Asteroid Mining Evaluation Model Based on AHP and TOPSIS

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Abstract. It is assumed that future mining trips to asteroids will be possible and that humans will be able to bring valuable minerals back to Earth for investment at a relatively safe cost. Therefore, it is important to explore the impact of asteroid mining on global equity.First，we first used hierarchical analysis to determine the weights using five indicators: military, economic, scientific research, social, and environmental. Then the five superior indicators were subdi-vided into 20 inferior indicators, and the data from each national statistical office were used to score the strength of the eight countries using the TOPSIS method based on entropy weighting, while cluster analysis of the data was performed to verify that our model was better.

Keywords: Global equity, AHP, TOPSIS.

1. Introduction

Today, as humans continue to seek resources in space, can an international commitment to global equity like the Outer Space Treaty continue to hold.[1]It is assumed that future mining trips to asteroids will be possible and that humans will be able to bring valuable minerals back to Earth for investment at a relatively safe cost. Therefore, it is important to explore the impact of asteroid mining on global equity. [2]

First, question one requires us to measure global equity, and our team's definition of global equity is to use national strength to measure that in terms of benefits [3], the strong should be satisfied that they can benefit more but not spill over, the weak can have some benefits to acquire, and the weak progress together with the support of the strong. So, the issue of global equity was transformed into the evaluation of national strength, and we first used hierarchical analysis to determine the weights using five indicators: military, economic [4], scientific research, social, and environmental. Then the five superior indicators were subdivided into 20 inferior indicators, and the data from each national statistical office were used to score the strength of the eight countries using the TOPSIS method based on entropy weighting, while cluster analysis of the data was performed to verify that our model was better [5].

2. Problem Background

In general, asteroids are objects in the solar system that orbit the sun like other planets such as Earth, but are much smaller in size and mass than other planets[6]. According to a report from the Chinese Academy of Sciences, the point of mining asteroids is to detect and "grab" potentially rare minerals on them, such as diamonds and platinum, which may be present. Thus, back in 1967 most countries signed the United Nations Outer Space Treaty agreeing that "the exploration" and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit of all nations, regardless of their degree of national development, and shall be the province of all mankind [7].

The United Nations (UN) aims to promote global peace and reduce inequality. The Outer Space Treaty, signed in the early years, provided the legal basis for projects to promote multinational access to space, and today there is also the International Space Station and the Internet. At the same time, asteroid mining has encountered many problems [3], such as uncertainty about funding sources and

excessive costs that do not match the value of the minerals. Today, there are disparities in the development status of each country, thus it is important to develop an equitable policy to adapt to the current era [8].

3. Hierarchical Analysis Modeling

3.1. Results of Weighting for Hierarchical Analysis Model Solving

First, for global equity, we define it as on-demand distribution, not equal distribution. Strong countries have sufficient funds and scientific research strength[9], and accordingly will have stronger ability to research space minerals, and should allocate more resources if they have more demand for space minerals, while weak countries do not have excessive scientific research strength and funds, and should allocate less resources if they have less demand for space minerals. Secondly, the power possessed by a country for survival [10], development and in-fluence on the outside constitutes national power. National power is an objectively existing entity that has its own pursuit, object of action and manifold manifestations. We use five main indicators to express national power, including military, economic, scientific research, social and environment to measure national power [2]. To simplify our subsequent calculations, these first-level indicators are described here uniformly using sets I.

$$I = \{MY, EC, EN, SY, ET\} \tag{1}$$

MY, EC, EN, SY, ET, they represent the military, economy, education, society and environment respectively. Each level of indicators contains a secondary indicators, and 17there is a secondary indicator of our model, as showed in the figure1 .

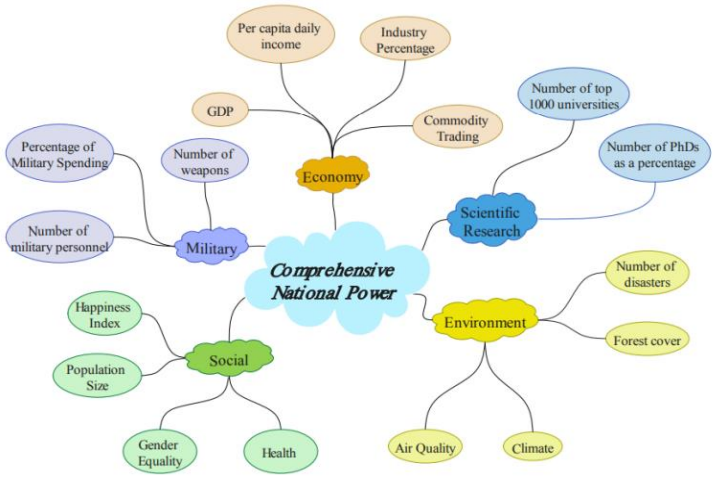


Figure. 1 Impact on the country's overall power indicators map

In the process of establishing the national strength system, the strong performance indicators are divided into5 first grade indexes, and the first grade indexes are composed of 17 Secondary indications. The details are as following.

●Military

The level of modernization of a country's national defense and military is a symbol of national strength and an important component element of national power. Promoting the modernization of national defense and military is an inevitable requirement to maintain national security and safeguard the interests of the country and its people. The modernization of the defense and military forces is conducive to enhancing the influence and voice of the country in international affairs, and then it can carry more weight in the discussion of asteroid mining. Accordingly, we use armed forces personnel, military expenditure as a percentage of GDP, and the number of weapons as a secondary indicators to reflect the military level of the country.

