SELECTION OF TECHNOLOGICAL VEHICLES TO THE GEOLOGICAL AND MINING CONDITIONS WITH AN APPLICATION OF STOCHASTIC GROUP DECISION AIDING METHOD

SAWICKA Hanna[1], BODZIONY Przemysław[2], SAWICKI Piotr[1]

[1]*Poznan University of Technology, Division of Transport Systems, Poznan, Poland, EU,*
hanna.sawicka@put.poznan.pl; piotr.sawicki@put.poznan.pl
[2]*AGH University of Science and Technology, Surface Mining Department, Cracow, Poland, EU,*
przembo@agh.edu.pl

Abstract

This paper deals with the selection of technological vehicles to the specific mining and geological conditions in open cast surface mining. The problem is formulated as a multiple criteria ranking of variants, which are different types of technological vehicles. They are evaluated by the family of ten criteria according to several aspects, including: economy, technology and construction, exploitation and reliability. Vehicle selection is carried out by the group of decision makers involved in the decision process. They are professionals with different expertise profiles. The solution of the problem is performed with an application of stochastic group decision aiding method proposed by the authors. This approach is composed of five phases, i.e.: 1) analysis of the decision situation, 2) construction of variants, and definition of the set of criteria, 3) evaluation of variants, 4) preference modeling and computations, 5) construction of the stochastic ranking. The obtained results are compared with the previous research on selection of technological vehicles based on separate individual preferences of each expert.

Keywords: Vehicle selection, surface mining, haul trucks, multiple criteria decision aiding, group of experts

1. INTRODUCTION

Road transport carried out by haul and articulated trucks is a dominant one, and sometimes it is the only one possible mode of transportation in surface mining. The share of transport expenditures in the surface mining indicates the importance of the role the transport plays in the overall mining process. High costs generated by the output transport, in terms of investments and further exploitation, are estimated by around 60% of total operational costs [1]. The basic condition of transport efficiency is the selection of appropriate means of transport. All the methods typically applied into a transport means selection process can be divided into two key groups. In the first one an optimal vehicle's operating lifetime is based on analysis of operating expenditures with respect to the useful life (e.g. [2, 3]). The second group of the methods is concentrated on the optimisation of economic viability of all repairs activities with respect to the effectiveness of mining output transport (e.g. [4, 5]). In most of the papers an interaction between transport means and mining operating conditions is omitted and the multiple criteria character of the problem, as well.

One of the universal approaches applied to solve many decision problems is a multiple criteria decision aiding (MCDA) methodology [6, 7, 8]. It aims at giving the decision maker the tool, which enables his / her to solve complex decision problems, where different points of view are taken into consideration. Many real-world problems are solved using group support systems. In the literature are presented two main streams in solving multiple criteria decision making problems, which have at least two decision makers [9]. The first one are specialized group decision making tools e.g. Co-oP [10], SCDAS - Selection Committee Decision Analy-sis and Support [11], MEDIATOR [12], while the second one are group decision making tools designed to solve analysed decision problem, e.g. for classification of companies using experts' knowledge [13, 14]. An overview of the models of group decisions and negotiations is presented by Jelassi *et al.,* [15]. The authors discuss similarities and differences between the group decision making and negotiations with examples of the use of group decision support systems and negotiations support systems.

The use of group decision making, as one of the trends of multicriteria decision aiding methodology allows to reflect the multiplicity of points of view on the same problem expressed by several evaluation criteria, aggregation of preferences of many decision makers and the organization of the whole decision making process [10]. However, the most common problem is a method of aggregation of preferences expressed by different decision makers and simplification of these preferences into the deterministic information, while in many cases their character is stochastic.

In this paper a novel method solving a stochastic group decision aiding problem is proposed. This method is applied to solve a real-world ranking problem, where each variant is a specific haul truck evaluated by the set of criteria. Decision makers (DMs) are experts with specific professional mining perspective, including mining operations and machine design and its utilisation. The results of decision process are compared with the outcome of author's previous work presented in paper of Bodziony *et al.,* [16], where preferences of experts are considered separately. The approach applied in this paper is also a continuation of the authors' previous works on stochastic values of criteria in multiple criteria decision aiding problems presented in e.g. Sawicka [17], Sawicki and Sawicka [18].

