternatives are evaluated against various weighted attributes to obtain a preference rating that describes the performance of each alternative in achieving a target in terms of attributes. To increase the efficiency of MCDM estimation, the MCDM models can be combined with the theory of fuzzy sets, rough sets, grey sets, etc. [23].

The mentioned disadvantages of using MCDM are [8; 24]: obtaining different results when using MCDM to solve one multi-criteria problem; complexity of collecting initial information and its possible loss in the process of data aggregation; increasing complexity of the decision-making process. In works [8; 25; 26] it is noted that there are no universal MCDM methods suitable for all decision-making situations, which leads to the problem of choosing a MCDM method. Studies [25; 27] provide recommendations for such a choice.

Pic. 1 shows the distribution of MCDM methods in sustainable development [2] and sustainable engineering [9], and from 20 to 40 % of research is in sustainable transport and green supply chain management.

The most frequently used MCDM methods in the field of green logistics and management of green supply chains are [9; 14; 18; 19; 28]: AHP which is an analytical hierarchical process, ANP which is an analytical network process, TOPSIS which is a method of ordered preference through similarity to an ideal solution, DEMATEL which is a method of testing and evaluating decision making, ELECTRE which is a method of exclusion and choice in reality, PROMRETHEE which is a method of organising sorting of preferences for evaluating alternatives, VIKOR which is a multi-criteria optimisation and trade-off solution. The most common methods used in combination with other methods are AHP and fuzzy AHP [9].

MCDM methods are used to solve problems related to sales planning, choosing a green supplier, managing reverse flows (reverse logistics), assessing the location of logistics infrastructure, organising and planning transportation [28].

RESULTS

Basic Stages of Using MCDM

The decision-making process using MCDM includes three main stages (Pic. 2):

1. *Structuring the problem to be solved*. At the stage, goals and objectives are determined; analysis of possible solutions (alternatives) that can be implemented to achieve the goals is performed; a system of criteria is established by which alternatives should be evaluated; the persons participating in the decision-making, as well as the expert group are identified. The information obtained at this stage serves as the basis for determining which MCDM method can be used.

