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Evaluation of the Impacting Factors on Sustainable Mining Development, Using the Grey-Decision Making Trial and Evaluation Laboratory Approach

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ABSTRACT

Due to great effect of mining operation on environment and dependent sides, paying attention to the aspects of sustainable development (SD) is important. A conjugation of Grey theory and Decision-Making Trial and Evaluation Laboratory (DEMATEL) is able to find out cause and effect relations among the triple mining SD components and their effective factors. Grey–DEMATEL approach has been used in order to effectively quantify indicators of sustainable development of a copper mine located in south east Iran. This systematic approach transformed the quantitative and qualitative information into a analogous scale and measured the interrelationships among the SD components and their factors. Hierarchical Grey-based DEMATEL compensated the incomplete and uncertain environmental and socio-economic information. The obtained results indicated that social component with an R value of 10 is relatively strong direct influencer on the other components and the economic component is the least direct influencer with R= 8.49. Among the social impacting factors, employment of local work forces is the most important factor that needs to be consider with sustainable development objectives.

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1. INTRODUCTION

Sustainable development was being used widely in many areas of the human life. The “Our Common Future” report was published in 1987 defined sustainable development as considering long lasting conditions to provide the needs of all generations [1]. In 1990’s a related definition of this report concerned three environmental, economic and social principles across generations to achieve sustainable development and economic growth [2, 3].

Successful economic development requires capacity increasing of industries in each country. Mining, play an important role in human history and is one of the most important industries for economic growth in any countries. Fast growth of world prices of many minerals, makes the mining very perspective for development [4]. Since the mining operation applies on non-renewable resources, it basically, will cause the unsustainability due to the various reasons such as limited resources of the earth and insufficient and incomplete data [5, 6]. Therefore, integrating sustainable development with mining industry process is a major challenge while Whitmore [7] named the sustainable mining as "the emperor's new clothes”. Sustainable development in mining, means investing in the projects that are economically profitable, technically suitable, environmentally responsible and socially accepted [8]. In 1990’s, the focus on sustainable mining widened to include social, environmental and financial ones.

The main purpose of researches on sustainable mining is to increase the benefits, to reduce the risks significantly and to provide favorable conditions for the mining industry [9–13]. Von Below [14] considered the impact of environmental effects stated that the technological innovation and environmental reconstruction are in line with SD. Flochi [15] developed a procedure to quantify the environmental impact of mining operation. Odell [16] considered the environmental, economic and social impacts of mining

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operation at the mine design stage. Laurence [17] reviewed the literature on sustainable development in the mining industry in order to provide guidance for mine operators to improve the sustainability of their mine sites. Philips [18] developed a mathematical model to determine the SD. Osanloo [19] confirmed that sustainable mining activities must be organize as Green Mining in the future. Narrei and Osanloo [20, 21] regarded to reduce the undesireble environmental impacts in determining revenues. Xu et al. [22] based on the SD researches explained that ecological costs were reducing economic profits. In fact many of the sustainability interpretations have focused on environmental protection as environmental management however the socio-economic issues have taken little consideration [23].

However, providing a model for evaluating sustainable development in mine industries that can assess all issues related to sustainable developments is important. In this manner the impacting factors of sustainable mining should be identified and considered in a model and investigate their inter-relationships in order to estimate sustainable development in mining industry. Rahmanpour and Osanloo [24] used Environmental Impact Assessment (EIA) to evaluate SD of the Sungun mine. Ataei et al. [23] used a semi-quantitative model for environment impacts to assess the sustainability level of Alborz coal mining complex. The impacting factors involved in the sustainable development were investigated structuraly by Norouzi Masir et al. [25] in an underground coal mine.

The major weakness associated with the previous studies is the uncertainty and incomplete mining information. There is no analytical interpretation about the details and impacting components of sustainable development and their correlations. The aim of this study is applying sustainability principles by analyzing impacting factors when qualitative and quantitative information exist in operational functions. To scale these relationships with a hierarchical structure and consider the uncertainty of the information, we use a Grey- relying Decision Making based Trial and Evaluation Laboratory method.

The modeling approach introduced in this paper, incorporates a number of stages: the recognition of factors of mining operations that affects sustainable development, identification of their relations based a grey scale, changing the grey scale into a crisp scale, utilizing DEMATEL method steps, and finally attain a causal relationship diagram.