2. PROPOSED METHODOLOGY

The proposed approach is composed of five iterative phases presented in **Figure 1**. Phase 1 is dedicated to an analysis of the decision situation. Context of a decision problem is considered in details and reflected in the next phases of the procedure. During phase 2, set of variants (phase 2.1) and set of criteria (phase 2.2.) are constructed. While creating variants a specific character of a single solution is articulated and modelled. By defining the set of criteria a comprehensive evaluation of each variant is performed and presented in the next phase. Phase 3 is devoted to the complex evaluation of variants with respect to the previously defined set of criteria. Finally, a vector of the values of criteria describes each variant, and the output of the phase 3 is a matrix of performances.

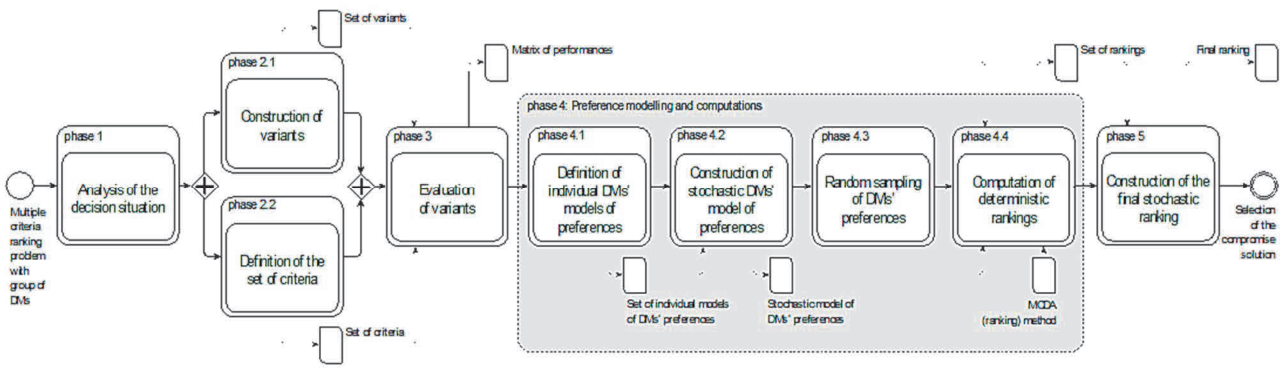

Figure 1 Key phases of the proposed procedure. Own work

Phase 4 is concentrated on advanced preferences' modelling, their application in multiple criteria decision aiding method and computations. These preferences are expressed by the group of experts (several decision makers) involved in the problem solution. The individual DMs' preferences refer to criteria, i.e. their relative importance, as well as to performances of variants, i.e. the tolerance of performance differences. They are presented as models and then they are integrated (see phase 4.2) into the single stochastic model. During phase 4.3 a random sampling of preference stochastic values is repeatedly performed, and each sample is an input data for computation of deterministic ranking (see phase 4.4). In the last phase of the procedure (see phase 5) the set of all previously generated rankings is transformed into the single stochastic ranking.

3. APPLICATION OF THE METHODOLOGY

3.1. Analysis of the decission situation

The decision situation presented in this paper comes from a real-world problem analysed in the surface mining. Vehicle transport is one of the most important technological processes in this area and its selection is a difficult and complex task. The mining process profitability is strictly dependent on overall cost of fleet's exploitation. Strong impacts on its selection have exploitation conditions and the user's preferences and experience. Thus, a rational design of transportation system based on haul trucks should result from thorough analysis of several aspects, including technology, exploitation, machine design and economy.

