*UNIVERSITY OF BELGRADE*
*TECHNICAL FACULTY IN BOR*
*MANAGEMENT DEPARTMENT*

# INTERNATIONAL MAY CONFERENCE ON STRATEGIC MANAGEMENT


## STUDENTS SYMPOSIUM ON STRATEGIC MANAGEMENT

# PROCEEDINGS

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# INTERNATIONAL MAY CONFERENCE ON STRATEGIC MANAGEMENT

# STUDENTS SYMPOSIUM ON STRATEGIC MANAGEMENT

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# INTERNATIONAL MAY CONFERENCE ON STRATEGIC MANAGEMENT

# ORE DEPOSIT EVALUATION BY USING COMPROMISE PROGRAMMING

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**Izvod**

The main task for decision maker in mine exploitation is ore deposit evaluation, which is very important from technical as well as from economic point of view. This is one of the Multiple Criteria Decision Making (MCDM) problems because decision makers are faced with different alternatives and a number of conflicting criteria. This paper proposes Compromise Programming for ore deposit evaluation and ranking. The criteria weights are> determined by using Entropy Method. This methodology is demonstrated with real case study involving 4 alternative ore deposits and 6 evaluation criteria.

**Keywords:** Compromise Programming, Entropy Method, ore deposit.

## 1. INTRODUCTION

Many authors have proposed different analytical models as aid in solving conflict management problems. One of the most popular methods certainly belongs to the Multi Criteria Decision Making (MCDM). Duckstein and Opricovic (1980) said that MCDM may be considered as a complex and dynamic process including one managerial level and one engineering level. The managerial level includes defining goals and selecting an optimal alternative, while engineering level defines alternatives and indicate the consequences of selecting any one of them [1]. Belton and Stewart (2002) define MCDM as „*an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter*“ [2].

MCDM methods have been classified in many different ways. One of the basic categorizations makes a distinction between multi-objective decision making (MODM) and multi-attribute decision making (MADM). The main distinction between them is based on the number of alternatives under evaluation. MADM methods are intended for election discrete alternatives. MODM methods are more appropriate for multi-objective planning problems, when there is the problem of simultaneous maximization or minimization of several objectives subject to a set of constrains [3, 4, 5, 6].

Application of the MCDM methods can be found in many papers that consider decision making process in different fields such as transportation problems, supplier and vendor selection, investment analysis and others [7-11]. MCDM methods are very useful for solving decision making problems in the field of natural resources management and become very popular in recent years. These methods are mostly used in the field of renewable resources such as water resources [12-15], forest resources [16-18], sustainable energy management [19-22] etc. Attention is mainly concentrated on previous mentioned fields, but decision making in mineral resources management is somewhat neglected.

Usually, authors consider mining method selection by using MCDM methods. The examples could be found in the papers of Alpay and Yavuz (2007), Samimi Namin et al. (2008) Naghadehi et al. (2009), and Azimi et al. (2011) [23-26]. Also, sustainable development of mining sector and impacts on the environment in combination with using MCDM methods are very common theme in the papers. Examples are reviews include [27-31]. But, before selection of mining method and assessment of environmental impacts, managers should choose appropriate ore deposit for exploitation which characteristics should be optimal from every point of view, such as economic, technical and ecological.
This paper proposes Compromise Programming (CP) for ore deposit evaluation and selection, based on technical aspects of exploitation. Entropy Method is used for determining the criteria weights. The paper is organized as follow: in section 2 the CP and Entropy Method is represented; section 3 presents a framework for ore deposit evaluation; in section 4 the numerical example based on real data is given; and section 5 contains conclusions.

## 2. METHODOLOGIES

In the following sub-sections 2 MCDM methods, which are integrated in this research, are discussed. They are: CP method, that is used for evaluation and ranking of the alternatives and Entropy Method, which is used for determination of criteria weights.

### 2.1. Compromise Programming

CP is developed by Zeleny (1973) and Yu (1973) [32, 33]. It relies on the concept of distance to analyze multi-objective problems. There is no limitation of distance to the geometric sense of distance between two points. A proxy is used for measuring degrees of human preferences. CP selects alternative that has the least distance from the ideal point [32]. Compromise solution that is achieved by using this method can be viewed as minimizing a regret of decision maker (DM) for not obtaining the ideal solution [34].