2. MATERIALS AND METHODS

2. 1. Sustainable Development in Mining Industry

Sustainable development, generally performs by combination of three key components: economic activities, protection of environment and natural resources and social development [4].

Figure 1 shows the values of economy, environment and society that have partly overlapping would ideally indicate the sustainability [3].

There are many specific factors which lead to affect mining sustainability. The factors that are not specific could find thorough the literatures. Table 1 summarizes the classification of most effective factors of mining sustainable development into three economic, social, and environmental classes based on literature [25].

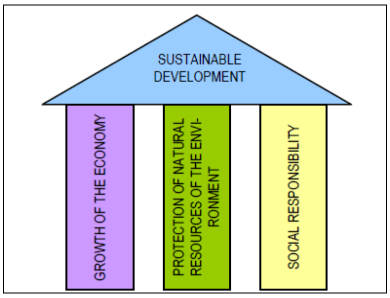

Figure 1. Three key components of “sustainable development” [4]

TABLE 1. Factors involved for sustainable development in mining [25]

Main class factors	Sub factors
Environmental	Air pollution
	Water pollution
	Soil pollution
	Noise
	Forest protection
	land disturbance
	Energy and fuel
Economic	Fixed price
	Capital expenditures
	Operating costs
	Rate of return
	Share in domestic production
	Net present value
Social	Employment of local work force
	Local satisfaction
	Regional culture
	Skills and knowledge
	Health, and safety
	Protecting the rights of future generations

2. 2. Grey-DEMATEL Technique

2. 2. 1. Grey Theory In order to handel the ambiguity of human decisions due to limited, uncertain and incomplete information, a grey theory can be used [26] that give adequate results using a comparatively small content of data or with large variability in factors [27–30]. It is obviouse that the exact value of a grey number is unknown, but a range within which the value lies is known. Grey theory show effective results in areas deals with uncertain and nondescript problems such as economics, medicine, geography, earthquakes, industry, etc. A grey system is a system other than white (system with completely known information) and black (system with completely unknown information) systems, and thus has partially known and partially unknown characteristics.

Factor x denotes a closed and confined set of real numbers. In Equation (1), the ⊗X as a grey number, is a distance with specific upper, $\overline{X}$, and lower limits, $\underline{X}$, for X [26] and [31].

$$\otimes X = \left[\underline{X}, \overline{X}\right] = \left[X' \in \otimes X \middle| \underline{X} \le X' \le \overline{X}\right] \tag{1}$$

A grey number operation is an operation defined on sets of intervals, rather than real numbers. Equations (1)–(5) display basic grey number mathematical processes [32]:

$$\otimes X_1 + \otimes X_2 = \left[\underline{X_1} + \underline{X_2}, \overline{X_1} + \overline{X_2}\right] \tag{2}$$

$$\otimes X_1 - \otimes X_2 = \left[\underline{X_1} - \overline{X_2}, \overline{X_1} - \underline{X_2}\right] \tag{3}$$

$$\begin{aligned}\otimes X_1 \times \otimes X_2 = (&\min(\underline{X_1}\underline{X_2}, \underline{X_1}\overline{X_2}, \overline{X_1}\underline{X_2}, \overline{X_1}\overline{X_2}),\\ &\max(\underline{X_1}\underline{X_2}, \underline{X_1}\overline{X_2}, \overline{X_1}\underline{X_2}, \overline{X_1}\overline{X_2}))\end{aligned} \tag{4}$$

$$\otimes X_1 \div \otimes X_2 = (\underline{X_1}, \overline{X_1}) \times (\frac{1}{\overline{X_2}}, \frac{1}{\underline{X_2}}) \tag{5}$$

$\otimes X_{ij}^{p}$ is defined as the grey number for decision-making factor, p, that will evaluate the effect of i factor on j factor. Also, $\underline{X_{ij}^{p}}$ and $\overline{X_{ij}^{p}}$ are, respectively, the lower and upper grey values of the grey number $\otimes X_{ij}^{p}$ [31].

