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A Comprehensive Utilization Efficiency Evaluation of Iron Tailings based on the Differential — Benefit Evaluation

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Abstract

At present, in the evaluation of iron tailings resources, the single evaluation of a certain aspect is limited to the qualitative evaluation, and there is no uniform standard in either theory or method. In this paper, based on the grey group analytic hierarchy process and fuzzy mathematics as the analysis tool, the benefit of the iron tailings resources is analyzed, From resource benefit, economic benefit, environmental benefit and social benefit several aspects to build the differential - efficiency index system and established the differential- benefit evaluation model and the influence of iron tailings resource evaluation of the weight of each index distribution, is obtained by correlation analysis and the likelihood of benefit index influencing the size of the order, to a certain extent, verified the rationality of the index weight, provides a theoretical guidance for iron tailings resource utilization.

Keywords: *Benefit Evaluation Correlation Analysis, Grey Group analytic Hierarchy Process Fuzzy Teaching Differential,*

1. Introduction

At present, there are still great limitations on the evaluation method of iron tailings resources. Most of the evaluation of the single item in a certain aspect is limited to the qualitative evaluation, and the guidance of actual production is very small (Zhiwei, Chongke and Chao, 2013). The feasibility evaluation of iron tailings resources development is closely related to many factors, which should be considered in the process of exploitation and utilization (Jiabin, Wenlong and Jitao, 2009; Jiabin, Wenlong and Lianghui, 2010). Because of iron tailings resources is less competitive compared with the traditional iron ore resources, so this paper on the development and utilization of iron tailings resource of the benefit evaluation, considering it as a very important restricting factors, namely the external conditions of mining enterprises, the external conditions mainly including mining enterprises in regional economic development level, the surrounding transportation condition and the status of the water and electricity supply situation, labor supply and minerals and additional product sales market situation and other situation.

Therefore, based on the evaluation in the process of iron tailings resource utilization efficiency, combined with the differential conditions (Xinlei, *et al.*, 2007) the

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differential - benefit evaluation model was established, and on the basis of the index weight of the various factors influencing the iron tailings resource evaluation are analyzed, providing reference for the efficient utilization of iron tailings resources.

2. The Establishment of the Differential - Efficiency Index System

For the development and utilization of iron tailings resource evaluation, an evaluation index system shall be established, and it should follow certain principles, in order to evaluating factors more accurately that influence the development and utilization of iron tailings resource in establishing differential - benefit system should follow the following principles.

The selected indexes can scientifically reflect the exploitation and utilization of iron tailings resources. In this paper, the author choose the operational indexes of differential conditions and comprehensive benefits by means of expert consultation. The principle of independence should be insisted when determining the index, and consider the independence of each index, and avoid one index to decide on another index, so as to achieve the relative independence of each index. The selected indexes are representative, and the selection of the criterion is the key indicator of the efficiency.

Based on the above analysis, the criteria of establishing the index system, combined with expert consultation and

Table 1. Differential - benefit indexes

Target file://C:\Program Files (x86)\Youdao\Dict\7.0.1.0227\resultui\dict\?keyword=layer A	Criterion layer B	Big index layer C	Small index layer D
Iron tailings resources evaluation A	Differential conditions B_1	Internal level differential conditions C_1	Iron tailings reserve D_1
			Iron tailings deposit characteristics D_2
			Iron tailings nature D_3
			Hydrogeological condition D_4
		External differential conditions C_2	Scale of production construction D_5
			Regional economic development D_6
			Transportation D_7
			Water supply D_8
			Electricity supply D_9
			Labor condition D_{10}
	Comprehensive benefits B_2	Resources benefit C3	Stock number D_{11}
		Economic benefit C5	Net profit D_{12}
		Environmental benefits C_6	Tons of energy consumption D_{13}
			Effluent utilization D_{14}
			Mine reclamation rate D_{15}
		Social benefits C_7	Economic contribution (tax) D_{16}
			Construction of harmonious mining area D_{17}

grading, have been screened several times and finally established the differential - benefit index system as shown in Table 1.

