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COMPARISON OF MULTIPLE-CRITERIA DECISION-MAKING METHODS - RESULTS OF A SIMULATION STUDY

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ABSTRACT. **Background:** Today, both researchers and practitioners have many methods for supporting the decision-making process. Due to the conditions in which supply chains function, the most interesting are multi-criteria methods. The use of sophisticated methods for supporting decisions requires the parameterization and execution of calculations that are often complex.
So is it efficient to use sophisticated methods?
Methods: The authors of the publication compared two popular multi-criteria decision-making methods: the Weighted Sum Model (WSM) and the Analytic Hierarchy Process (AHP). A simulation study reflects these two decision-making methods. Input data for this study was a set of criteria weights and the value of each in terms of each criterion.
Results: The iGrafx Process for Six Sigma simulation software recreated how both multiple-criteria decision-making methods (WSM and AHP) function. The result of the simulation was a numerical value defining the preference of each of the alternatives according to the WSM and AHP methods. The alternative producing a result of higher numerical value was considered preferred, according to the selected method. In the analysis of the results, the relationship between the values of the parameters and the difference in the results presented by both methods was investigated. Statistical methods, including hypothesis testing, were used for this purpose.
Conclusions: The simulation study findings prove that the results obtained with the use of two multiple-criteria decision-making methods are very similar. Differences occurred more frequently in lower-value parameters from the "value of each alternative" group and higher-value parameters from the "weight of criteria" group.

Key words: weighted sum model, analytic hierarchy process, multiple-criteria decision-making, simulation study.

INTRODUCTION

In the conditions in which contemporary supply chains function, multiple-criteria decision-making methods are of great interest to both theoreticians and practitioners. They allow analyses to be conducted in complex environments and under a variety of criteria. It makes it possible to make an optimal choice for a selected criterion or a set of criteria, which is a particularly important feature from a scientific point of view. However, the opinions of practitioners on the process of decision-making are often different. Seeking an optimal solution from the point of view of a specific criterion or a set of criteria certainly is a desired goal, nonetheless the efficiency of the decision-making process is frequently of greater significance. Productivity is understood as the sum of effectiveness of an action in order to achieve a goal - making the right decision and putting it into effect efficiently, i.e. executing the decisive process at the lowest possible cost.

Literature on the subject describes many multiple-criteria decision-making methods. They may be divided on the basis of various criteria. One of them is the complexity of a method, and, consequently, cost of its application in the decision-making process.

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Complex methods frequently require complicated parametrisation and numerous calculations. This, in turn, prolongs the time of executing the decision-making process and may lower its productivity. Thus, a particularly significant criterion for selecting the method which supports decision-making is not only the results of the method, but also its practicability. This is particularly important to practitioners working within contemporary supply chains. Intensive competition, a multitude of opportunities and the threats typical for this environment require effective and efficient decision-making.

The research presented in the article compares the results of employing two multiple-criteria decision-making methods: the weighted sum model (WSM) and the analytic hierarchy process (AHP). The first one has been described as a simple method, which does not require excessive costs in the decision-making process. The second one has been described as complex. The purpose of the research was to choose the method of assessing variants of material flow in supply chains, in order to determine economic lot size.

2 MULTIPLE-CRITERIA DECISION-MAKING METHODS

Review of multiple-criteria methods

Problems analysed today are usually very complex, which is why decision-makers often have difficulties making the right decision. In the light of this, increased interest in multiple-criteria decision-making methods has been observed in recent years. Currently, many solutions which allow analysis to be conducted using a model of a decision-making situation, with the use of a number of criteria, have been developed. Multiple-criteria methods may be applied to decision-making in potentially every area of human activity.