In order to get a crisp number, a de-greying method is needed. The Converting Fuzzy data to Crisp Scores (CFCS), is effective for achieving crisp values [33, 34]. The modified CFCS method includes three following steps:

(1) Normalizing the grey value

$$\underline{\tilde{X}_{ij}^{p}} = (\underline{X_{ij}^{p}} - \min \underline{X_{ij}^{p}}) \Big/ \Delta_{\min}^{\max} \tag{6}$$

$$\overline{\tilde{X}_{ij}^{p}} = (\overline{X_{ij}^{p}} - \min \overline{X_{ij}^{p}}) \Big/ \Delta_{\min}^{\max} \tag{7}$$

where,

$$\Delta_{\min}^{\max} = \max \overline{X_{ij}^{p}} - \min \underline{X_{ij}^{p}} \tag{8}$$

(2) Calculating the total normalized of crisp value

$$Y_{ij}^{p} = \frac{\left(\underline{\tilde{X}_{ij}^{p}}\left(1 - \underline{\tilde{X}_{ij}^{p}}\right) + \left(\overline{\tilde{X}_{ij}^{p}} \times \overline{\tilde{X}_{ij}^{p}}\right)\right)}{\left(1 - \underline{\tilde{X}_{ij}^{p}} + \overline{\tilde{X}_{ij}^{p}}\right)} \tag{9}$$

(3) Computating the final crisp values

$$Z_{ij}^{p} = \min \underline{X_{ij}^{p}} + Y_{ij}^{p} \Delta_{\min}^{\max} \tag{10}$$

2. 2. 2. DEMATEL Method The DEMATEL method by using a mixture of matrices is able to exploit and visualize intricate relations among the variables [35, 36] then ranking them based on their relationships [37].

The DEMATEL method assumes a system contains a set of components, with a couple of relations that can be rated as either cause or effect groups. This structural method realizes the inter-relations among the system's components dependently compared with other multi attribute decision- making methods (MADM) like Analytical Hierarchical Process (AHP), and eventually represents the effectiveness of each factor via a causal diagram [38, 39].

The DEMATEL methodology incorporates following five generic stages:

1. Generating the direct relation matrix: Set the number of known factors and the number of respondents to be 'n' and H, respectively. Each k respondent has evaluated the influence of each factor over another factors based on an integer scale ranging from 0, 1, 2, 3 to 4. They respectively represents no, very low, low, high and very high influence among the factors. Then the initial relation matrix were determined based on the influence points from the responders.

2. Calculating average matrix: Opinions of the whole respondents were averaged using Equation (11) in which a_{ij} represents each element of the matrix A and $\bar{a}_{ij}$ is the average of each element of the matrix A.

$$\overline{a_{ij}} = \frac{\sum_{k=1}^{H} a_{ij}^{k}}{H} \tag{11}$$

3. Normalizing the direct relation matrix: Through Equations (12) and (13), the normalized direct-relation matrix N is obtained:

$$N = \frac{A}{s} \tag{12}$$

$$s = \max\left(\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}, \max_{1 \le j \le n} \sum_{i=1}^{n} a_{ij}\right) \tag{13}$$

4. Calculating the total relation matrix: The total relation matrix T calculated using Equation (14):

$$T = \sum_{m=1}^{\infty} N^i = N(I-N)^{-1} \quad (14)$$

I is the identity matrix.

5. Obtaining the cause and effect parameters: R and D are n×1 and 1×n vectors respectively that show sum of row (R_i) and column (D_j) for each row i and column j from the total relation matrix (T). The sum of i^{th} row elements of matrix T, r_i, outlines direct and indirect acts appointed by factor i to the other factors. d_j, the sum of the j^{th} column elements of matrix T, summarizes both direct and indirect acts received by factor j from the others.

When i = j, the (R_i+D_j) operator displayes the whole effects received and conveyed by factor i; it describes the significance grade that the factor i plays in the entire system. The net effect that the factor i convey through the procedure, forms the (R_i-D_j) operator. Throughly, a factor is corporated to the cause class, while (R-D) value is positive, on the other hand, the factor marks as the effect factor when (R-D) value is negative [40]. A causal diagram can be depicted with the values of R+D and R-D represented on the x-axis and the y-axis, respectively.

3. IMPLEMENTING GREY-BASED DEMATEL FOR SD

To describe the grey relying DEMATEL process for SD, a case survey from a copper mine located in Sistan and Baluchestan province- SE Iran was utilized based on the summary flowchart steps are shown in Figure 2.