3. Based on Grey Group Analytic Hierarchy Process and Fuzzy Mathematical Model of Differential - Benefit Evaluation Model

The grey group hierarchy process (Xiaoli, 2016; Xia, 201) is the mathematical treatment of the judgment matrix with certain differences established by different experts under the same goal or criterion. In the form of grey number, the judgment matrix is presented as a grey matrix, and an appropriate algorithm is used to solve the final weight. Grey group analytic hierarchy process (ahp) based on analytic hierarchy process (ahp) to process, so the different decision makers still need the 1–9 scale of ahp to compare two index factors, to construct the different judgment matrix under the same goal or criterion. See Table 2.

Note: a_{ij}= {2, 4, 6, 8, 1/2, 1/4, 1/6, 1/8} the importance level is somewhere in between a_{ij}= {1, 3, 5, 7, 1/3, 1/5, 1/7, 1/9} the assignment of the corresponding value.

The steps of calculating the weight of indicators by the grey group hierarchy process:

1. A comparative analysis of the two or two importance of a differential index by m experts, $A^{(1)}, A^{(2)}, \ldots, A^{(k)}$ ($k = 1, 2, \ldots, m$) can be obtained by comparing the contrast judgment matrix with the traditional method.
2. A consistency judgment is made for each element in the established m white matrixes, Sort the m elements by size, if $a_{ij}^{(1)} \le a_{ij}^{(2)} \le \cdots a_{ij}^{(m)}$ and calculate the median and mean variance, use a_{ij}, δ_{ij} to represent.

$$a_{ij} = \begin{cases} a_{ij}^{(k+1)} & m = 2k+1 \\ \dfrac{a_{ij}^{(k)} + a_{ij}^{(k+1)}}{2} & m = 2k \end{cases}$$

$$\delta_{ij} = \sqrt{\frac{1}{m-1}\sum_{k=1}^{m}(a_{ij}^{(k)} - a_{ij})^2}$$

The error is given in this paper is e>0, (the error is related to the number of experts, usually ε, 1 or 0.5). If there is δ_{ij} less than ε, the element satisfies the consistency requirement. If there is no δ_{ij} less than ε, m specialists need to be retuned for the comparison of the elements.

$$\overline{A} = \begin{bmatrix} 1 & \overline{a_{12}} & \overline{a_{13}} & \cdots & \overline{a_{1n}} \\ & 1 & \overline{a_{23}} & \cdots & \overline{a_{2n}} \\ & & \vdots & \cdots & \vdots \\ & & 1 & \cdots & \cdots \\ & & & & 1 \end{bmatrix}$$

$\overline{a_{ij}} = [a_{ij}^{1}, a_{ij}^{2}]$, and:

$$a_{ij}^{1} = \begin{cases} a_{ij}(\frac{k+1}{2}) & m = 2k+1,\ k \text{ is odd number} \\ \frac{1}{2}(a_{ij}^{\frac{k}{2}})+(a_{ij}^{\frac{k}{2}+1}) & m = 2k+1,\ k \text{ is even number} \\ a_{ij}(\frac{k+1}{2}) & m = 2k,\ k \text{ is odd number} \\ \frac{1}{2}(a_{ij}^{\frac{k}{2}})+(a_{ij}^{\frac{k}{2}+1}) & m = 2k,\ k \text{ is even number} \end{cases}$$