The list below presents selected multiple-criteria methods which support decision-making (with original spelling):

- elementary methods:
  - WSM (Weighted Sum Method) [Wang, Jing, Zhang, Zhao, 2009],
  - WPM (Weighted Product Method) [Wang, Jing, Zhang, Zhao, 2009];
- additive methods:
  - SAW (Simple Additive Weighting Method) [Churchman, Ackoff, 1954],
  - F-SAW (Fuzzy Simple Additive Weighing Method) [Tzeng, Huang, 2011],
  - SMART (Simple Multi-Attribute Ranking Technique) [Edwards, 1971],
  - SMARTER (Simple Multi-Attribute Ranking Technique Exploiting Ranks) [Edwards, 1994];
- analytical hierarchy method and related methods:
  - AHP (Analytical Hierarchy Process) [Saaty, 1980],
  - REMBRANDT (Ratio Estimation in Magnitudes or deciBells to Rate Alternatives which are Non-DominaTed) [Lootsma, 1992],
  - F-AHP (Fuzzy Analytic Hierarchy Process) [Mikhailov, Tzvetinov, 2004],
  - ANP (Analytic Network Process) [Saaty, 1996],
  - F-ANP (Fuzzy Analytic Network Process) [Tzeng, Huang, 2011],
  - MACBETH (Measuring Attractiveness by a Categorical Based Evaluation TecHnique) [Bana e Costa, Vansnick, 1999];
  - ZAPROS methods ЗАмкнутые ПРоцедуры у Опорных Ситуаций):
  - ZAPROS I [Larichev, Moskovich, 1995],
  - ZAPROS III [Larichev, 2001];
- ELECTRE methods (ELimination Et Choix Traduisant la REalia):
  - ELECTRE I [Roy, Bouyssou, 1993],
  - ELECTRE Iv [Roy, Bouyssou, 1993],
  - ELECTRE Is [Roy, Bouyssou, 1993],
  - ELECTRE III [Roy, Bouyssou, 1993],
  - ELECTRE TRI [Roy, Bouyssou, 1993],
  - ELECTRE I + SD [Zaraś, Martel, 1994],
  - ELECTRE III + SD [Nowak, 2004];
- PROMETHEE methods (Preference Ranking Organisation METHod for Enrichment Evaluations):
  - PROMETHEE I [Brans, 1982],
  - PROMETHEE II [Brans, 1982],
  - PROMETHEE II + veto [Górecka, Muszyńska, 2011],

  - EXPROM (EXtension of the PROMethee method) [Diakoulaki, Koumoutsos, 1991],
  - EXPROM II + veto [Górecka, Szałucka, 2013],
  - PROMETHEE II + veto + SD [Nowak, 2005],
  - EXPROM II + veto + SD [Górecka, 2010];
- using points of reference:
  - TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [Hwang, Yoon, 1981],
  - F-TOPSIS (Fuzzy Technique for Order Preference by Similarity to Ideal Solution) [Jahanshahloo, Hosseinzadeh Lotfi, Izadikhah, 2006],
  - VIKOR (VIsekrzterijumska Optimizacija i Kompromisno Resenje) [Opricovic, 1998],
  - DEMATEL (DEcision Making Trial and Evaluation Laboratory) + ANP + VIKOR [Tzeng, Huang, 2011],
  - BIPOLAR [Konarzewska-Gubała, 2009],
  - BIPOLAR zmodyfikowany [Trzaskalik, Sitarz, Dominiak, 2013],
  - BIPOLAR + SD [Górecka, 2009];
- interactive methods:
  - STEM-DPR (STEp Method for Discrete Decision Making Problems under Risk) [Nowak, 2008],
  - INSDECM (INteractive Stochastic DECision Making Procedure) [Nowak, 2006],
  - ATO-DPR (Analysis of Trade-Offs for Discrete Decision Making Problems under Risk) [Nowak, 2010].

Each of the methods has been briefly summarised in a research paper [Trzaskalik, 2014]. Point 2.2. describes in more detail only the methods which form a direct basis for the article.

A short summary of selected methods - AHP and WSM

The hierarchical structure of the AHP method (analytical hierarchy process) means that the general goal lies on the highest level of the hierarchy. It is broken down into independent assessment criteria determined by the decision maker's preferences. They are located on the next level of the hierarchy. This hierarchy may be composed of many levels, which means that the criteria considered may be divided into subcriteria, which in turn may be subject to yet another division. Decisive variants under consideration are on the lowest level of hierarchy. A nine-degree grading scale, called Saaty's scale [Saaty 1980)] is used for comparisons. The AHP method requires a decision-maker to [Bozarth, Handfield 2007]:

- identify a set of the most important criteria and define their mutual relations involving domination (determining the hierarchy of criteria),
- define domination-related relations between available options in reference to individual criteria (determining the hierarchy of options),
- use the information to calculate absolute indicators of preference for individual options, where the higher the indicator, the higher the preference of a specific variant.