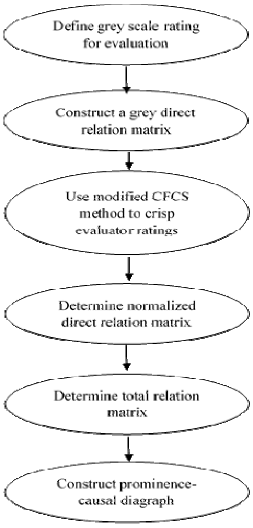

Figure 2. Graphical presentation of the grey relying DEMATEL method

This region is characterized by the presence of copper mineral deposits. Two types of mineralization include porphyry and vein types have been identified in these areas. Agriculture and farming are at present the backbone of the region's economy. In the early periods mining contributed significantly to annual income. There are few studies available mainly concentrate on the economic benefits of copper mining industry contribution to the regional growth. The mining industry in this region provides few number of skilled and unskilled jobs both directly and indirectly. Some of the positive socioeconomic contributions made by this mine are: employment generation, provision of some infrastructure such as access road and attraction of economic.

No detailed environmental impact assessment is the result of lack of a general environmental and pollution control legislation and guidelines. There is no management of mining reclamation in the region currently. Hence, investigations of the nature of mining impacts on the environment have not been well documented. Therefore, more research and monitoring activities need to be done especially on the contamination of soils and water, changing of vegetation and other natural resources, dust, leaching of pollutants from tailings and disposal areas and health problems for people located within the environment.

To begin the evaluation, questionnaires were designed according to the SD components and their impacting factors described in Table 1, based on a grey linguistic scale.

Table 2 shows the linear and non-overlapping scales that have been assumed for each linguistic interval extented from no (N) to very high influence (VH).

Initial grey relationship matrices were developed based on the influence ratings obtained from the respondents' assessments consisting of 15 experts in the geology, minig engineering and environment fields. Average grey relation matrix is computed using Equation (11) while the same weightings were given to all responders' opinions. After that, the average grey relation matrix is transformed to crisp relation matrix, Z, utilizing modified- CFCS method based on the Equations 6-10.

TABLE 2. The grey linguistic scale designed for the answered questionnaires

Linguistic assessment	Associated grey values
No influence (N)	(0, 0]
Very low influence (VL)	(0, 0.25]
Low influence (L)	(0.25, 0.5]
High influence (H)	(0.5, 0.75]
Very high influence (VH)	(0.75, 1]

The matrix of crisp relations is normalized to obtain the matrix of direct crisp relations, N, using Equations (12) and (13). The matrix of total relation, T, developed using Equation (14). Using Equations (15) and (16), the summation of row elements, r_i, and the summation of column elements, d_j, for the matrix of total relations, T, are computed as n×1 and 1×n vectors. The cause and effect operators (R+D) and (R-D) are calculated from the matrix of total relation. Finally, in order to have a obvious image of the structure and relations amongst the SD components and their factors the graphical representation (the prominence–causal relationship diagram) and digraphical relationships are constructed. A digraph is a diagram composed of nodes called vertices and arrows called arcs going from a vertex to a vertex. A digraph depicts binary (cause-and-effect) relationships among factors in a complex situation. By using arrows, it can be illustrated what impacts each factor and which factors are impacted by it. Arrows draw from each factor to the ones it causes or influences.

4. RESULTS AND DISCUSSION

In order to detect the cause- effect relations among SD components and their impacting factors, a compound of Grey theory and DEMATEL methodologies were utilized. By using Equation (11) the matrix of average grey relation is computed for the main components of the sustainable development of mining operations: environmental, economic, and social components and their impacting factors.

In the next step the modified-CFCS method is used to obtain the crisp value matrix of direct-relation for each component and impacting factors. The crisp relation matrices obtained using Equations 6‑10.

The normalized directed-relationship matrices N are generated using the Formulas (12) and (13) for each component and impacting factors.

The matrices of total direct-relationships (T) are characterized using Expression (14) for each component and impacting factors and are shown in Tables 3-6.

By using Expressions (15) and (16), the degree of the influence for each component of SD, environmental impacting factors, economic impacting factors and social impacting factors were obtained (see Table 7).