Table 2. Level 9 of AHP

Number	Criticality class	a_{ij} assignment
1	*i* elements are more important than *j* elements	1
2	*i* elements are slightly more important than *j* elements	3
3	*i* elements are obviously more important than *j* elements	5
4	*i* elements are intensely more important than *j* elements	7
5	*i* elements are absolutely more important than *j* elements	9
6	*i* elements are less important than *j* elements	1/3
7	*i* elements are obviously less important than *j* elements	1/5
8	*i* elements are intensely less important than *j* elements	1/7
9	*i* elements are absolutely less important than *j* elements	1/9

$$a_{ij}^{2}=\begin{cases} a_{ij}\left(\frac{3k+3}{2}\right) & m=2k+1, k \text{ is odd number} \\ \frac{1}{2}\left(a_{ij}^{\frac{3k}{2}+1}\right)+\left(a_{ij}^{\frac{3k}{2}+2}\right) & m=2k+1,\ k \text{ is even number} \\ a_{ij}\left(\frac{3k+1}{2}\right) & m=2k, k \text{ is odd number} \\ \frac{1}{2}\left(a_{ij}^{\frac{3k}{2}}\right)+\left(a_{ij}^{\frac{3k}{2}+1}\right) & m=2k,\ k \text{ is even number} \end{cases}$$

3. The upper triangular element can form a comparison judgment m grey matrixes for the analysis of the established comparison judgment white matrix. Use A to represent.
4. The grey matrix is compared and the white matrix A is compared , the process is as follows:

$$a_{ij}=a_{ij}^{\ 1}+\lambda_{ij}(a_{ij}^{\ 2}-a_{ij}^{\ 1})$$

$$\lambda_{ij}=\frac{a_{ij}^{\ 2}-a_{ij}^{\ 1}}{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}a_{ij}^{\ 2}-a_{ij}^{\ 1}} \quad (i=1,2,\cdots n-1;\ j=i+1,\cdots n)$$

$$a_{ij}=\frac{1}{a_{ji}} \qquad (i,j=1,2,\cdots n)$$

5. For the matrix A that has been listed, the relative weight of the index can be calculated and the consistency of the matrix must be tested, if CR<0.1, through consistency check, otherwise, the judgment matrix A need to be reconstructed.
6. Grey correlation coefficient and grey correlation analysis

Grey relational degree (Zhibo, 2013; Yan and Yanping, 2010) is an indicator of the similarity between two grey systems. Suppose there are two sequences $\{X_i(t), X_j(t)\}$, and when t=k, the grey relational degree of the period is defined as:

$$r_{ij}=\frac{1}{n}\sum_{k=1}^{n}\varepsilon_{ij}(k)$$

Among them $\varepsilon_{ij}(k)$ is the grey correlation coefficient, it can be calculated as:

$$\varepsilon_{ij}(k)=\frac{\Delta_{\min}+\rho\Delta_{\max}}{\Delta_{ij}(k)+\rho\Delta_{\max}}$$

$$\Delta_{ij}(k)=\left|X_i(k)-X_j(k)\right|$$

The maximum and minimum values of absolute difference for each moment is $\Delta_{\max}$ and $\Delta_{\min}$ respectively. Generally $\Delta_{\min}=0, \rho$ is resolution ratio, $0<\rho<1$, usually take $\rho=0.5$.

7. Modeling of grey systems

Suppose there are K influencing modes, which can form an eigenvector with several influencing characteristic parameters. The K eigenvectors that affect the eigenvectors form an eigenmatrix that affects the pattern:

$$X_R=\begin{bmatrix} X_{R1} \\ X_{R2} \\ \vdots \\ X_K \end{bmatrix}=\begin{bmatrix} X_{R1}(1) & X_{R1}(2) & \cdots & X_{R1}(n) \\ X_{R2}(1) & X_{R2}(2) & \cdots & X_{R2}(n) \\ \vdots & \vdots & \cdots & \vdots \\ X_K\ (1) & X_K\ (2) & \cdots & X_K\ (n) \end{bmatrix}$$

If there is P set of data to be checked, the same can be used to form the data feature matrix:

$$X_T=\begin{bmatrix} X_{T1} \\ X_{T2} \\ \vdots \\ X_K \end{bmatrix}=\begin{bmatrix} X_{T1}(1) & X_{T1}(2) & \cdots & X_{T1}(n) \\ X_{T2}(1) & X_{T2}(2) & \cdots & X_{T2}(n) \\ \vdots & \vdots & \cdots & \vdots \\ X_K\ (1) & X_K\ (2) & \cdots & X_K\ (n) \end{bmatrix}$$

Each feature vector represents a “influence mode”, which can be attributed to pattern recognition of the data to be detected. In the grey recognition, the correlation degree analysis can be used to identify the influence pattern, which is called grey influence pattern recognition. The basic principle is shown in figure 1.