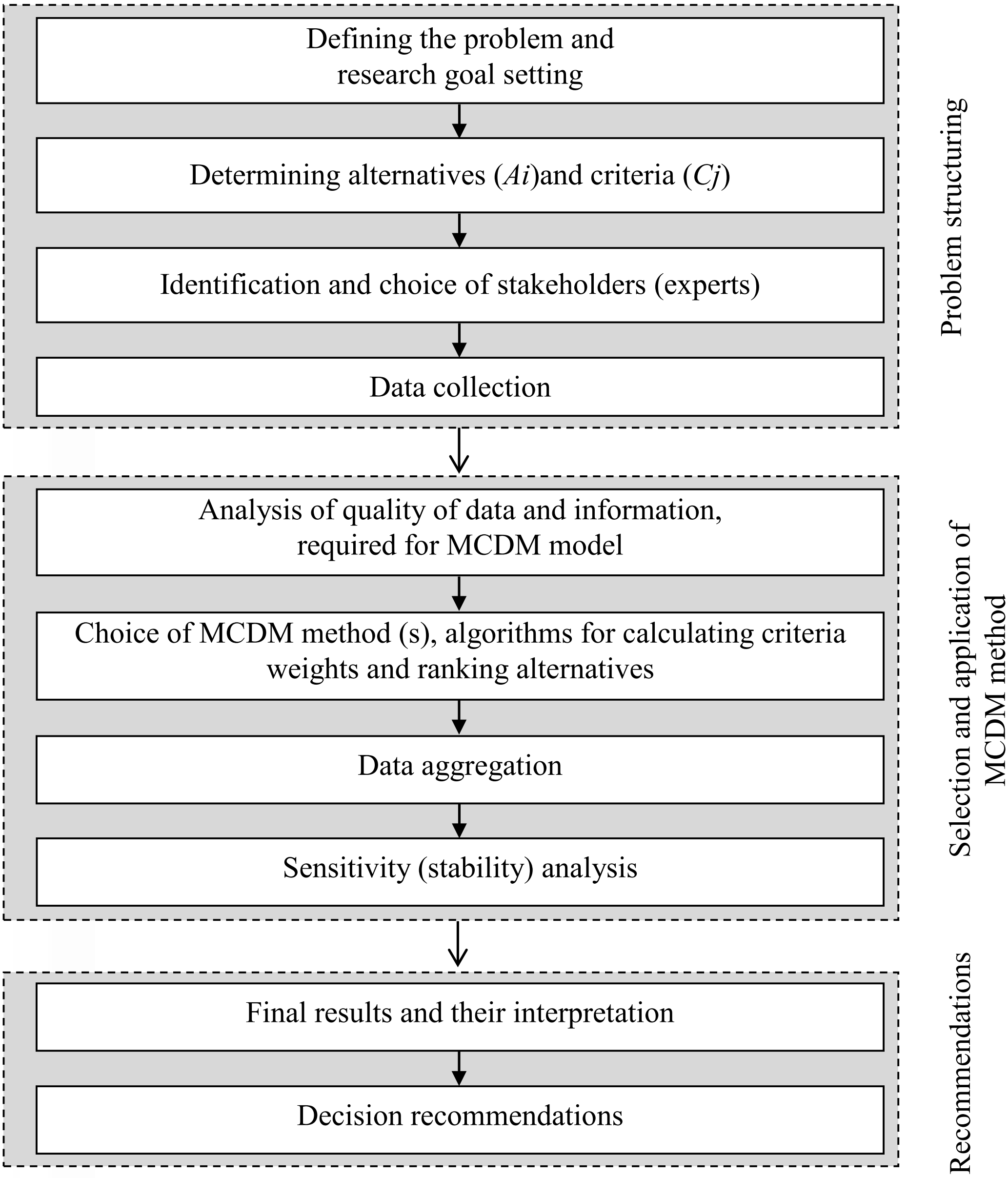
2. *Selection and application of MCDM method*. At this stage are developed and performed: the initial decision matrix; assessment of the importance of each criterion in relation to the goal; assessment of the preference for each alternative in relation to the criteria; calculation of general weighted estimates of alternatives; aggregation of alternative estimates; ranking of all possible alternatives based on total weighted scores. The use of different MCDM methods at this stage affects the final result of assessment.

3. *Recommendations for decision-making*. The higher the overall weighted score is, the preferable the alternative will be. The results obtained should be further examined by performing a sensitivity analysis to assess stability of the results obtained.

If parties with different interests are involved in the decision-making process, it is advisable to use the Multi actor multi criteria analysis method (MAMCA) [29]. In MAMCA, a hierarchical structure of goals / objectives / criteria is formed within the general model in the form of separate modules for each stakeholder, which are subsequently grouped together. This allows stakeholder groups to create their own criteria trees and consider which criteria are of interest for a specific decision-making problem [4].

An Example of Using MCDM when Choosing Green Logistics Tools

As an example of comparing various MCDM methods, this paper presents the problem of assessing and choosing solutions for implementation of green logistics tools for the transportation element of the logistics system. The initial data for the problem being solved were:

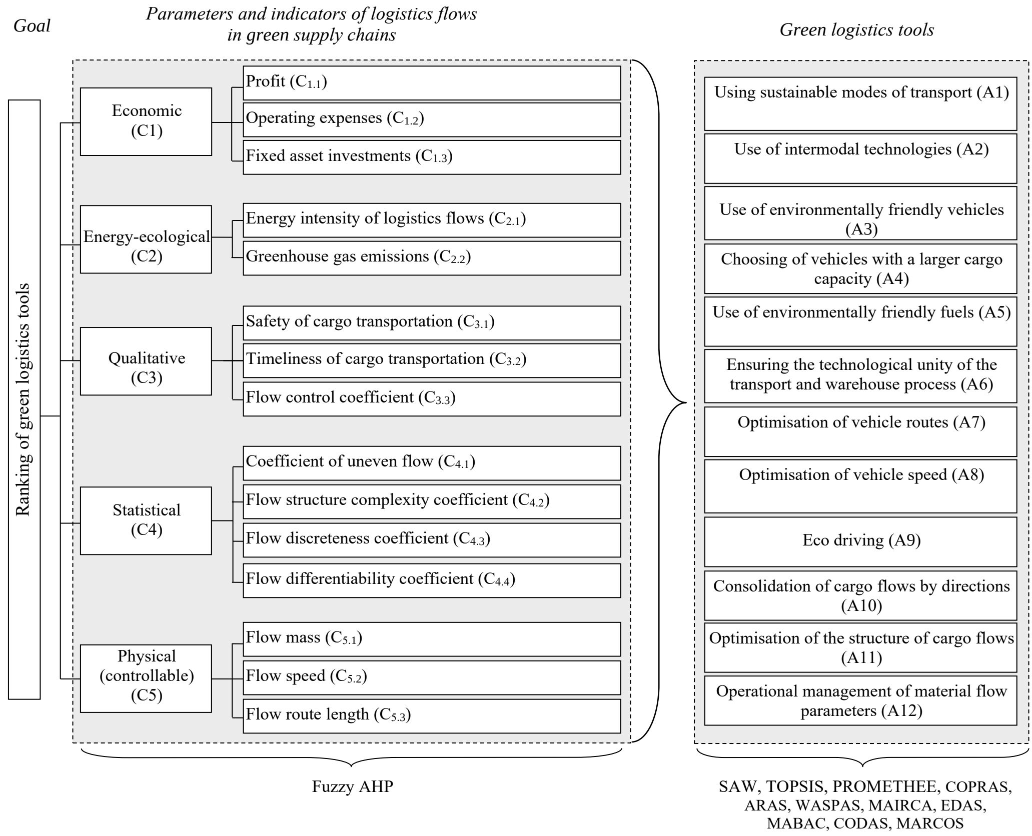


Pic. 2. General scheme of using MCDM (developed by the author).

- System of indicators of logistics flows [3].
- System of tools for green logistics [30].
- A model for managing logistic flows [31].
- Weight coefficients of parameters and indicators of logistics flows, as well as the results of an expert assessment of the tools of green logistics [32].

Pic. 3 shows a general diagram of the MCDM model. The criteria (C1–C5) and sub-criteria (C1.1–C.5.3) of the model are five groups of parameters and 15 indicators of logistics flows [3], alternatives (A1–A12) are the tools of green logistics of the transportation element of the logistics system [31].

The ranking of green logistics tools (alternatives A1–A12) is performed using eleven different MCDM methods: SAW (Simple Additive Weighting) [33]; TOPSIS (Technique for the Order of Preference by Similarity to Ideal Solution) [22]; PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) [34]; COPRAS (Complex Proportional Assessment) [35]; ARAS (Additive Ratio Assessment) [36]; WASPAS (Weighted



Pic. 3. Scheme of the model for assessing management decisions on the choice of tools for green logistics (developed by the author).

Aggregated Sum Product Assessment) method [37]; MAIRCA (Multi-Attributive Ideal-Real Comparative Analysis) [38]; EDAS (the Evaluation based on Distance from Average Solution) [39]; MABAC (Multi-Attributive Border Approximation Area Comparison) [40]; CODAS (COmbinative Distance-based Assessment) [41]; MARCOS (Measurement of Alternatives and Ranking according to Compromise Solution) [42]. The calculation methods and the stages of implementation of each method can be found in the referenced scientific literature.

The initial decision-making matrix (X) includes alternatives $A = \{A_1, A2, ..., A_m\}$, the assessment of which is performed according to the criteria $C = \{C_1, C_2, ..., C_n\}$.

