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THE ANALYSIS PROCEDURE AND APPLICATION OF MULTICRITERIA DECISION-MAKING METHODS IN SELECTION OF INDUSTRY EQUIPMENT

Abstract: *Business intelligence and decision-making are one of the critical aspects of modern business, therefore in this paper the approach of mathematical decision-making methods application is analyzed, which can be useful for decision-makers in the decision-making process. This paper presents the concept of applying multi-criteria decision methods through the basic phases. Also, the paper presents the classification of exact decision-making methods. Particular attention has been paid to the analysis of methods of multi-attribute decision-making methods, and their application in the selection of process equipment in various fields of industry.*

Keywords: *Business intelligence, decision-making, exact decision-making methods, equipment selection*

1. INTRODUCTION

Decision-making represents an essential business aspect in every company because the sustainable success of the company depends on a large extent on success and reliability of the decision-making process itself. Management should make the right business decisions based on the information extracted from the relevant data collected.

The motivation for this research comes from the fact that the management team is not always 100% sure that the chosen decision is the most appropriate. Therefore, the decision makers can check and test their estimations and assumptions by using some exact decision-making methods. Decision-making methods are mathematically based methods, which should help decision-makers and give them support during the decision-making process. In the same time, they should not be a strict tool of which application a business decision is made.

Decision-making methods can be applied to solving different types of problems. Choosing the appropriate method is a procedure that requires special attention because depending on whether or not the appropriate method is chosen for the considered problem, the accuracy of the obtained solution depends on it. If a method is chosen that does not correspond to the problem under consideration or does not solve the problem in the desired way, then the application of the method cannot give reliable results, nor does it make sense to apply the method in such way.

The goal of this research is to present an insight into exact decision-making methods and its application in process equipment selection. The significance of decision making is mostly presented in a variety of business processes such as strategy, management, marketing, etc. In compliance with that, the problem statement may be formulated as a way of analysis of the decision-making methods, so that the process of selection process equipment would be sufficiently reliable.

The paper is organized in the following way: section 2 gives the literature review of business intelligence and decision making, section 3 explains exact decision-making methods that are used for solving of the considered problem, with a special overview of the methods of Multiple Attribute Decision Making (MADM) methods. Section 4 presents the procedure of application and analysis of multicriteria decision-making methods.

2. THE LITERATURE REVIEW OF BUSINESS INTELLIGENCE AND DECISION MAKING

The term business intelligence is usually understood as collecting and analyzing available and relevant data from internal and

external sources, which can be of use in the process of business decision-making. In addition, the most commonly used business intelligence definition concept is the use of modern information-communication (ICT) technologies in decision-making. One of the often cited definitions of business intelligence is [1]: "Business intelligence is the process of collecting available internal and relevant external data, and processing them into useful information that can help management in the decision-making process."

As can be deduced from the above definition, business intelligence is directly related to the decision-making process. Decision-making is a very complex process and can depend on a large number of factors. In the literature, a large number of different classifications of the decision-making process can be found, depending on the considered criteria.

Harrison [2] classifies the decision-making process according to the following criteria:

- by the amount of available data and knowledge of the problem under consideration [3]:
  - decision-making in the conditions of certainty,
  - decision-making in conditions of risk,
  - decision making in conditions of uncertainty and
  - decision-making in conditions of risk and uncertainty;
- by the assessment of satisfaction of the decision making process with available data [4]:
  - terminally and
  - research decision making;
- by the subject of decision-making [5]:
  - decision-making in private life and
  - business decision making;
- by the hierarchical level in which the decision is made:
  - operative,
  - tactical and strategic decision-making;
- by the structure of decision making [6]:
  - structured and
  - unstructured decision – making;
- by the number of decision makers:
  - single criteria and
  - multi-criteria decision-making.