The WSM method (weighted sum method) is presently the most popular and the most common multiple-criteria decision-making method. Its distinctive feature is the intuitive nature of the algorithm of conduct. In the WSM method, instead of comparing pairs of criteria to determine priorities and assess preferences, a decision-maker assigns weight to individual criteria and assesses options with reference to all criteria [Bozarth, Handfield 2007].

Both methods are commonly applied to scientific theory and business practice. Therefore, they will not be further summarised here. Interested parties will find detailed examples of calculations (method execution procedure) in this paper [Bozarth, Handfield 2007]: AHP, WSM.

When comparing both multiple-criteria methods supporting the decision-making process, it should be stated that the AHP (advanced) method is more complicated in execution than the WSM (simple) method, i.e. it is more time-consuming and labour-intensive. The question posed by the authors of the article is under what conditions (set of parameters) both methods (WSM and AHP) will point to the same alternatives, and under what conditions they will indicate different ones (with seeking an answer to the second part of the question considered most meaningful).

EFFICIENCY OF A DECISION-MAKING PROCESS

The decision-making process is the key element of one of the fundamental management functions, i.e. planning. According to Kisielnicki, planning is in fact a decision-making process. As he puts it, "[it is]... a decision-making process whose task is to achieve set goals" [Kisielnicki 2008]. When interpreting planning as a process, its stages should be specified. Klasik [Klasik (ed.), 1993] distinguishes the following stages: setting goals, identifying problems, seeking alternative solutions, assessing consequences, making a choice, implementing a plan, monitoring the execution. Klasik's first five tasks of planning are related to decision-making. Kisielnicki and Turyna share his view on the relationship between planning and decision-making. In their opinion, planning is a decision-making process which has the form of a sequence of deliberate actions, such as intellectual analyses or judgments, which lead to the selection of the best solution according to a specific criterion [Kisielnicki, Turyna 2012].

These ideas indicate that an efficient decision-making process and efficient planning are similar processes. Reference books describe two approaches to the description of efficiency: a purposive and a systemic approach. The purposive approach was presented, among others, by Frankowska and Jedliński [Frankowska, Jedliński 2011]. They attribute its name to the triad of "purposes-effects-outlays", according to which an organisation is established to achieve specific goals with the help of incurred costs. M. Bielski [Bielski, 1992] claims, on the other hand, that the systemic approach prefers the assessment of opportunities and possibilities of future development to the organisation's achievement of assumed goals. I. Pisz and I. Łapuńska presented the criteria of logistics project efficiency. They divided this phenomenon into four dimensions: financial, stakeholders, process learning and growth [Pisz, Łapuńska, 2016].

In view of the above considerations, the efficiency of a decision-making process will in this article be interpreted as purposive efficiency accordant with the approach presented by M. Frankowska and M. Jedliński [Frankowska, Jedliński 2011] as the sum of two factors:
- effectiveness of action - ability to achieve set goals;
- efficiency of action - an optimal use of owned resources (may be related to the rationality of management, economy or profitability).

A method will be considered effective when its results are the same as for a different method. In terms of efficiency, the lower the costs incurred in order to perform the multiple-criteria decision-making method, the more efficient it is considered. It is not possible to actually determine which of the alternatives is better, since the analysis covers the way the method works and not the entire process of planning and carrying out tasks.

RESULTS OF A SIMULATION STUDY

Description of a simulation model

The iGrafx Process for Six Sigma simulation software recreated both multiple-criteria decision-making methods: WSM and AHP. The simulation model analysed making decisions on the basis of two alternative variants (A1, A2) based on three criteria (C1, S2, C3). The input data used to carry out the simulations were the values of nine parameters divided into two groups:
- value of each alternative (A1_C1, A2_C1, A1_C2, A2_C2, A1_C3, A2_C3) - assessment of each alternative according to each of the criteria - 6 parameters;
- weight of criteria (C1, C2, C3) - defining the significance of each of the criteria – 3 parameters.