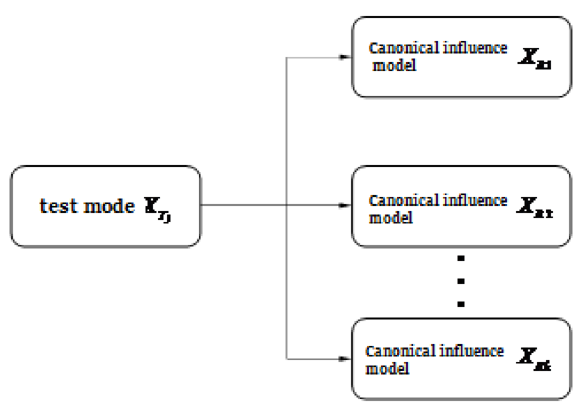

Figure 1. Basic diagram of grey influence pattern recognition

Set the j test mode vector to be $\{X_{Tj}\}$, the calculation of the correlation between the vector $\{X_{Tj}\}$ and the affected mode vector $\{R_{Ri}\}$ (i = 1, 2, …, k), a relational degree sequence can be drawn: $\{r_{T_jR_i}\} = \{r_{T_jR_1}, r_{T_jR_2}, \cdots r_{T_jR_k}\}$. Order the related degree sequence from big to small: $r_{T_jR_r} > r_{T_jR_s} > \cdots$ The test mode X_{T_j} is provided, the order of probability of a certain risk pattern.

4. Simulation

According to the established in view of the iron tailings resource differential - index system of benefit evaluation model, using the grey group ahp method to construct m judgment matrixes, and the differences of each expert to construct judgment matrix consistency judgment, and then the experts to establish judgment matrix has been treated by grey comparative judgment matrix, and then on the bleaching process, the relative weight of the indexes are calculated.

Table 3. The expert's judgment matrix for representing relationships of A-B_i

Experts 1	A	B_1	B_2
	B_1	1	1/3
	B_2	3	1
Experts 2	A	B_1	B_2
	B_1	1	1/5
	B_2	5	1
Experts 3	A	B_1	B_2
	B_1	1	1/4
	B_2	4	1

1. The criterion layer index is relative to the weight of the target layer.

The judgment matrix of relation to the evaluation of the target layer A-B_i is shown in Table 3.

The upper triangular element of the upper triangular element, which is established by different experts, is transformed into an albino judgment matrix. The matrix is shown in Table 4.

Table 4. Judgment matrix after relationship processing of A-B_1

A	B_1	B_2
B_1	1	0.2611
B_2	3.8200	1

Similarly, on the basis of expert advice to internal conditions C_1 – D_i of each index based on AHP method (Ming, 2014) 9 magnitude scale on the relative importance of judgment, to construct judgment matrix, after processing into bleaching of judgment matrix as shown in Table 5.

Table 5. Judgment matrix after the internal level difference processing

C_1	D_1	D_2	D_3	D_4
D_1	1	5.4918	3.4918	7.1066
D_2	0.1821	1	0.2568	3.1230
D_3	0.2864	3.8941	1	4.1230
D_4	0.1407	0.3202	0.2425	1

Table 6. Judgment matrix after external differential processing

C_2	D_5	D_6	D_7	D_8	D_5	D_{10}
D_5	1	7.1952	3.0488	5.0488	5.0488	6.1952
D_6	0.1390	1	0.1431	0.2009	0.2009	0.3347
D_7	0.3280	6.9881	1	3.4392	3.4392	5.4392
D_8	0.1981	4.9776	0.2908	1	1	2.1952
D_9	0.1981	4.9776	0.2908	1	1	2.1952
D_{10}	0.1614	2.9876	0.1839	0.4555	0.4555	1

The matrix of the judgment matrix for the relationship C_2–D_i of external differential conditions is shown in Table 6 after processing.