TABLE 3. Total relation matrix for components of SD

	EN	EC	S
EN	2.73	3.29	3.57
C	2.65	2.66	3.18
S	3.19	3.48	3.37

* EN, EC, and S represent the environmental, economic, and social components respectively.

TABLE 4. Total relation matrix for environmental impacting factors

	AP	SP	WP	N	FP	LD	EF
AP	0.56	0.62	0.8	0.71	0.81	0.74	0.84
SP	0.51	0.36	0.6	0.43	0.58	0.58	0.6
WP	0.61	0.55	0.57	0.65	0.66	0.71	0.76
N	0.6	0.55	0.62	0.47	0.56	0.66	0.71
FP	0.46	0.39	0.59	0.51	0.44	0.62	0.66
LD	0.66	0.59	0.74	0.68	0.7	0.59	0.82
EF	0.57	0.54	0.62	0.56	0.57	0.54	0.54

* AP, SP, WP, N, FP, LD, and EF indicate the air pollution, soil pollution, water pollution, noise, forest protection, land disturbance, energy and fuel respectively.

TABLE 5. Total relation matrix for economic impacting factors

	FP	CE	OC	ROR	SP	NPV
FP	0.52	0.81	0.7	0.85	0.82	0.68
CE	0.48	0.48	0.6	0.69	0.64	0.55
OC	0.56	0.66	0.46	0.65	0.66	0.53
ROR	0.44	0.56	0.57	0.48	0.6	0.53
SP	0.51	0.55	0.51	0.57	0.45	0.47
NPV	0.64	0.66	0.64	0.77	0.71	0.48

* FP, CE, OC, ROR, SP, and NPV indicate the fixed price, capital expenditures, operating costs, rate of return, share in domestic production, and net present value respectively.

TABLE 6. Total relation matrix for social impacting factors

	ELF	LS	RC	SK	HS	PRG
ELF	0.81	1.09	1.02	0.99	0.98	0.97
LS	0.89	0.79	0.9	0.86	0.85	0.83
RC	0.75	0.91	0.7	0.84	0.81	0.74
SK	0.83	0.88	0.88	0.71	0.83	0.81
HS	0.67	0.81	0.73	0.72	0.59	0.69
PRG	0.87	0.93	0.93	0.89	0.88	0.7

* ELF, LS, RC, SK, HS, PRG indicate the employment of local work force, local satisfaction, regional culture, skills and knowledge, health, and safety and protecting the rights of future generations respectively.

A quick review at the R-sum and D-sum columns of Table 7 exhibits that social component is relatively strong direct influencer on other components with an (R) value of 10, whereas economic component is the least direct influencer with (R) value of 8.49. On the other hand, values for the economic component are determined by the other components. As shown in the cause and effect diagram (Figure 3), economic and social components are grouped into effect criteria category ((R-D) values are -0.95 and -0.1 respectively)

TABLE 7. The degree of prominence and net cause/effect values

Components	R sum	D sum	R+D	R-D
Components of SD				
EN	9.59	8.56	18.15	1.03
EC	8.49	9.44	17.93	-0.95
S	10	10.1	20.1	-0.1
Environmental impacting factors				
AP	5.08	3.97	9.05	1.11
SP	3.66	3.6	7.27	0.06
WP	4.51	4.54	9.05	-0.03
N	4.16	3.99	8.15	0.17
FP	3.66	4.32	7.98	-0.64
LD	4.78	4.43	9.21	0.34
EF	3.93	4.94	8.86	-1.01
Economic impacting factors				
FP	4.39	3.15	7.53	1.24
CE	3.45	3.72	7.17	-0.3
OC	3.52	3.49	7.01	0.03
ROR	3.18	4.01	7.19	-0.8
SP	3.06	3.89	6.95	-0.8
NPV	3.9	3.24	7.15	0.66
Social impacting factors				
ELF	5.87	4.81	10.7	1.06
LS	5.12	5.42	10.5	-0.3
RC	4.74	5.16	9.9	-0.4
SK	4.94	5.01	9.95	-0.1
HS	4.22	4.94	9.16	-0.7
PRG	5.21	4.74	9.95	0.47

and environment is a cause component ((R-D) value is 1.03) which is tended to be influenced. Plotting the digraph can help to observe general patterns and relationships among all the programs simultaneously and in pairs. Digraph structure of network correlations is shown in Figure 4, display relationship amounts in matrix T that are more than the arithmetic averaging of matrix T (3.12), threshold value. The arrow represents the orientation from cause component to the effect component. Crossing relationships between components are represented in the figure. The correlation network shows that the social component received more influences than the other components.

