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SELECTION OF PRODUCTION LINES IN METALLURGICAL INDUSTRY BY USING COMPROMISE PROGRAMMING METHOD

Abstract

Every organization today faces the problem of decision making. In this regard, the intent of the paper is to present an approach based on multi-criteria decision-making methods. Primarily, proposed approach is aimed to help solving problem of choosing optimal production lines in the metallurgical industry. Proposed approach is based on the use of the AHP method for determining the weights of the criteria, whereas the Compromise Programming is used for the selection of the alternatives. The usability, applicability and efficiency of the proposed approach is demonstrated in conducted case study of selection of production lines in metallurgical industry.

Keywords*: metallurgical industry; production lines; MCDM; Compromise Programming*

1 INTRODUCTION

Metallurgy represents a science that is aimed at production of metal alloys. Most often it includes refining, alloy production, shaping and refining, as well as studying the structure, composition and properties of metals. By type of metal is most often divided into black (iron and steel) and metallurgy of non-ferrous metals (obtaining all other metals). Legrand et al. [1] states that "metallurgical industry mainly transforms steel or its derivative products into products with either better surface properties (thanks to the surface transformations....), or into different shape products (lamination...), involves some processing tools which can generate flaws (cracks, grooves...) within the process".

Until now, multiple-criteria decision-making (MCDM) is often used as a tool for solving a wide range of complex problems. In the simplest sense, MCDM can be defined as the selection of an alternative from the set of available alternatives [2]. Also, very rapid development of the MCDM field has caused a creation of many MCDM methods, such as: SAW, AHP, PROMETHEE, ELECTREE, COPRAS, MOORA, ARAS and MULTIMOORA and so on. Comparisons of some of them are given by Mardani et al. [3] and Turskis and Zavadskas [4]. So far, MCDM methods have been successfully applied in solving problems in metallurgical industry such as: thermoplastic matrix selection for fibre metal laminate using fuzzy VIKOR and entropy measure for objective weighting [5] and selecting a

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Complementary Metal Oxide Semiconductor (CMOS) Image Sensors by using a fuzzy MCDM framework [6].

Based on the above stated, the main aim of the paper is to provide effective approach based on the MCDM methods for selection of the production lines in the metallurgical industry. For the weights determination AHP method is applied whereas for the ranking of alternatives compromise programming is applied.

Therefore, paper is organized as follows. In Section 1 Introductory considerations are presented. In section 2 applied methodology is explained. In section 3 conducted case study is presented. Finally, conclusions are given at the end of the manuscript.

2 METHODOLOGY

The Method of Analytical Hierarchical Processes (AHP), which is proposed by Saaty [7] is one of the most popular methods of multi-criteria decision making. The popularity of this method is influenced by hierarchical problem structuring and and comparison in pairs. Therefore, for determining the weights of the criteria, AHP method was applied.

The concept of Compromise Programming (CP) was proposed by Yu [8] and Zeleny [9]. Until now, CP was applied in order to solve different problems, such as: Fuzzy-based heat and power hub models for cost-emission operation of an industrial consumer using compromise programming [10], a Nadir Compromise Programming for supplier selection problem under uncertainty [11], empowering cash managers through Compromise Programming [12] and so on.

The basic idea of the CP is to determine the alternative that has the least distance from the ideal solution (ideal point).

For some problems of multi-criteria decision-making that involves *m* alternatives that are evaluated on the basis of *n* criteria, the procedure for selecting the most acceptable alternative can be represented as follows:

$$\min L_{p,i} = \left\{ \sum_{j=1}^{n} w_j^p \left(\frac{x_j^* - x_{ij}}{x_j^* - x_j^-} \right)^p \right\}^{\frac{1}{p}}, \tag{1}$$

where $L_{p,i}$ is the distance metric of alternative *i* for a given parameter p; w_j is the weight of criterion *j*; x_{ij} is the performance of alternative i to criterion j; x_j^* and x_j^- are the best and the worst performance of alternative *i* for criterion j, $i = 1, 2, \ldots, m$; *m* denotes number of alternatives, and $j = 1, 2, \ldots, n$; *n* denotes the number of criteria.