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{pmatrix} \end{array}, \quad (1)$$

where m – the number of alternatives equal to 12;

n – the number of criteria equal to 15,

xij – assessment of the value of the i-th alternative A according to the j-th criterion C.

The values of the weighting coefficients of the criteria C1.1–C.5.3 were calculated by the fuzzy AHP method (Pic. 4), the results of an expert assessment of alternatives are presented in Table 1 [32]. The value of criteria C1.1, C1.3, C3.1, C3.2, C3.3, C5.1, C5.2 tends to the maximum («benefit» group), criteria C1.2, C2.2, C2.2, C4.1, C4.2, C4.3, C4.4, C5.3 tends to a minimum (group «expenses»).

Using the data in Table 1 and Pic. 4, the calculation of the normalised decision-making matrix and data aggregation are performed in accordance with the selected MCDM methods. The results of ranking alternatives using eleven MCDM methods are presented in Table 2 and Pic. 5.

The analysis results show that the most preferred alternative is A1 which is the «use of intermodal technologies and multimodal transportation» (ranked first within all eleven methods), the least preferred alternative is A5 which is the «use of environmentally friendly

Pic. 4. Weight coefficients of indicators of logistics flows [32].

Table 1

Initial decision-making matrix [32]

A_i/C_j	C1.1 (max)	C1.2 (min)	C1.3 (max)	C2.1 (min)	C2.2 (min)	C3.1 (max)	C3.2 (max)	C3.3 (max)	C4.1 (min)	C4.2 (min)	C4.3 (min)	C4.4 (min)	C5.1 (max)	C5.2 (max)	C5.3 (min)
A1	3,302	4,309	4,642	4,309	5,000	2,000	1,260	3,302	2,000	2,520	2,289	2,289	2,884	2,884	3,302
A2	4,309	3,557	4,000	4,642	4,309	3,915	3,915	3,634	3,634	3,684	3,420	2,466	2,289	3,634	3,915
A3	2,289	3,175	3,557	3,634	4,642	2,000	1,817	2,080	1,817	2,000	1,817	2,289	2,289	2,289	2,080
A4	3,302	3,915	2,924	4,000	4,217	2,000	2,000	1,817	3,420	2,289	4,309	2,289	4,000	2,000	1,260
A5	3,302	3,634	1,817	3,634	3,557	1,000	1,000	1,000	1,587	1,260	1,260	1,260	1,000	1,587	1,000
A6	2,714	3,915	2,884	2,884	2,884	3,302	4,309	4,309	4,309	2,289	2,080	2,080	2,000	2,884	2,080
A7	2,520	3,302	1,817	2,621	2,884	1,817	2,884	3,634	2,289	2,289	2,080	2,289	1,442	2,520	3,107
A8	2,466	2,884	1,260	2,080	1,442	1,587	2,884	2,000	2,000	1,442	1,587	1,817	1,587	5,000	1,817
A9	1,587	2,289	1,000	2,080	2,621	1,000	1,587	1,817	1,587	1,442	1,442	1,000	1,260	2,884	1,442
A10	2,621	3,175	1,260	3,000	3,000	2,289	2,884	3,302	2,714	3,634	2,714	3,915	4,309	2,884	3,175
A11	3,175	2,884	1,587	2,884	2,621	2,289	3,175	3,634	3,175	5,000	2,289	2,884	3,000	3,420	2,080
A12	2,289	2,884	1,587	3,000	3,000	2,621	4,309	4,309	4,309	3,915	3,302	3,557	2,884	3,634	3,302

fuels and lubricants (fuels)» (ranked 12th within 10 methods of 11). The discrepancy in the rank in the alternatives is explained by the use of different algorithms and methods for normalising the initial decision matrix and data aggregation in the methods, as well as by the presence of many alternatives with a small difference in the estimates between them.