For the influence of internal and external differential conditions on the comprehensive condition of the differential level, the experts agree that the internal level difference condition has more influence. The results of the judgment matrix established by experts are shown in Tables 7–10.

Table 7. Judgment matrix after processing of differential conditions

B_1	C_1	C_2
C_1	1	6.6667
C_2	0.1500	1

Table 8. Judgment matrix after environmental benefit processing

C_5	D_{13}	D_{14}	D_{15}
D_{13}	1	1.6667	5.6667
D_{14}	0.6000	1	3.6667
D_{15}	0.1765	0.2727	1

Table 9. Judgment matrix after social benefit processing

C_6	D_{16}	D_{17}
D_{16}	1	0.2254
D_{17}	4.4366	1

Table 10. judgment matrix after comprehensive benefit processing

B_2	C_3	C_4	C_5	C_6
C_3	1	6.7668	2.1917	4.1917
C_4	0.1478	1	0.2005	0.3386
C_5	0.4563	4.9875	1	3.1917
C_6	0.2386	2.9533	0.3133	1

Check whether the following judgment matrix conforms to the consistency requirement. The specific steps are as follows: (1) Consisteney Index *CI* $CI = \frac{\lambda \max - n}{n-1}$; (2) Consistency Ratio (Xue, *et al.*, 2012)

$CR = \frac{CI}{RI}$, among them, *RI* can be found in the table, the *RI* standard value is shown in Table 11. If $CR < 0.1$, through consistency check, otherwise the judgment matrix is adjusted and the calculation is recalculated.

Table 11. average random consistency index standard value (*RI*)

N	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The maximum eigenvalue and consistency ratio values *CR* of the judgment matrix established by MATLAB (Yuan, 2009) are shown in Table 12.

It can be seen from the above table that the judgment matrix established by the target layer, criterion layer and small index layer is all tested by consistency, so the weight value of each index can be calculated by using the above judgment matrix.

2. Affirmation of the target weight.

Target weight according to the characteristic root method, (Shaokun, Shujuan and Yan, 2005), the concrete steps of calculating relative weight D_k are illustrated with relative weight C_1 calculation. D_k relative to C_1, judgment matrix $C_1 - D_k$ is C_1, $|\lambda C_1 - E| = 0$ The maximum eigenvalue B_1 can be calculated, $\lambda_{\max}(C_1) = 4.2079$, the corresponding eigenvector is $w_{\max}(C_1)$.

$$C_1 = \begin{bmatrix} 1.0000 & 5.4918 & 3.4918 & 7.1066 \\ 0.1821 & 1.0000 & 0.2568 & 3.1230 \\ 0.2864 & 3.8941 & 1.0000 & 4.1230 \\ 0.1407 & 0.3202 & 0.2425 & 1.0000 \end{bmatrix}$$

$$w_{\max}(C_1) = (0.9008 \;\; 0.1660 \;\; 0.3921 \;\; 0.0857)$$

After normalization treatment of $w_{\max}(C_1)$ and drawn D_k relative to C_1, the target weight is $w_{\max}(D_k C_1)$.

$$w_{\max}(C_1) = (0.9008 \;\; 0.1660 \;\; 0.3921 \;\; 0.0857)$$

Use the same method for other judgment matrix for weight calculation according to the hierarchical structure model, using the above numerical criterion layer and index layer can be obtained and the relative weight of the index of small relative to the target layer, specific said as shown in Table 13.

3. The typical risk characteristic matrix and the determination of the mode vector of the pending inspection.

There are six risk factors that affect the effectiveness of enterprise merger, that is $n = 6$, the merger plan is 6, that is $m = 6$, and get Eigen matrix.