The parameter p, in equation (1), is used to represent the importance of the maximal deviation from the ideal point. By varying the parameter p from 1 to infinity, it is possible to move from minimizing sums of individual deviations to minimizing the maximal deviations to the ideal point, in a decision-making process. More precisely, when the parameter p has a value of 1, all the distances in relation to the ideal point have the same significance, and in this case the sum of the distance in relation to each criterion is calculated, and the alternative with the lowest sum value is the most acceptable. The choice of a particular value of this compensation parameter p depends on the type of problem and desired solution [13].

The best x_j^* and the worst x_j^- performance for criterion j should be determined as follows:

$$x_j^* = \begin{cases} \max\limits_i x_{ij}; & j \in \Omega_{\max} \\ \min\limits_i x_{ij}; & j \in \Omega_{\min} \end{cases}, \text{ and} \tag{2}$$

$$x_j^- = \begin{cases} \min\limits_i x_{ij}; & j \in \Omega_{\max} \\ \max\limits_i x_{ij}; & j \in \Omega_{\min} \end{cases}, \tag{3}$$

where $\Omega_{\max}$ and $\Omega_{\max}$ denote the set of benefit and cost criteria, respectively.

Determination of the most acceptable alternative with application of compromise programming method is considered to be relatively simple, but also efficient and understandable for decision makers. Accordingly, we suggest application of this method when solving problems of production lines in the metallurgical industry.

Below will be presented evaluation of alternatives based on application of AHP and CP methods in group environment.

In a group environment, decisions are made based on the views of several respondents, usually experts in the relevant field. In the literature, several approaches to group decision-making have been considered, and as a commonly used procedure, it is possible to indicate the approach in which:

- determine the group weights of the criteria based on the weights of the criteria obtained from each respondent using the AHP method;
- determine group performances of alternatives in relation to the criteria based on the performances of alternatives obtained from each respondent;
- determine overall performances, i.e. the significance of each alternative of some MCDM method, and, in given case, using CP method, based on group weights and group performances.

Group weights and group performances can be determined by using the following formula:

$$w_j = \frac{1}{K}\sum_{k=1}^{K} w_j^k \,, \tag{4}$$

$$x_{ij} = \frac{1}{K}\sum_{k=1}^{K} x_{ij}^k \,, \tag{5}$$

where w_j^k denotes significance of the *j*-th criteria obtained based on the standpoints of the *k*-th respondent, x_{ij}^k denotes performance of the *i*-th alternative in relation to the *j*-th criteria obtained from *k*-th decision maker; i=1,2, ..., m; j=1,2, ..., n; k =1,2, ..., K.

3 CASE STUDY- SELECTION OF PRODUCTION LINES IN METALLURGICAL INDUSTRY

In the considered case study evaluation of five production lines in the metallurgy industry was carried out based on the opinions of the five domain experts.

Production lines have been evaluated from three points of view:

- reliability, reflected in time and maintenance and repair costs, as well as the number of planned and unplanned downtime of the production line.
- the quality of the products on these lines.
- productivity.

Therefore, the following criteria have been adopted for the purpose of evaluating production lines:

- C_1 – Exploitation indicator,
- C_2 – maintenance and repair indicator,
- C_3 – performance indicator, and
- C_4 – quality indicator.

Table 1 shows the group weights obtained by using AHP method and applying formula (4) based on the standpoints of the five decision makers.

Table 1 Group weights of the evaluation criteria

	E_1	E_2	E_3	E_4	E_5	w_i
C_1	0.128	0.114	0.141	0.138	0.128	0.130
C_2	0.265	0.192	0.141	0.125	0.265	0.197
C_3	0.333	0.337	0.263	0.309	0.333	0.315
C_4	0.275	0.358	0.455	0.428	0.275	0.358

After determining group weights, each of the five experts have evaluated alternatives in relation to the selected set of criteria. For the evaluation of the alternatives, the five-step Likert scale was used as shown in table 2.