The distance measure used in CP belongs to the family of $L_P -$metrics and expressed as:

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

where $L_{p,i}$ is distance metric of $i-$th alternative for a given parameter $p$, $w_j$ is the weight of $j-$th criterion, $x_j^*$ is the most desirable value of $j-$th criterion, respectively, $x_{ij}$ is performance ratings of $i-$th alternative on $j-$th criterion, $i = 1,2,..., m$ and $j = 1,2,..., n$.
In order to avoid scale effects and to make all criteria values commensurable formula (1) is complemented and written as follows:

$$\min L_{p,i} = \left\{ \sum_{j=1}^{n} w_j^p \left( \frac{x_j^* - x_{ij}}{x_j^* - x_j^-} \right)^p \right\}^{1/p}, \quad (2)$$

where $x_j^-$ is the most undesirable value. This normalization process guarantees that equation will have values between 0 and 1.

Parameter $p$ represents balancing factor which reflects the attitude of the DM with respect to compensation among deviations [35]. Different aspects of CP algorithm is caused by different values of $p$. If $p=1$ than all deviations from $x_j^*$ are taken into account in direct proportion to their magnitudes. If $2<p<\infty$, than the largest deviation has the greatest influence. Value of $p$ depends on the type of problem and desired solution [33]. Possible compensation is smaller when the conflict between DM is greater [36, 37].

### 2.2. Entropy Method

Entropy was first introduced to information theory by Shannon 1948 [38, 39]. This method demonstrates that a broad distribution represents more ambiguity than a sharply peaked one [40], and has been widely used in many different fields such as engineering, economy, etc. In this paper the criteria weights are determined by the Entropy Method which is highly reliable and easy to use. Determination of the criteria weights is performed by following formula:

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}\left(1-e_j\right)}, \tag{3}$$

where $j=,...,n.$

The output entropy $e_j$ of the $j-\text{th}$ factor is calculated as:

$$e_j = -\frac{1}{\ln(m)}\sum_{j=1}^{n} r_{ij}\ \ln\left(r_{ij}\right), \tag{4}$$

where $j=,...,n..$

Criteria weights determined in the shown way should satisfy the term: $\sum_{j=1}^{n} w_j = 1$.

## 3. A FRAMEWORK FOR ORE DEPOSIT EVALUATION

The procedure for ore deposit evaluation can be expressed using the following steps:

***Step 1.*** **Determine key evaluation criteria and alternatives which will be ranked.** Available alternatives and most important criteria should be identified.
In this case, data are taken over from the paper entitled *Ore deposit selection by using TOPSIS and AHP method* [41] and they are slightly modified. Compared ore deposits from Central Serbia are:

- **$A_1$ - Juzni revir - Majdanpek district**
- **$A_2$ - Severni revir - Majdanpek district**
- **$A_3$ - Borska reka - Bor district**
- **$A_4$ - Cerovo - Bor district**

A small number of criteria are used to forming a simple framework, and nature of these criteria is only technical, but they are sufficient for showing the applicability of this method. The criteria are followed:

- ***$C_1$*-Copper content in ore** (%). The ore deposit with higher copper content has the advantage.
- ***$C_2$*-Silver content in ore** (g/t). The ore deposit with higher silver content has the advantage.
- ***$C_3$*-Gold content in ore** (g/t). The ore deposit with higher gold content has the advantage.
- ***$C_4$*-Examination of balance reserves.** Explored masses of the minerals in the deposit or part of the deposit which can be rationally and economically used with present techniques and technologies of exploitation and processing. Better examined deposits have the advantage.
- ***$C_5$*-Location.** Geospatial position of the ore deposit and transport infrastructure. The ore deposit which has better position and which is closer to the major highways is desirable.
- ***$C_6$*-Mining-geological conditions of exploitation.** Mining-geological conditions include many characteristics of ore deposit, such as: shape of ore body, depth, contact with the surrounding rocks and others that are very significant for selection of exploitation method and have influence on the exploitation costs [41].

In the mentioned paper, which example is used, information about ore deposits are retrieved from study that is a part of extensive study entitled *Potentials of economic development of Timocka Krajina* and from *Field guide.* [42, 43].

***Step 2.* Forming the decision-making matrix.** The Table 1 represents the decision-making matrix [44].

*Table 1. The decision-making matrix*

| ***Alternatives*** | ***Criteria*** | | | |
|---|---|---|---|---|
| | $C_1$ | $C_2$ | **…** | $C_j$ |
| $A_1$ | $x_{11}$ | $x_{12}$ | ... | $x_{1j}$ |
| $A_2$ | $x_{21}$ | $x_{22}$ | ... | $x_{2j}$ |
| . | . | . | . | . |
| $A_i$ | $x_{1j}$ | $x_{n2}$ | ... | $x_{ij}$ |
| $W$ | $w_1$ | $w_2$ | ... | $w_j$ |

where $A_1, A_2, ..., A_i$ represent possible alternatives among which DM have to choose, $C_1, C_2, ..., C_j$ are criteria with which alternative performance are measured, $x_{ij}$ is the rating of alternative $A_i$ with respect to the criteria $C_j$, $w_j$ is the weight of the criteria $C_j$, $i = 1,..., m$, $m$ is number of alternatives, and $j = 1,..., n$, $n$ is number of criteria [45].
Transformation of the qualitative criteria into quantitative is performed using the numerical scale shown in Table 2:

*Table 2. Transformation of qualitative into quantitative values*

| Qualitative value | Quantitative value | |
|---|---|---|
| | benefit - max | cost - min |
| Very high | 9 | 1 |
| High | 7 | 3 |
| Average | 5 | 5 |
| Low | 3 | 7 |
| Very low | 1 | 9 |

***Step 3.*** **Determine the criteria weights.** The criteria weights are very important for the MCDM models. In this paper the criteria weights are determined using Entropy Method and formula (3).

***Step 4.*** **Determining the most acceptable alternative**, by using formula (2). The most acceptable solution has the least distance from the ideal point.

## 4. NUMERICAL EXAMPLE

Table 3 shows four ore deposit $A_1, A_2, A_3$ and $A_4$ which are evaluated against six evaluation criteria $C_1, C_2, C_3, ..., C_6$, which are already mentioned.

*Table 3. Raw data*

| | Copper content % | Silver content g/t | Gold content g/t | Examination of balance reserves | Location | Mining-geological conditions of exploitation |
|---|---|---|---|---|---|---|
| | max | max | max | max | min | max |
| Juzni revir | 0.335 | 1.260 | 0.188 | high | average | high |
| Severni revir | 0.306 | 2.001 | 0.263 | high | average | high |
| Borska reka | 0.620 | 1.920 | 0.240 | average | very low | very low |
| Cerovo | 0.340 | 1.800 | 0.110 | high | low | low |

Transformation of qualitative criteria into quantitative is performed by using numerical scale given in Table 2 and it is presented in Table 4.

*Table 4. Initial decision-making matrix*

| Alternatives | Criteria | | | | | |
|---|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ |
| | Copper content % | Silver content g/t | Gold content g/t | Examination of balance reserves | Location | Mining-geological conditions of exploitation |
| | max | max | max | max | min | max |
| $A_1$ | 0.335 | 1.260 | 0.188 | 7 | 5 | 7 |
| $A_2$ | 0.306 | 2.001 | 0.263 | 7 | 5 | 7 |
| $A_3$ | 0.620 | 1.920 | 0.240 | 5 | 9 | 1 |
| $A_4$ | 0.340 | 1.800 | 0.110 | 7 | 7 | 3 |

The criteria weights, which are calculated using formula (3), are given in Table 5.

*Table 5. The criteria weights*

| Criteria | $w_j$ |
|---|---|
| $C_1$ | 0.1356 |
| $C_2$ | 0.0428 |
| $C_3$ | 0.1368 |
| $C_4$ | 0.0276 |
| $C_5$ | 0.0929 |
| $C_6$ | 0.5643 |

Based on data from Tables 4 and 5, using formula (2) for $p = 1$, $p = 2$ and $p = \infty$, the overall performance indexes are calculated and shown in Table 6. The ranking order is also given in Table 6.

*Table 6. Ranking results*

| Alternatives | CP | | | | | |
|---|---|---|---|---|---|---|
| | $p = 1$ | **Rank** | $p = 2$ | **Rank** | $p = \infty$ | **Rank** |
| $A_1$ | 0.2330 | 2 | 0.1466 | 2 | 0.2330 | 2 |
| $A_2$ | 0.1356 | 1 | 0.1356 | 1 | 0.1356 | 1 |
| $A_3$ | 0.6824 | 3 | 0.5723 | 4 | 0.6284 | 3 |
| $A_4$ | 0.6920 | 4 | 0.4209 | 3 | 0.6920 | 4 |

As can be seen from Table 6, the best ranked alternative is $A_2$. In the case when $p = 2$ the ranking order is different from the other two, but $A_2$ alternative is in the first place in all three cases.

## 5. CONCLUSION

The model, which is presented in this paper, uses CP for ore deposit evaluation. It is necessary to consider the impact of multiple-criteria on the decision process, and CP method provides an easy and understandable procedure for that matter. Entropy Method is used for determining the criteria weights to avoid subjectivity in decision making. In this case only technical aspects of exploitation are reconsidered. Integrated model, which would take into account economic and social aspects of exploitation besides technical, would be more reliable.
DM in mining companies could make appropriate decisions about starting exploitation of ore deposits by using the proposed framework which enables them to evaluate available alternatives against a number of conflict criteria. But, MCDM methods are still insufficiently used in mineral resources management.

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