Each of the parameters could assume a value from 1 to 10. At first, the parameters were used to determine the preference index for each alternative with the use of the WSM method. Further on, values of these parameters were transformed into preference indices in accordance to Saaty's scale used in the AHP method. The quotient method was applied to the transformation. Assuming that the value of parameter A was higher than the value of parameter B (if not, the formula assumed the reciprocal value 1/SaatyAB), the quotient formula is as follows:

$$Saaty_{AB} = Ceiling\left(\frac{Param.A}{Param.B}\right) \qquad (1)$$

Due to the number of possible combinations of states of parameters (109), a full-factor experiment was not conducted. In a limited plan for each of the parameters, three states were distinguished. They were assigned proper numerical values:

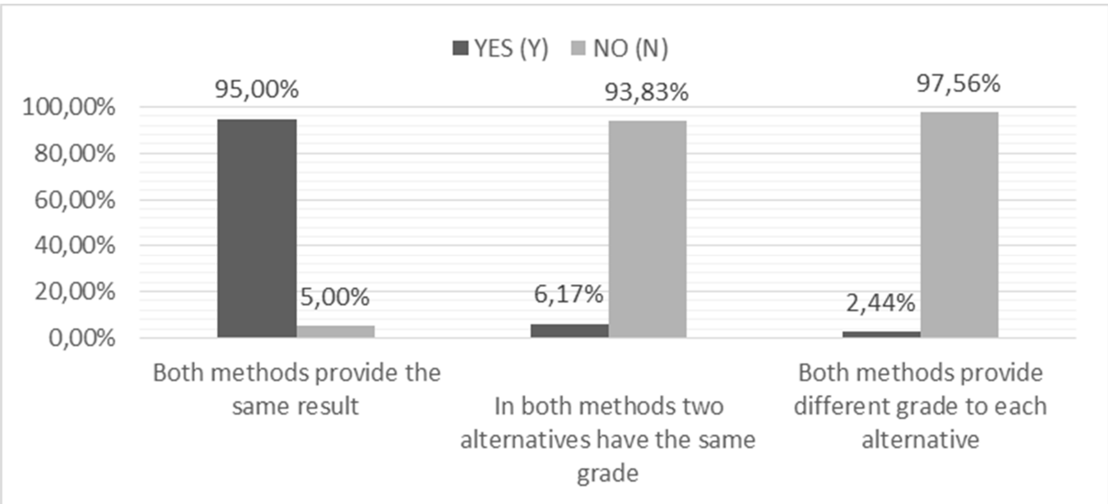
- low - value of parameter 2;
- mean - value of parameter 5;
- high - value of parameter 8;

In an experiment so planned, the number of simulations, assuming one iteration (based on the lack of random elements), was 39=19 683.

The result of the simulation was a numerical value defining the preference of each of the alternatives according to the WSM and AHP methods. The alternative producing a result with a higher numerical value was considered preferred according to the selected method.

Analysis of results

The analysis of simulation results verified in how many cases both analysed methods pointed to the same alternative. The results have been presented in Figure 1.



Source: Own study

Fig. 1. Comparison of results of WSM and AHP methods
Rys. 1. Porównanie wyników metod WSM i AHP

Both methods indicated the same results in 95% of cases. In some of the results (6.17% of total results), both methods did not clearly indicate any preferred variant (both alternatives obtained the same preference index). From the perspective of analysing the effectiveness of both methods, the cases in which both methods clearly indicated the other alternative were of particular interest. Such cases represented 2.44% of total results. Having identified specific conditions in which disparities occurred, the authors measured mean parameter values for equal and different results. Table 1 presents results of the analysis.

Table 1. Mean value of parameters in the same and different results
Tabela 1. Średnie wartości parametrów dla wariantów tych samych i różnych wyników

	Both methods provide the same result	In both methods two alternatives have the same grade	Both methods provide different grade to each alternative
	Mean value of each alternative		
YES (Y)	5,005	5,000	4,825
NO (N)	4,912	5,000	5,004
	Mean weight of criteria		
YES (Y)	4,988	5,000	5,463
NO (N)	5,232	5,000	4,988

Source: Own study

Results presented in column 3 are particularly important for further analysis. They depict mean parameter values in a situation where both methods gave different results for both alternatives. From a scientific point of view, it is important to indicate the statistical significance of differences between mean parameter values in conditions in which the methods clearly pointed to different outcomes. The analysis was based on two statistical tests (for each parameter group).