As it can be seen in Table 7, the largest (R) value of (5.08) shows that the air pollution has the most influence between the impacting factors, whereas soil pollution and forest protection with the smallest (R) value of 3.66 have the least influence on the other factors. With the greatest D value= 4.94 among other factors, energy and fuel receive the most impact from other factors. On the other hand, soil pollution receives the least impact from the other factors with D value equal 3.6.

Cause and effect diagram (Figure 5) shows that water pollution, forest protection and energy and fuel factors are categorized into effective parameters with negative (R-D) values and air pollution, soil pollution, noise and land disturbance are cause parameters with positive (R-D) values. Network relationships among all environmental impacting factors calculated using threshold value= 0.61. Figure 6 exhibits the energy and fuel impacting factor receive the most and soil pollution the least influence from the others.

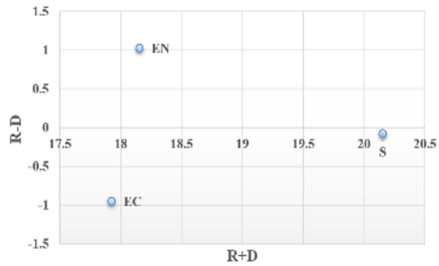

Figure 3. Causal relations among component of SD

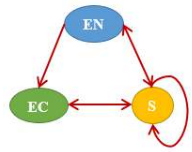

Figure 4. Digraph of influential relationships

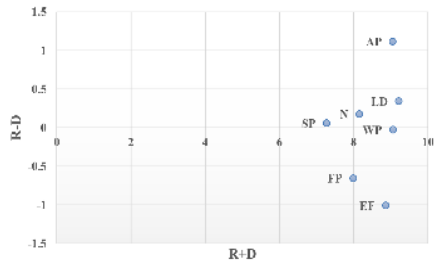

Figure 5. Causal relations among environmental impacting factors

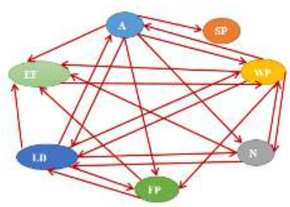

Figure 6. Digraph of influential relationships among all environmental impacting factors

Calculations show (Table 7) that the fixed price with the greatest (R) value= 4.39 has the most action among the economic impacting factors. Rate of return receive the most impact from other factors. Based on the cause and effect diagram (Figure 7) capital expenditures, share in domestic production and rate of return classified as effective parameters and fixed price, operation costs and net present value are cause parameters. With threshold value equal to 0.6, the diagram chart (Figure 8) shows that share in domestic production receives more influences from the other factors and the net present value has the most impact on the other factors.

The maximum amount of R value (=5.87) in Table 7 is the sign of the maximum degree of influence that employment of local work force has among the social impacting factors. Since, health and safety have the minimum impact on the social impacting factors.

Based on the Causal relations chart shown in Figure 9, negative amounts of (R-D) of local satisfaction, regional culture, skills and knowledge and health and safety assort these parameters as effective parameters and positive amounts of (R-D) of employment of local work force and protecting the rights of future generations is ranked theme as cause parameters. An arithmetic average equal to 0.84 is calculated as threshold value in order to draw the digraph of influential relationships among all social impacting factors (Figure 10). This graph show that local satisfaction, regional culture and skills and knowledge receive more influence than the other impacting factors. In contrast, the protecting the rights of future generations receive least influence by the other impacting factors and has more impact on the other impacting factors.