Table 12. the maximum eigenvalue and *CR* value of the judgment matrix after processing

judgment file://C:\Program Files (x86)\Youdao\Dict\7.0.1.0227\resultui\dict\?keyword=matrix	A	B_1	B_2	C_1	C_2	C_5	C_6
maximum eigenvalue	2.0000	2.0000	4.0795	4.2079	6.3051	3.0007	2.0000
the CR value	0	0	0.0294	0.0770	0.0492	0.0006	0

Table 13. combination weight of differential - benefit evaluation system

A	B	$W^1(i)$	C	$W^2(i)$	D	$W^3(i)$	w_{ik}	w_{ijk}
Iron tailings resources evaluation *A*	B_1	0.2070	C_1	0.8696	D_1	0.5832	0.5072	0.1050
					D_2	0.1075	0.0935	0.0194
					D_3	0.2538	0.2207	0.0457
					D_4	0.0555	0.0483	0.0100
			C_2	0.1304	D_5	0.4501	0.0587	0.0122
					D_6	0.0301	0.0039	0.0008
					D_7	0.2585	0.0337	0.0070
					D_8	0.1021	0.0133	0.0028
					D_9	0.1021	0.0133	0.0028
					D_{10}	0.0571	0.0074	0.0015
	B_2	0.7930	C_3	0.5142	D_{11}	1.0000	0.5142	0.4078
			C_4	0.0582	D_{12}	1.0000	0.0582	0.0462
			C_5	0.3013	D_{13}	0.5595	0.1686	0.1337
					D_{14}	0.3442	0.1037	0.0822
					D_{15}	0.0963	0.0290	0.0230
			C_6	0.1263	D_{16}	0.1840	0.0232	0.0184
					D_{17}	0.8160	0.1031	0.0818

Table 14. Correlation coefficient

$\varepsilon_{\Pi k}(k)$ / i	$k = 1$	$k = 2$	$k = 3$	$k = 4$	$k = 5$	$k = 6$
$i = 1$	0.6611	0.5770	0.3605	1.0000	0.3797	0.4050
$i = 2$	1.0041	0.4469	1.0816	0.4422	0.5349	0.7718
$i = 3$	0.8957	0.4389	1.0816	0.4422	0.7137	0.5376
$i = 4$	1.0416	0.3950	1.0816	0.4422	0.7831	0.5376
$i = 5$	1.0816	0.3950	1.0816	0.4422	0.7831	0.5376
$i = 6$	1.0816	0.4275	1.0816	0.4422	0.7831	0.5376

Table 15. Relational grade

$r_{\Pi k1}$	$r_{\Pi k2}$	$r_{\Pi k3}$	$r_{\Pi k4}$	$r_{\Pi k5}$	$r_{\Pi k6}$
0.5639	0.7136	0.6849	0.7135	0.7202	0.7256

$$T_K = \begin{bmatrix} T_{K1} \\ T_{K2} \\ T_{K3} \\ T_{K4} \\ T_{K5} \\ T_{K6} \end{bmatrix} = \begin{bmatrix} 0.5832 & 0.4501 & 1 & 1 & 0.5595 & 0.1840 \\ 0.1075 & 0.0301 & 0 & 0 & 0.3442 & 0.8160 \\ 0.2578 & 0.2585 & 0 & 0 & 0.0963 & 0 \\ 0.0555 & 0.1021 & 0 & 0 & 0 & 0 \\ 0 & 0.1021 & 0 & 0 & 0 & 0 \\ 0 & 0.0571 & 0 & 0 & 0 & 0 \end{bmatrix}$$

In the same way, we can obtain the model vector of the pending inspection which is composed of the important degree of risk factors.

$$X_{\Pi} = \{0.8696, 0.1304, 0.5142, 0.0582, 0.3013, 0.1263\}$$

4. Calculate correlativity.

Regard X_{Π} = {0.8696,0.1304,0.5142,0.0582,0.3013,0.1263} as generating factor and T_{ki}(i = 1, 2, 3, 4, 5, 6) as sub-factors, then the initialization $\{X_{\Pi}\}$ is processed and the correlation coefficient matrix is obtained.