Table 2 Five-step Likert scale used for evaluation of performances of alternatives in relation to the set of criteria

Rating	Meaning
5	Excellent performances
4	Good performances
3	Average performances
2	Bellow average performances
1	Bad performances

The performance of the alternatives obtained from the five experts are shown in the tables 3-7.

Table 3 Performances of alternatives in relation to the criteria obtained form the first decision maker

	C_1	C_2	C_3	C_4
A_1	4	4	4	4
A_2	3	4	5	4
A_3	4	3	4	3
A_4	5	5	5	4
A_5	3	5	3	4

Table 4 Performances of alternatives in relation to the criteria obtained form the second decision maker

	C_1	C_2	C_3	C_4
A_1	4	3	4	4
A_2	4	5	5	5
A_3	5	3	4	4
A_4	5	5	5	3
A_5	3	5	3	4

Table 5 Performances of alternatives in relation to the criteria obtained form the third decision maker

	C_1	C_2	C_3	C_4
A_1	5	5	4	4
A_2	5	5	3	3
A_3	4	4	4	3
A_4	5	4	4	4
A_5	3	5	3	4

Table 6 Performances of alternatives in relation to the criteria obtained form the fourth decision maker

	C_1	C_2	C_3	C_4
A_1	4	4	4	4
A_2	4	3	5	5
A_3	3	4	5	3
A_4	3	3	5	3
A_5	3	5	3	4

Table 7 Performances of alternatives in relation to the criteria obtained form the fifth decision maker

	C_1	C_2	C_3	C_4
A_1	4	3	5	4
A_2	3	3	4	3
A_3	3	2	5	3
A_4	3	4	4	4
A_5	3	4	3	4

Finally, group performances obtained by applying formula (5) are shown in table 8.

Table 8 Group performances of alternatives obtained from five experts

	C_1	C_2	C_3	C_4
A_1	4.200	3.800	4.200	4.000
A_2	3.800	4.000	4.400	4.000
A_3	3.800	3.200	4.400	3.200
A_4	4.200	4.200	4.600	3.600
A_5	3.000	4.800	3.000	4.000

The normalized and weighted normalized decision matrix was obtained using the following formula:

$$\bar{x}_{ij} = \frac{x_j^* - x_{ij}}{x_j^* - x_j^-}, \tag{6}$$

$$v_{ij} = w_j \frac{x_j^* - x_{ij}}{x_j^* - x_j^-}, \tag{7}$$

where $\bar{x}_{ij}$ denotes normalized performance of the i-th alternative in relation to the j-th criteria, and v_{ij} denoted weighted normalized performance of the i-th alternative in relation to the j-th criteria.

The normalized and weighted normalized decision matrix are shown in tables 9 and 10.

Table 9 Normalized decision making matrix

	C_1	C_2	C_3	C_4
A_1	0.0000	0.6250	0.2500	0.0000
A_2	0.3333	0.5000	0.1250	0.0000
A_3	0.3333	1.0000	0.1250	1.0000
A_4	0.0000	0.3750	0.0000	0.5000
A_5	1.0000	0.0000	1.0000	0.0000

Table 10 Weighted normalized decision making matrix

	C_1	C_2	C_3	C_4
A_1	0.0000	0.1233	0.0787	0.0000
A_2	0.0433	0.0986	0.0393	0.0000
A_3	0.0433	0.1972	0.0393	0.3583
A_4	0.0000	0.0740	0.0000	0.1791
A_5	0.1298	0.0000	0.3147	0.0000

Overall performances of alternatives, as well as rank of alternatives, for parameter p=1, are shown in table 11.

Table 11 Overall performances of alternatives, for parameter p=1

Alternatives	$L_{1,i}$	Rank
A_1	0.2019	2
A_2	0.1812	1
A_3	0.6381	5
A_4	0.2531	3
A_5	0.4445	4

As shown in table 11, the most acceptable alternative is an alternative, i.e. production line designated as A_2.

Overall performances of alternatives, as well as rank of alternatives, for parameter p=5, are shown in table 12.