The decision problem (phase 1 in **Figure 1**) considered in this paper is defined as the haul truck selection for a specific exploitation conditions in surface mining. In the analysis carried out, a group of decision makers i.e. team of experts, is examined. They are represented by 3 academic experts and 2 mining managers (including one who is also an academic expert in the field of surface mining technology). Their priorities and preferences differ and they are strongly depended on professional experience and background.

3.2. Construction of variants and definition of the set of criteria

The decision problem is composed of 7 variants of haul trucks and 10 evaluation criteria (phase 2 in **Figure 1**). The set of variants consists of 21 vehicles accepted for analysis. It is defined *a'priori* - it is inalterable during the decision procedure. It includes the existing fleet of haul trucks with different types and new vehicles, as well. They are utilised in two selected reference opencast mines. When defining the variants, the mines' similar exploitation conditions have been taken into account, as well as the specificity of the transport environment, i.e.: a) mining-geological conditions, b) mineral deposits operating system, c) transport distan-ce, d) type of road surface (bituminous surface, hard-macadam surface, mixed road surface), e) differences in the levels of transport road, f) the amount of output transported during single transport cycle, g) the nature and quality of sourced minerals, h) weather and road changing conditions in the seasons.

The vehicles have been evaluated by the set of criteria, representing different aspects such as: economic (C_1 - total investment costs [PLN], minimized criterion; C_2 - total operating costs [PLN / 5.000 engine hours], minimized criterion), technical-construction (C_3 - maximum power [kW], maximized criterion; C_4 - maximum torque [Nm] maximized criterion; C_5 - minimum turning radius [m], minimized criterion; C_6 - payload capacity [Mg], maximized criterion), exploitation and reliability (C_7 - unit energy consumption [-], minimized criterion; C_8 - reliability index [%], maximized criterion; C_9 - stream damage parameter [damages / engine hours], minimized criterion; C_{10} - ergonomics and driver comfort [points], maximized criterion). More information about the family of criteria is presented in paper Bodziony *et al.,* [16].

3.3. Evaluation of variants

The set of 7 variants, denoted from A_1 to A_7 has been evaluated by the family of 10 criteria (phase 3 in **Figure 1**). The resulted matrix of performances is presented in **Table 1**. Based on that it is hard to select the best variant. Some of the vehicles have the most desirable characteristic on one criterion, such as e.g. A_2 on criterion C_2, A_5 on criterion C_5 while on the other criteria these variants are evaluated as the worst, e.g. A_2 on criterion C_6, A_5 on criterion C_2. Thus, the application of the one of MCDM methodology becomes crucial to solve this problem.

Table 1 Matrix of performances. Own work

Criteria			Variants						
Name	Unit	Preferences	A_1	A_2	A_3	A_4	A_5	A_6	A_7
C_1	thous. PLN	min	740	815	1.018	1.959	1.262	1.844	1.610
C_2	thous. PLN / 5000 eng.h	min	2.509	1.982	2.326	2.381	2.576	2.456	2.106
C_3	kW	max	448	440	522	533	371	522	520
C_4	Nm	max	2.237	2.350	2.731	3.326	2.167	2.739	3.091
C_5	m	min	10.2	10.0	9.0	8.5	7.2	9.6	9.6
C_6	Mg	max	45.0	42.0	55.0	64.0	45.0	63.1	64.9
C_7	-	min	0.831	0.797	0.827	0.790	0.540	0.877	0.851
C_8	%	max	66	61	61	92	92	57	85
C_9	damages / 1000 eng.h	min	7.18	9.36	15.0	6.46	6.15	9.10	6.46
C_{10}	points	max	43.7	38.2	82.8	116.1	96.0	72.7	98.2

3.4. Modelling of preferences and computations

The decision makers have been asked about their attitude to the way of expressing the preferences. All of them agree that the weights of criteria should be given on a scale, such as the best criterion has the highest weight and the worst - the lowest one. In decision makers opinions some of the criteria are indifferent, thus their weights have the same values. Moreover, the decision makers perceive some of the variants as indifferent on one criterion, while on the other they are weekly or strongly preferred. It is hard to compare some of the considered vehicles. One of the MCDM methods, which can reflect such a way of modeling the preferences and decision makers hesitation is ELECTRE III [6, 8]. This method is based on the outranking relation. The definition of the model of the DM's preferences is determined by the indifference q_j, preference p_j, and veto v_j thresholds and weights w_j for each criterion j. Then the outranking relation is constructed. Finally, the ranking of alternatives is generated. At this point the outranking relation is exploited.