When using the decision-making methods, the criteria that have the most significant impact on the selection of the method is the number of decision-makers. The approach for problem-solving is significantly different in individual and group decision making. Characteristic for individual decision making is to decide by the individual, assuming all responsibility for him, while in group decision making this procedure is much more complex but can give more reliable results. The problem of group decision making can undoubtedly be conflicts and disagreements among group members. The way of the decision-making in the group, which each organization seeks to reach, is a consensus, on which exact decision-making methods are based.

3. EXACT DECISION-MAKING METHODS

Exact decision-making methods are mathematical methods that make decision-makers easier to make decision-making and direct them to the right path in solving a particular problem. Therefore, these methods necessarily do not need to provide a final solution to the problems that decision-makers will adopt, but rather a solution that decision-makers should first take into consideration. The basic classification of mathematical methods is based on the number of criteria that are considered in solving a problem. Thus, exact decision-making methods can be divided into single-criteria and multi-criteria decision-making methods. Figure 1 shows the general classification of the decision-making method. Classification of the decision-making method was made by the relevant literature [7-12].

Since the process of equipment selection is related to the analysis of equipment (in this case these are alternatives) from the aspect of a number of criteria, this paper considers the multi-attribute decision-making methods.

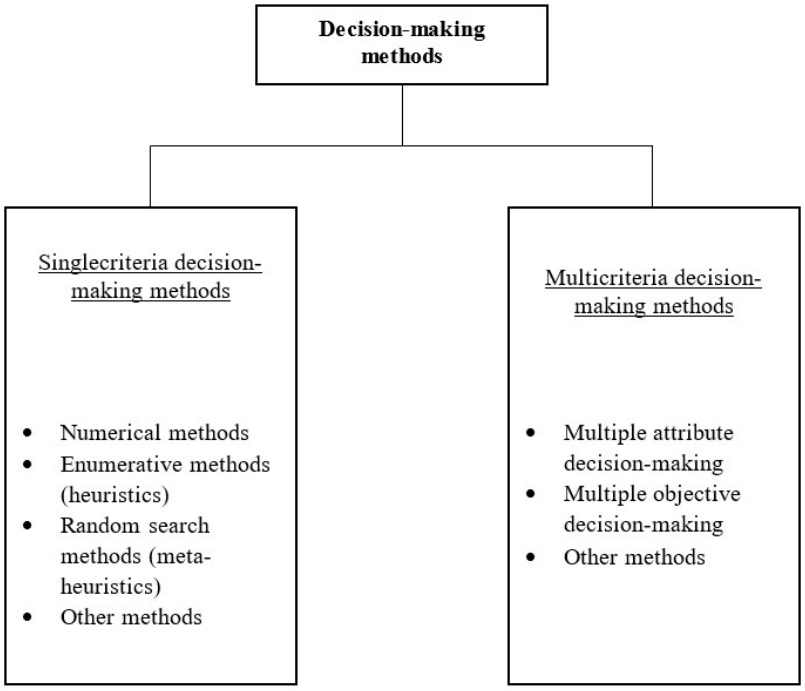

Figure 1 – Classification of exact decision-making methods

3.1 Multi-attribute decision-making methods – MADM

Multi-attribute decision-making methods (MADM) are used to select optimal alternatives, classification or rank of alternatives, by considering two or more decision criteria. According to the relevant literature, the methods of multidimensional decision-making can be classified into [8-12]:

- utility methods,
- outranking methods,
- compromise methods and
- other methods.

The utility methods are most often used in determining the weight coefficients of the criteria, and this is their primary purpose. Some of the most commonly used methods in the literature, which belong to the utility methods, are AHP [13], ANP [14], method of additive weight factors [15], SMART method [16], MACHBET [17], Best-Worst [18], etc.

The outranking methods, as their name suggests, have the application to solve the problem when it is necessary to rank the considered alternatives. The most commonly used methods in this group are ELECTRE [19,20], PROMETHEE [21], NAIADE [22], REGIME [23], ORESTE [23] etc. In addition to the above methods, some authors in this group classify AHP, which, besides being used to determine the weight coefficients of the criteria, can also provide a ranking alternative.