Calculate by correlation coefficient matrix, and take Into the formula $r_{\Pi ki} = \frac{1}{n}\sum_{k=1}^{n} \varepsilon_{\Pi ki}(k)$ and drawn:

Because 0.7256>0.7202>0.7136>0.7135>0.6849>0.5639, so the correlation of D_{ki} to C_{ki} is $r_{\Pi k6} > r_{\Pi k5} > r_{\Pi k2} > r_{\Pi k4} > r_{\Pi k3} > r_{\Pi k1}$. May safely draw the conclusion: in the iron tailings resources development and utilization of the evaluation of comprehensive benefit, the benefit influence of probability (from big to small order): poor social benefit, environmental benefit and external conditions, economic, resources, internal poor conditions.

5. Conclusion

This paper uses the grey group analytic hierarchy process and fuzzy mathematics analysis method, from the resource benefit, economic benefit, environmental benefit and social benefit of multiple aspects, differential - benefit evaluation model is established. Based on the analysis of the benefits of iron tailings, the comprehensive benefit is the main index in the evaluation of iron tailings resources. The resource efficiency plays a decisive role in the evaluation of comprehensive benefit. In the evaluation of iron tailings resources, the importance of resource conservation and full utilization should be strengthened. Benefit is obtained by correlation analysis influence a probability is: the poor social benefit, environmental benefit and external conditions, economic, resources, poor internal conditions, to a certain extent, the objectivity of indexes at all levels. Differential - benefit evaluation model for the accurate and quantitative evaluation of iron tailings resource, clear iron tailings resource efficiency, provides complete theoretical support, to the actual production has a certain guiding significance.

6. References

1. Zhiwei, C., Chongke, J., & Chao, Y. (2013). On the investigation and evaluation of iron ore tailings resources. *Theoretical Study Of Urban Construction: Electronic version*, *13*.
2. Jiabin, C, Wenlong, J, & Jitao, F. (2009). Economic analysis model and application of iron tailings utilization. *Resources Science*, *31*(1), 152–156.
3. Jiabin, C, Wenlong, J, & Lianghui, Y. (2010). Research and development of the investigation and evaluation of resources of iron ore tailings mining. *3*, 60-62.
4. Xinlei, F., Fangwei, Z., Mingli, Z., et al. (2007). A new method for multi attribute decision making based on range theory. *Journal of Liaocheng University (Natural Science Edition), Natural Science Edition*, *20*(2), 33–35.
5. Xiaoli, Z. (2016). Decision model based on grey number information and its application. North China University of water conservancy and hydropower.
6. Xia, W. (2015). Construction and application of decision model based on grey number information. Nanjing University of Aeronautics & Astronautics.
7. Zhibo, W. (2013). Evaluation of technological innovation capability of enterprises based on AHP- grey relational grade model. Statistics and Decision Making, *4*, 51–53.
8. Yan, X., Yanping, Z. (2010). Evaluation of competitiveness of private enterprises based on AHP and grey relational analysis. *Reform and Strategy*, *26*(7), 83–85.
9. Ming S. (2014). Comparison between analytic hierarchy process (AHP) and network analytic hierarchy process (ANP). *Chinese and Foreign Entrepreneurs*, *10*, 67–68.
10. Xue, D., Gang, L., Haojian, C., Junyang, C., & Junfeng, Z. (2012). Analysis and application of analytic hierarchy process weight calculation. *Mathematical Practice and Understanding*, *42*(07), 93–100.
11. Yuan, L. (2009). Matlab implementation of fuzzy analytic hierarchy process. *Silicon Valley*, (17), 2, 38.
12. Shaokun, W., Shujuan, L, Yan, L. (2005). Using analytic hierarchy process (AHP) to determine the weight of customer requirements. *Machine Design and Manufacture*, (06), 170–172.