Based on the opinions collected from the decision makers (phase 4.1 in **Figure 1**), the matrix of preferences including the above mentioned thresholds and weights, has been constructed (phase 4.2 in **Figure 1**). Its values are presented in **Table 2** as the ranges of variations of individual preferences [16].

Table 2 Stochastic model of DMs' preferences. Own work

Criteria	Ranges of variation			
	Weights w_j	Thresholds		
		Indifference q_j	Preference p_j	Veto v_j
C_1	(5, 30)	(20, 100)	(150, 500)	(300, 1000)
C_2	(10, 30)	(20, 70)	(60, 200)	(100, 400)
C_3	(2, 10)	(5, 50)	(20, 100)	(100, 200)
C_4	(2, 9)	(50, 200)	(100, 500)	(300, 800)
C_5	(1, 10)	(0.5, 2.0)	(1.0, 3.0)	(2.5, 5.0)
C_6	(10, 15)	(2, 5)	(8, 15)	(12, 30)
C_7	(7, 10)	(0.01, 0.05)	(0.01, 0.15)	(0.10, 0.30)
C_8	(10, 20)	(5, 10)	(10, 15)	(20, 30)
C_9	(5, 10)	(0.2, 0.5)	(0.5, 5.0)	(1.0, 10.0)
C_{10}	(5, 20)	(5, 20)	(10, 30)	(30, 50)

Next, the random sampling has been carried out (phase 4.3 in **Figure 1**). The algorithm AS 183 of Wichman & Hill [19] has been applied. Based on this phase, 100 computational experiments with an application of the deterministic multiple criteria ranking method ELECTRE III has been carried out (phase 4.4). Their results are presented as 100 ranking matrices including relations between variants, such as indifference (*I*), preference (*P*), inverse preference (P^-) and incomparability (*R*).

3.5. Construction of the final stochastic ranking

The construction of the final stochastic ranking is based on the computation of the probability of a particular relation between variants (phase 5 in **Figure 1**). The ranking matrix and final stochastic ranking are presented in **Figures 2a** and **2b**.

a)

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
A_1	I=1.000	P=0.600 I=0.400	P^-=0.767 P=0.100 I=0.067 R=0.067	P^-=1.000	P^-=1.000	P^-=1.000	P^-=1.000
A_2	P^-=0.600 I=0.400	I=1.000	P^-=0.967 I=0.033	P^-=1.000	P^-=1.000	P^-=1.000	P^-=1.000
A_3	P=0.767 P^-=0.100 I=0.067 R=0.067	P=0.967 I=0.003	I=1.000	P^-=1.000	P^-=1.000	P^-=0.700 I=0.300	P^-=1.000
A_4	P=1.000	P=1.000	P=1.000	I=1.000	P=0.833 R=0.133 I=0.033	P=1.000	P=0.467 R=0.433 P^-=0.100
A_5	P=1.000	P=1.000	P=1.000	P^-=0.833 R=0.133 I=0.033	I=1.000	P=0.833 R=0.167	P^-=0.533 R=0.400 I=0.033 P=0.033
A_6	P=1.000	P=1.000	P=0.700 I=0.300	P^-=1.000	P^-=0.833 R=0.167	I=1.000	P^-=1.000
A_7	P=1.000	P=1.000	P=1.000	P^-=0.533 I=0.433 P=0.033	P=0.533 R=0.400 I=0.033 P^-=0.033	P=1.000	I=1.000

b) c)