Compromise methods are also used to rank alternatives, that is, choosing the optimal alternative, as well as the ranking methods, but their logic is somewhat different. The basis of the principle by which these alternatives are ranking is that the optimal solution is determined based on its distance from the positive and negative ideal points. The most often used methods in this group are TOPSIS [24], COPRAS [25], VIKOR [26] and Compromise programming [27].

In addition to the above three subgroups, the method of multi-attribute decision-making in this group includes some methods that due to their nature cannot be strictly classified in any of these subgroups. Such methods are, for example, DEMATEL [28], FLAG [29] and SMAA [30].

4. PROCEDURE OF APPLICATION AND ANALYSIS OF MULTI-CRITERIA DECISION MAKING

According to the literature sources [31,32,33] the problem-solving process using multi-criteria decision-making methods can be divided into five phases: 1) defining the goal, alternatives, and criteria, 2) determining the weight (importance) of the criteria, 3) forming a decision matrix, 4) applying one of the MCDM methods, and 5) determining value, rank, or set of optimal solutions.

Phase 1: At the very beginning, it is necessary to define the aim of problem-solving, which can be the determination of rank alternatives, classification of alternatives, determination of the optimal alternative, etc. Then, alternatives (possible solutions) and criteria, or characteristics of the alternatives based on which they are compared, are defined.

Phase 2: The weights of the criteria is determined at this stage. Depending on whether decision makers have the same or different importance in deciding, the aggregation of their assessments into group consensus can be done in several ways. If decision-makers have the same importance in deciding, aggregation can be done using the methods of arithmetic, geometric, harmonic, square mean, and others. If the decision-makers do not have the same importance, then the OWA operator [33] can be applied. In the case that the decisions of the decision makers are expressed by linguistic expressions that the expressions are modeled using the fuzzy numbers [34] and not on any of the standard scale measures, then the FOWA operator [35] can be applied.

The most commonly used methods for determining the weight of the criteria are AHP, ANP, and Best-Worst, or methods belonging to the group of utility methods.

Phase 3: At this stage, the decision-making matrix is formed. Decision makers, at this stage, express their estimates, either on a scale of measures of real numbers (Saaty's scale [1-9], school scale [1-5], scale [0-1]) or with linguistic expressions. These statements can be modeled in a variety of ways, such as, for example, using a fuzzy numbers type-1, fuzzy numbers type-2, intuitionistic fuzzy sets, rough sets, etc.

In order to make estimates of decision makers comparable and how they could be aggregated, it is necessary to normalize the estimated values. Some of the most common types of normalization used in the literature are linear, vector, and percentage normalization.

Phase 4: The decision-making method should be fully compatible and adequate for the problem under consideration. For example, if the considered problem is ranking of alternatives, it is necessary to choose one of the ranking methods, and a suitable method for this should be chosen based on a comparative analysis of methods belonging to that group of methods. Also, when choosing a method, methods from the group of methods that have been selected should be considered.

When analyzing the considered methods, it is necessary to pay attention to the following characteristics:

- determine the problem to be solved and the scope of application of the considered methods,
- the representation of the method in the literature when solving problems from the discussed area,
- the representation of the method in other areas,
- the way of presenting estimates of decision makers in existing papers related to the discussed methods and
- examine the advantages and disadvantages of each considered method.

Phase 5: After the selection of the method, the method itself should be applied to the considered problem. The method should be chosen based on whether it is necessary to choose the optimal alternative, rank alternatives, identify alternatives or determine acceptable and unacceptable solutions. If necessary, the chosen method needs to modify or supplement in a certain way. The solution obtained by applying the chosen method should not be strictly and necessarily accepted by the decision-makers, but rather serve as an adjunct to decision-making.