- A pair of statistical hypotheses for parameters indicating the value of each alternative:
  H0: All means are equal.
  H1: Means of data representing different results are lower.
- A pair of statistical hypotheses for parameters indicating the weight of criteria:
  H0: All means are equal.
  H1: Means of data representing different results are greater.

The test of statistical hypotheses was conducted for significance level $\alpha = 0{,}05$. P value for both pairs was below 0.001, which means that zero hypotheses may be rejected in favour of alternative hypotheses. Thus, there is a dependency between the parameter values of each group and results preferred by either of the methods. It has been statistically proven that results more frequently differ in lower-value parameters from the "value of each alternative" group and higher values of parameters from the "weight of criteria" group.

CONCLUSIONS

The results of simulation studies prove that findings obtained with the use of two multiple-criteria decision-making methods are very similar. The results of both methods analysed, WSM and AHP, differed in 5% of cases. Excluding the ones in which one of the methods did not clearly indicate a preferred option, the results differed only in 2.44% of cases. The differences occurred more frequently in lower-value parameters from the "value of each alternative" group and higher-value parameters from the "weight of criteria" group.

A statement on the absence of significant differences in results of both multiple-criteria decision-making methods was based on an assumption that the alternative chosen by both methods was better (both presented the same option as the preferred choice). The authors claim that the connection between the multiple-criteria decision-making method and the results of a decision made in an actual supply chain is an issue which is much more strongly correlated to the determination of the value of each alternative, not the logic of the method itself.

With reference to the efficiency of multiple-criteria decision-making methods, it should be ascertained that the WSM method is more efficient. WSM method is simple and does not require any complex parametrisation. Its application therefore requires smaller outlays in the decision-making process. Thus, the efficiency of this method is greater than in the case of the AHP method. In an event when results of both methods do not differ significantly it may be stated that their effectiveness is similar. Using the commonly applied definition of efficiency (as a combination of effectiveness of action and efficiency of action), if the two methods are characterised by similar effectiveness, the one with greater efficiency is more efficient. Considering the results of the study, the WSM method should be considered as such.

Due to the suggested size of the article and the introductory nature of its content, the authors have only presented an initial analysis of the results. In the future, the authors see the possibility to extend the study on two levels. The first one is the detailing level. The analysis of the study on this level will focus on analysing single cases in which results of both methods differ. Such an analysis requires employing different research apparatus, and its purpose will be to determine the influence of dependencies between the weight of criteria and value of each alternative and lack of comparability of results between WSM and AHP. The second level extends the study to include other methods for transforming the parameters that steer the analysed multiple-criteria decision-making methods. The article focuses on the quotient method. Studying and comparing results for the differential method and the expert method seems interesting.

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PORÓWNANIE WIELOKRYTERIALNYCH METOD WSPOMAGAJĄCYH PODEJMOWANIE DECZYJI - WYNIKI BADAŃ SYMULACYJNYCH

STRESZCZENIE. **Wstęp:** Obecnie teoretycy i praktycy dysponują wieloma metodami wspomagającymi proces podejmowania decyzji. Z uwagi na warunki, w jakich funkcjonują współczesne łańcuchy dostaw najbardziej interesujące wydają się metody wielokryterialne. Wykorzystanie skomplikowanych metod wymaga jednak wieloetapowej parametryzacji i przeprowadzenia rozbudowanych obliczeń.
Czy zatem efektywne jest stosowanie skomplikowanych metod?

Metody: Autorzy publikacji porównali dwie popularne wielokryterialne metody wspomagające proces podejmowani decyzji: metodę punktową ważoną (WSM) oraz metodę hierarchiczną (AHP). W modelu symulacyjnym odzwierciedlono funkcjonowanie obu tych metod. Dane wejściowe do symulacji stanowiły wartości parametrów: ocena alternatywy oraz waga kryterium.