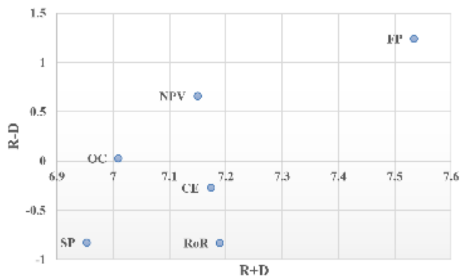

Figure 7. Causal relations among economic impacting factors

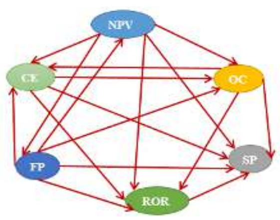

Figure 8. Digraph of influential relationships among all economic impacting factors

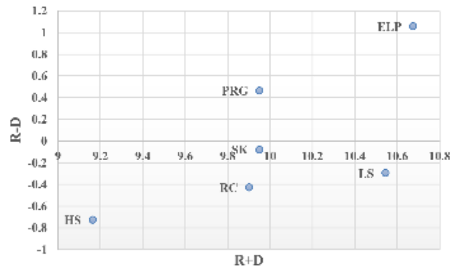

Figure 9. Causal relations among social impacting factors

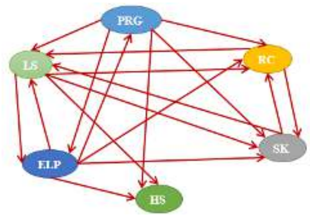

Figure 10. Digraph of influential relationships among all social impacting factors

5. CONCLUSIONS

Mining industries provide most of the materials and amounts of energy we rely on. As mining activities may cause destruction and disturbance of the environment and large social impacts; the detection and valuation of business operations' impacts on the environment and society are important for successful economic development.

In recent years the importance of sustainable development (SD) as an ongoing process has been steadily growing, especially while considering environmental, economic and social issues.

DEMATEL procedure has been used to detect the relationships among the SD components in many cases. As, the DEMATEL method has the lack of success to determine the vague values and converse with the data loss, unsured situations, and disagreed opinions. So a Grey- relying DEMATEL procedure has been used to effectively quantify indicators of sustainable development of a copper mine located in south east of Iran. This systematic approach transformed the quantitative and qualitative data into a equivalent scale and measured the interrelationships among the SD components and their factors. Finally by drawing the digraph, the SD components and their factors ranked based on their relationships.

The R-sum and D-sum values exhibit that social component is relatively strong direct influencer on other components with an (R) value of 10, whereas economic component has the least direct influence with (R) value of 8.49.

Cause and effect parameters of the three environmental, economic and social categories were determined. The largest (R) value of (5.08) among environmental impacting factors shows that the air pollution has the most action among the impacting factors, soil pollution and forest protection with the smallest (R) value of 3.66 receive the most impact from other factors. The fixed price (R=4.39) has the most influence between the economic impacting factors whereas rate of return has the least influence on the other factors. The maximum amount of R value (=5.87) is the sign of the maximum degree of influence that employment of local work force has among the social impacting factors.

It suggests that mining activities in this area, must be inforced to protect the environment and people health and culture, adopte the mining procedure based on the standards and earn the public and legal acceptance.

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Evaluation of the Impacting Factors on Sustainable Mining Development, Using the Grey-Decision Making Trial and Evaluation Laboratory Approach

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چکیده

به دلیل تاثیر گسترده فعالیت‌های معدنکاری بر محیط زیست و زمین‌های اطراف، توجه به جنبه‌های توسعه پایدار امری ضروری است. ترکیب روش‌های تئوری خاکستری (Grey theory) و دیمتل (DEMATEL) قادر به شناسایی روابط علت و معلولی مولفه‌های سه گانه توسعه پایدار معادن و فاکتورهای مؤثر آن‌ها می‌باشد. روش دیمتل خاکستری به منظور کمی کردن مولفه‌های توسعه پایدار یک معدن مس واقع در جنوب شرق ایران بکار رفته است. روش سلسله مراتبی دیمتل خاکستری (Grey-based DEMATEL) ضعف مربوط به اطلاعات ناقص و غیردقیق محیط زیستی و اقتصادی- اجتماعی را پوشش داده است. نتایج حاصل نشان می‌دهد که مولفه اجتماعی با مقدار R برابر با ۱۰ به طور تقریبی، اثرگذارترین مولفه بر سایر مولفه‌ها است و مولفه اقتصادی با R= 8.49 کمترین تاثیر را بر سایر مولفه‌ها دارد. در بین فاکتورهای اثرگذار اجتماعی، بکارگیری نیروی کار محلی مهم‌ترین فاکتوری است که باید از دیدگاه توسعه پایدار مورد توجه قرار گیرد.

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