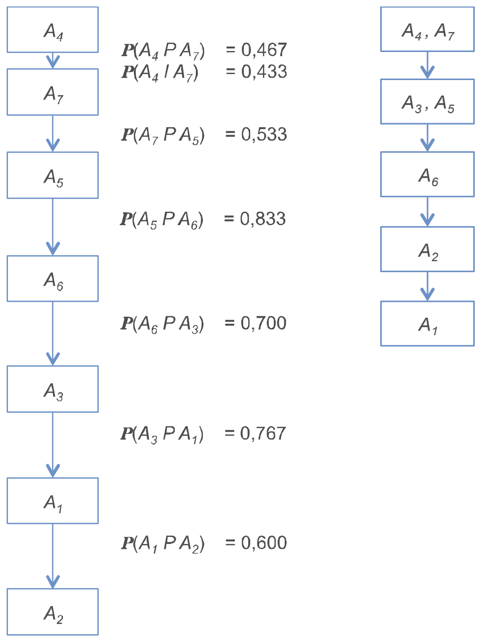

Figure 2 The final ranking matrix (a), final stochastic ranking (b), expert no. 2 ranking (c). Own work

The ranking matrix shows the relation between pairs of variants - an intersection of a row and a column, i.e. variant A_1 is preferred to variant A_2 with the probability of preference relation *P*, which equals 0.600. The probability of indifference relation between this pair of variants is 0.400. Based on the information presented in the ranking matrix, the final ranking has been constructed. Variant A_4 located at the top of it is a compromise solution. Next position in a ranking holds variant A_7 and the preference relation between A_4 and A_7 is 0.467. These variants are very close in the ranking, because the probability (P) of the indifference relation $P(A_4\ I\ A_7)$ between them equals 0.433. Third, fourth and fifth position in the ranking have variants A_5, A_6 and A_3, respectively. Variant A_1, which is one before last, is preferred to the last variant in the ranking, i.e. A_2. The preference relation *P* between them equals 0.600. This ranking, especially the top of it, is compared to the final order of variants obtained for preferences expressed by expert no. 2 (**Figure 2c**). In the first case the compromise solution is A_4, while in the second one - variant A_4, which is indifferent to variant A_7. There are at least two reasons of the differences between results. The deterministic ELECTRE III method doesn't present the distance between variants in the final ranking and three types of relations between them can be exploited, i.e. indifference *I*, preference *P* and incomparability *R*. The probability of relations between variants in the proposed methodology can be interpreted as the distance between them. If the values between indifference and preference relations are similar, then there is a weak preference of variant A_4 over A_7. Moreover, the result presented in **Figure 2b** is computed on the wide spectrum of preferences defined by different experts, while the ranking showed in **Figure 2c** reflects only one point of view.

4. CONCLUSIONS

In this paper a classical multiple criteria ranking method ELECTRE III has been presented. Based on that, it is possible to solve decision problem with deterministic values of criteria evaluating the set of alternatives, decision maker's preferences with his / her hesitations. However, some decision situations are complex, there are more than one decision maker and the application of existing methods would not be applicable or would not result in a desirable solution. Thus, the concept of stochastic multiple criteria decision aiding method to solve group decision problems aiming at ranking of variants has been presented. It is based on a compo-sition of classical methodologies, i.e. multiple criteria decision aiding and probability theory.

The proposed method has been successfully implemented in the real-world surface mining company, where seven variants, representing different haul trucks, has been considered. The final ranking obtained shows that the compromise solution is variant A_4. This result has been compared to the ranking calculated according to preferences of expert no. 2, selected arbitrary as the representative of the group of experts. In this case, variants A_4 and A_7 are indifferent. Thus, it is hard to decide which of them should be selected. Thanks to the proposed stochastic methodology, the weak preference of variant A_4 to variant A_7 has been specified, which helps to select the final result.

The future direction of the proposed methodology are as follows: 1) verification of the methodology on a wide range of problems, i.e. correct matching of wheel loaders or excavators and haul trucks, 2) representation of stochastic preferences by different types of probability distributions, 3) application of the other multiple criteria decision aiding methods, such as Promethee, AHP.

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