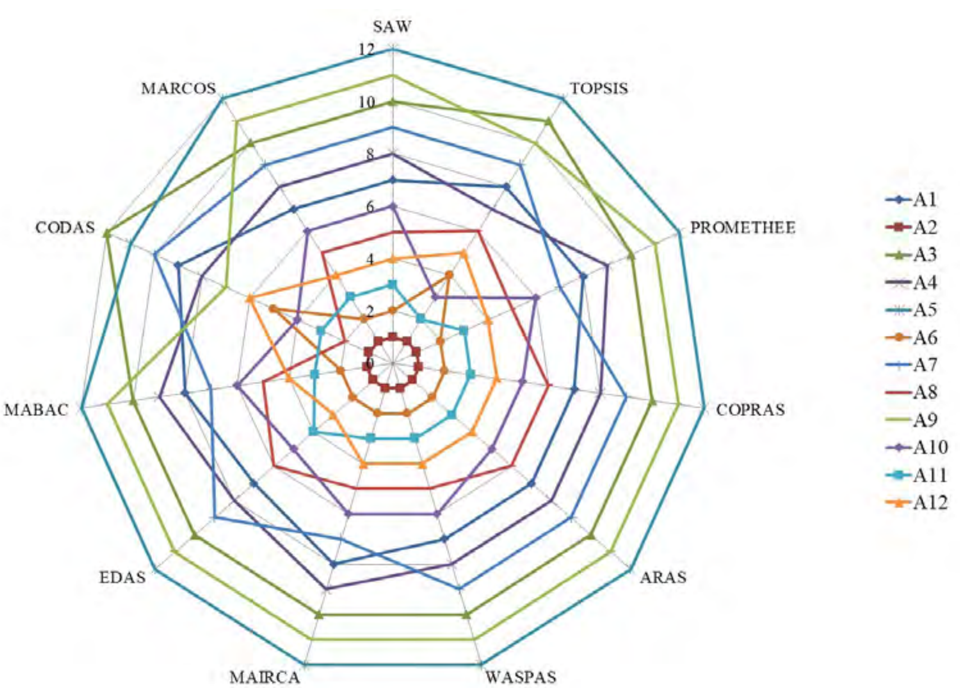
To determine the relationship between the ranking results obtained using various MCDM methods, Spearman's rank correlation coefficient is used [43] (Table 3).

Even though the considered MCDM methods use different methods of data normalisation and aggregation, a high correlation was achieved when ranking alternatives (the overall correlation

Table 2

Results of ranking alternatives by different MCDM methods

MCDM method	Alternatives (green logistics tools)											
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
SAW	0,610	0,751	0,529	0,595	0,437	0,694	0,584	0,672	0,514	0,662	0,686	0,682
	7	1	10	8	12	2	9	5	11	6	3	4
TOPSIS	0,079	0,103	0,060	0,082	0,053	0,096	0,074	0,094	0,066	0,096	0,102	0,095
	8	1	11	7	12	4	9	6	10	3	2	5
PROMETHEE	-0,046	0,155	-0,140	-0,053	-0,262	0,128	-0,031	0,091	-0,156	0,080	0,126	0,108
	8	1	10	9	12	2	7	5	11	6	3	4
COPRAS	81,33	100,00	70,28	79,18	56,29	91,38	75,62	86,95	65,73	87,39	89,88	89,71
	7	1	10	8	12	2	9	6	11	5	3	4
ARAS	0,613	0,755	0,530	0,598	0,427	0,690	0,573	0,659	0,498	0,660	0,680	0,678
	7	1	10	8	12	2	9	6	11	5	3	4
WASPAS	0,344	0,423	0,299	0,336	0,245	0,392	0,330	0,377	0,287	0,374	0,388	0,385
	7	1	10	8	12	2	9	5	11	6	3	4
MAIRCA	0,035	0,051	0,028	0,035	0,019	0,049	0,036	0,046	0,027	0,045	0,048	0,047
	8	1	10	9	12	2	7	5	11	6	3	4
EDAS	0,498	0,843	0,313	0,473	0,053	0,721	0,412	0,585	0,183	0,646	0,690	0,691
	7	1	10	8	12	2	9	6	11	5	4	3
MABAC	-0,014	0,170	-0,101	-0,020	-0,212	0,146	0,000	0,112	-0,115	0,102	0,144	0,127
	8	1	10	9	12	2	7	5	11	6	3	4
CODAS	-0,098	0,617	-0,620	-0,037	-0,552	0,111	-0,247	0,493	0,002	0,126	0,128	0,090
	9	1	12	8	11	5	10	2	7	4	3	6
MARCOS	0,566	0,696	0,491	0,552	0,406	0,644	0,542	0,623	0,477	0,615	0,637	0,633
	7	1	10	8	12	2	9	5	11	6	3	4