Table 12 Overall performances of alternatives, for parameter p=5

Alternatives	$L_{5,i}$	Rank
A_1	0.00003	2
A_2	0.00001	1
A_3	0.00620	5
A_4	0.00019	3
A_5	0.00312	4

Based on the data from table 12, it can be concluded that increase of parameter p does not affect the ranking of alternatives, which is why the production line designated as A_2 can be considered most appropriate under the given conditions.

CONCLUSIONS

In modern business, often are used different methods and algorithms in order to solve complex problems that accompany production and optimization of production factors, which have an impact on profitability. The complexity of the problem often requires the application of decision making methods in order to solve mentioned problems.

Every organization today faces the problem of decision-making. In this sense, one of the intentions of this paper was to present a model based on multi-criteria decision making methods, which aims to solve problem of selecting optimal production lines in the metallurgical industry.

The proposed model represents a hybrid AHP-CP model that was tested on a case study for the selection of production lines in the metallurgical industry. By applying this approach, the most acceptable production line was successfully selected. It was also found that an increase in the value of the parameter p does not affect the ranking order of the alternatives, which makes the production line designated as A_2 as the most appropriate under the given conditions. Previously stated shows that the proposed model is applicable and effective, especially as it can help the management in the selection of strategies in order to optimize the allocation of available resources.

REFERENCES

[1] Legrand A. C., Suzeau P., Renier E., Truchetet F., Gorria P., Meriaudeau F., Machine vision systems in the metallurgy industry. Journal of Electronic Imaging, 10(1) (2001) 274-283.

[2] Vujić D., Stanujkić D., Urošević S., Karabašević D., An approach to leader selection in the mining industry based on the use of weighted sum preferred levels of the performances method. Mining and Metallurgy Engineering Bor, (4) (2016), 53-62.

[3] Mardani A., Jusoh A., MD Nor K., Khalifah Z., Zakwan N. Valipour A., Multiple criteria decision-making techniques and their applications–a review of the literature from 2000 to 2014. Economic Research, 28(1) (2015) 516-571.

[4] Turskis Z. Zavadskas E. K., Multiple criteria decision making (MCDM) methods in economics: an overview. Technological and economic development of economy, 2 (2011) 397-427.

[5] Ishak N. M., Sivakumar D., Mansor M. R., Thermoplastic matrix selection for fibre metal laminate using fuzzy vikor and entropy measure for objective weighting. Journal of Engineering Science and Technology, 12(10) (2017) 2792-2804.

[6] Huang C. Y., Hung M. C., Jhu T. L., Tzeng, G. H., Selecting a CMOS sensor by using a fuzzy MCDM framework. In System Science and Engineering (ICSSE), 2010 International Conference on (pp. 119-123). IEEE.

[7] Saaty T.L., The Analytical Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill, New York, 1980.

[8] Yu P. L., A Class of Solutions for Group Decision Problems. Management Science 19(8) (1973) 936-946.

[9] Zeleny M., Compromise programming. In: Multiple Criteria Decision Making, eds: J. Cochrane L. & M. Zeleny, pp. 262-301, University of South Carolina Press, Columbia, SC, 1973.

[10] Khodaei H., Hajiali M., Darvishan A., Sepehr M., Ghadimi, N., Fuzzy-based heat and power hub models for cost-emission operation of an industrial consumer using compromise programming. Applied Thermal Engineering, 137 (2018) 395-405.

[11] Ekhtiari M., Zandieh M., Alem-Tabriz A., Rabieh, M., A Nadir Compromise Programming for Supplier Selection Problem under Uncertainty. International Journal of Industrial Engineering & Production Research, 29(1) (2018) 1-14.

[12] Salas-Molina F., Pla-Santamaria D., Rodríguez-Aguilar, J. A., Empowering Cash Managers Through Compromise Programming. In Financial Decision Aid Using Multiple Criteria (pp. 149-173). Springer, Cham, 2018.

[13] Tecle A., Shrestha B. P., Duckstein, L., A multi–objective decision support system for multi–resource forest management. Group Decision and Negotiation, 7(1) (1998) 23–40.