Wyniki: Model symulacyjny opracowano w oprogramowaniu iGrafx Process for Six Sigma. Odzwierciedlono w nim funkcjonowanie dwóch wielokryterialnych metod wspomagania procesu decyzyjnego: WSM oraz AHP. Wynikami symulacji były wartości liczbowe odzwierciedlające preferencję każdej z alternatyw według każdej z metod. Za wybraną przez daną metodę alternatywę uznawano tą, której wartość wskaźnika preferencji była wyższa. W analizie wyników poszukiwano zależności pomiędzy wartościami parametrów oraz różnicą wyników przedstawioną przez obie metody. Wykorzystano w tym celu metody statystyczne w tym testowanie hipotez.

Wnioski: Przedstawione rezultaty badań symulacyjnych wskazują, że wyniki uzyskane dwiema wielokryterialnymi metodami wspomagania decyzji są do siebie bardzo zbliżone. Różnice wyników pomiędzy nimi miały miejsce częściej w warunkach niższych wartości parametru ocena alternatywy oraz w wyższych wartości parametru waga kryterium.

Słowa kluczowe: metoda ważona, metoda AHP, wielokryterialne metody wspomagania decyzji, badania symulacyjne

EINE VERGLEICHSSTUDIE VON MEHRKRITERIEN-METHODEN FÜR DIE UNTERSTÜTZUNG VON ENTSCHEIDUNGSTREFFEN - ERGEBNISSE VON SIMULATIONSUNTERSUCHUNGEN

ZUSAMMENFASSUNG. Einleitung: Heutzutage verfügen die Theoretiker und Praktiker über viele den Entscheidungsprozess unterstützende Methoden. In Hinsicht auf die Gegebenheiten, in denen die gegenwärtigen Lieferketten in Funktion treten, scheinen die Mehrkriterien-Methoden am meisten interessant zu sein. Die Inanspruchnahme der komplizierten Methoden macht aber eine Mehretappen-Parametrisierung und Durchführung von ausgebauten Berechnungen erforderlich. Ist die Anwendung der komplizierten Methoden denn effektiv?

Methoden: Die Autoren der Veröffentlichung haben sich eine Vergleichsstudie vorgenommen und zwei populäre, den Entscheidungsprozess unterstützende Mehrkriterien-Methoden miteinander konfrontiert, und zwar: die gewichtete Punkt-Methode (WSM) und die hierarchische Methode (AHP). Im Rahmen eines Simulationsmodells wurde die Funktionsausübung der beiden Methoden projiziert. Die Eingangsdaten zur Simulation machten die zwei folgenden Parameterwerte: die Bewertung der Alternative und das Gewicht des Kriteriums aus.

Ergebnisse: Das Simulationsmodell wurde im Programm von iGrafx Process for Six Sigma ausgearbeitet. In diesem Programm widerspiegelte man die Funktionsausübung der beiden Mehrkriterien-Methoden für die Unterstützung des Entscheidungsprozesses: die WSM und die AHP. Die Ergebnisse der Simulation stellten die Zahlenwerte, die jeweils die Präferenz einer jeder Alternative gemäß jeder der beiden Methoden aufzeigen, dar. Für die durch die jeweilige Methode ausgewählte Methode wurde die als relevant anerkannt, deren Wert der Präferenz-Kennziffer höher war. Im Rahmen der Ergebnisanalyse wurde es nach der Abhängigkeit zwischen den Parameterwerten und der durch die beiden Methoden dargestellten Ergebnisdifferenz gesucht. Dabei hat man zu diesem Zweck statistische Methoden, darunter die Methode für Testen von Hypothesen in Anspruch genommen.

Fazit: Die erzielten und projizierten Ergebnisse der Simulationsuntersuchungen zeigen darauf hin, dass die mithilfe der Mehrkriterien-Methoden für die Unterstützung des Entscheidungsprozesses gewonnenen Resultate nicht allzu sehr differenziert sind. Die Ergebnisdifferenzen kamen öfter beim Vorhandensein der niedrigeren Werte des Parameters der Bewertung der Alternative und bei höheren Werten des Parameters des Kriteriumsgewichtes vor.

Codewörter: gewichtete Methode, AHP-Methode, Mehrkriterien-Methoden für Unterstützung des Entscheidungsprozesses, Simulationsforschungen

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