Pic. 5. Results of ranking green logistics tools using eleven MCDM methods.

Table 3

Spearman's rank correlation coefficient (results obtained by the author)

MCMD method	SAW	TOPSIS	PROMETHEE	COPRAS	ARAS	WASPAS	MAIRCA	EDAS	MABAC	CODAS	MARCOS
SAW	1,000	0,930	0,979	0,993	0,993	1,000	0,979	0,986	0,979	0,818	1,000
TOPSIS	–	1,000	0,909	0,951	0,951	0,930	0,909	0,930	0,909	0,881	0,930
PROMETH-EE	–	–	1,000	0,972	0,972	0,979	1,000	0,965	1,000	0,797	0,979
COPRAS	–	–	–	1,000	1,000	0,993	0,972	0,993	0,972	0,804	0,993
ARAS	–	–	–	–	1,000	0,993	0,972	0,993	0,972	0,804	0,993
WASPAS	–	–	–	–	–	1,000	0,979	0,986	0,979	0,818	1,000
MAIRCA	–	–	–	–	–	–	1,000	0,965	1,000	0,797	0,979
EDAS	–	–	–	–	–	–	–	1,000	0,965	0,783	0,986
MABAC	–	–	–	–	–	–	–	–	1,000	0,797	0,979
CODAS	–	–	–	–	–	–	–	–	–	1,000	0,818
MARCOS	–	–	–	–	–	–	–	–	–	–	1,000

coefficient was 0,949). SAW, MARCOS and WASPAS methods are fully consistent with each other and have the highest mean correlation coefficient among all methods, equal to 0,9688. The least consistent method is CODAS (mean correlation coefficient is 0,829). The difference in ranks is described in the literature [44; 45] and is justified by the use of various methods of data normalisation (for example, vector or linear normalisation).

The obtained results of ranking the tools of green logistics can be used to make management decisions to increase sustainability of the transportqtion element of the green supply chain.

CONCLUSION

The article examines the application of multi-criteria decision-making methods (MCDM) in green logistics and management of green supply chains, shows the features of application of the methods and substantiates the need for their use in supply chain management.

The developed combined MCDM model for assessing and choosing solutions for implementation of green logistics tools includes 12 alternatives and 15 criteria. The criteria weight was calculated using fuzzy AHP, ranking of alternatives was performed by eleven MCDM methods (SAW, TOPSIS, PROMETHEE, COPRAS, ARAS, WASPAS, MAIRCA, EDAS, MABAC, CODAS, MARCOS).

The calculated example of comparing eleven MCDM methods showed a high correlation of the results (correlation coefficient was 0,949). The most consistent are SAW, MARCOS and WASPAS methods, the least consistent are CODAS methods. According to the calculation results, the preferred alternative is the «use of intermodal technologies and multimodal transportation» (A1), the least preferred alternative is A5 which is the «use of environmentally friendly fuels and lubricants».

Further research can be related to development of a hybrid MCDM decision-making model for the choice of green logistics tools in supply chains, considering the interests of various stakeholders.

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