5. APPLICATION OF MULTI-ATTRIBUTE DECISION-MAKING METHODS IN THE SELECTION OF INDUSTRY EQUIPMENT

The problem of equipment selection is very often discussed in the literature, where the choice of equipment in different types of

industry is considered. In this paper, an analysis of the relevant papers was made from the aspect of the method that is applied and how the decision-makers present the estimates. This analysis is shown in Table 1.

Table 1 - Application of the MADM methods in solving the problem of industry equipment selection

Equipment type	Authors (year)	Method(s)	Modelling of uncertainty (expressions)	Other notes
Milling machines	Dağdeviren (2008)	AHP & PROMETHEE	Crisp values	Estimates expressed on Saaty's measuring scale [1-9]. The weights of criteria were determined using the AHP method, and the final ranking was obtained using the PROMETHEE method.
CNC vertical turning center for general use	Ayağ & Özdemir (2006)	Fuzzy AHP	Triangular type-1 fuzzy sets	For providing the decision-makers, estimations are used nine linguistic expressions. Conventional AHP method is extended according to [36]
Material handling equipment	Tuzkaya, Gülsün & Kahraman (2010)	Fuzzy ANP & Fuzzy PROMETHEE	Triangular type-1 fuzzy sets	F-ANP is used for determination of criteria priorities (weight factors), and F-PROMETHEE for determination of optimal solution (selection of alternative).
Thermal Power Equipment	Zhao & Guo (2014)	Fuzzy TOPSIS in combination with Fuzzy-Entropy Weighting Method	Triangular type-1 fuzzy sets	Fuzzy-Entropy Weighting Method is used for determining the weight factors and F-TOPSIS gives the rank of alternatives.
Equipment selection for iron mine	Lashgari, et al. (2012)	Fuzzy ANP & Fuzzy TOPSIS	Triangular type-1 fuzzy sets	F-ANP is used for determining the weight factors and F-TOPSIS for obtaining the optimal solution (equipment).
Equipment selection for copper open pit mine	Aghajani Bazzazi, et al. (2011)	Fuzzy AHP	Triangular type-1 fuzzy sets	Extended conventional AHP method according to [37].
Opencast mining equipment	Samanta, et al. (2002)	ANP	Crisp values	By directly comparing the value of alternatives, their rank is determined, respecting the importance of the criteria.
Conveyor equipment evaluation and selection	Nguyen, et al. (2016)	Fuzzy AHP & Fuzzy ARAS	Triangular type-1 fuzzy sets	F-AHP is used for determining the weight factors of criteria and subcriteria and F-ARAS method is used for determining the degree of utility of every alternative.
Lead-free equipment	Tang & Lin (2010)	Fuzzy AHP	Triangular type-1 fuzzy sets	In the paper is used F-AHP extended according to [38].

From the attached table it can be concluded that the problem of equipment selection is represented in different areas and branches of industry. The most commonly used methods in these papers are F-AHP and F-ANP, which suggests that the problem of equipment selection requires a hierarchical structuring of the problem. In fewer papers, none of these two methods are used, and then they are replaced by another method from the

group of utility methods. Apart from determining rank alternatives, these two methods are used in some cases to determine the weight coefficients of the criteria, and by using some of the ranking methods or compromise methods, the ranking of alternatives is determined. The decision makers decisions are usually expressed using Triangular type-1 fuzzy sets, and in rare cases with crisp values.

6. CONCLUSION

This research sets the direction for the appropriate selection of equipment that may be suitable for recycling. The literature review of business intelligence and decision making has been conducted. The decision-making methods, in the first place single criteria and multiple criteria have been analyzed. In the scope of that, an application of different methods has been the subject of analysis in the scope of appropriate equipment section. Talking in account the specification of criteria related to the selection of appropriate equipment for the recycling process, it may be suggested that multi-criteria decision making tools are suitable for this task. The literature indicates that the most used methods are fuzzy AHP, fuzzy TOPSIS, and fuzzy ANP. The future research should examine the impact of newly suggested methods such as a Best-Worst method.

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