●Economy

The economy is one of the basic elements of national power, and countries make extensive use of their respective economic power in their relations with each other. The use of economic power occurs in the economic sphere itself, but also exists and affects all other spheres. In the case of mining, if the economic power is significantly weaker than other countries, then the cost of development attrition is not affordable in the first place, so that the GDP of each country is also particularly important. In addition, merchandise trade, gross income per capita and industry as a percentage of GDP are also important. The activity of merchandise trade shows the circulation capacity of the country's economy, the presentation of gross income per capita reflects the economic capacity of the country's people, and the size of industry as a percentage of GDP highlights the importance that the country attaches to its industrialization.

●Scientific Research

Education helps lead people to form a correct world view, outlook on life and values, while education enables people to have a more objective and comprehensive view of the world, and a strong education country can cultivate more creative talents, broaden people's thinking and develop new technologies. Education plays an important role in all countries. For asteroid mining, in addition to a certain degree of economic strength and military power, scientific and technological research and development capabilities are also a need, after all, it is in the asteroid mining, to ensure the availability of tools. Then we filter the number of top 1000 universities in each country and the percentage of PhD students in the total population over the 25age of one year as a secondary indicators to observe the education level of each country.

●Social

The happiness index shows the quality of life of the people and their satisfaction with the country. If the happiness index is low, the people are not even satisfied with the basic life, let alone with the distant matter of asteroid mining. The number of people has an impact on the distribution of the benefits of mining, and health determines whether people can go to asteroids for mining, if their health is not up to standard, they can not withstand the impact of the ship to go to asteroids for mining.

●Environment

The quality of the environment indicates whether a country is using its natural resources wisely, such as per capita CO2 emissions, forest cover, disasters, climate, etc. If natural resources are used indiscriminately, will it be the same for asteroid mining? Of course, this is just a guess, but in order to be as fair as possible globally and to avoid uncontrolled mining in some powerful countries, we need to consider the environment as an indicator.

Based on the basic principle of hierarchical analysis, this paper firstly establishes a hierarchical structure model based on the above set of evaluating the strength of the country$I$ Five indicators in the hierarchical structure model was established, then a simple judgment matrix was constructed and a consistency test was conducted, and finally the size of the weights occupied by the five indicators was derived, which also provides a reference for the later inquiry. The flow chart is as follows.

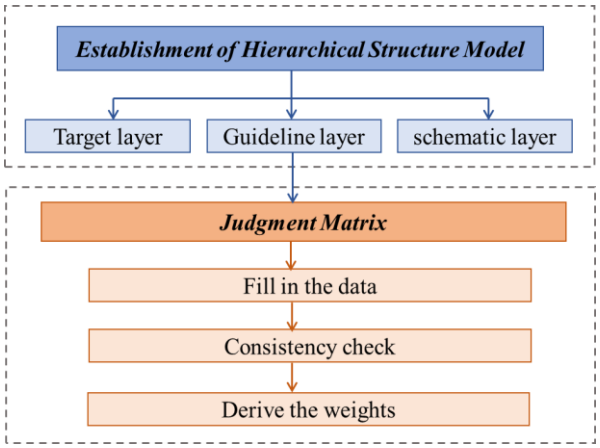


Figure. 2 Flow chart of analytic hierarchy process

Based on the evaluation of the country's strength, our team selected 5 excellent indicators and 20 inferior indicators as the criteria for evaluating the country's strength, as showed in figure 2.

In the hierarchical analysis method, the judgment matrix of each layer indicates the relative importance of each indicator in that layer to the corresponding indicator in the previous layer, as shown in the figure, the Hierarchical Structure Model is divided into three layers, but in this question we only establish a judgment matrix for 5 Excellent indicators. establish a judgment matrix for 5 Excellent indicators.

3.2. Solution of the Hierarchical Analysis Model

Step 1: Create the judgment matrix. Judgment matrix is shown as table1

Table 1 Judgment matrix

	Military	Economy	Scientific Research	Social	Environment
Military	1	1/2	2	3	4
Economy	2	1	2	4	5
Scientific Research	1/2	1/2	1	3	6
Social	1/3	1/4	1/3	1	2
Environment	1/4	1/5	1/6	1/2	1

Step 2: Consistency check

① Calculate the coincidence indicator *CI*

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{2}$$

② Find the corresponding mean random consistency index RI Relationship between n and RI is shown as table2.

Table 2 Relationship between n and RI

n	1	2	3	4	5	6	7	8	.....
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	.....

③ Calculating the inconsistency ratio CR

$$CR = \frac{CI}{RI} = \frac{0.0394}{1.12} \approx 0.035 \tag{3}$$

After step 2, it is calculated CR as 0.035 and less 0.1 than, so the judgment matrix passes the consistency check.

Step 3: Calculate and derive the judgement matrix

After passing the consistency test, we use the arithmetic mean method to find the weights of each indicator in the judgment matrix.

①the judgement matrix is divided by the column judgement matrix (each element divided by the sum of its columns).

②Adding up the columns of the judgment matrix (sum by row).

③the weight vector is obtained by dividing n each element of the summed vector by

Assume that there is judgment matrix *A*:

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{4}$$

Then the weight vector obtained by the Arithmetic average methodω_i

$$\omega_i=\frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n}a_{kj}}(i=1,2,\cdots,n) \tag{5}$$

Step 4: Derive weight. Weighting table of each index is shown as table3.

Table 3 Weighting table of each index

index	weight
Military	0.2639
Economy	0.3790
Scientific Research	0.2169
Social	0.0870
Environment	0.0533

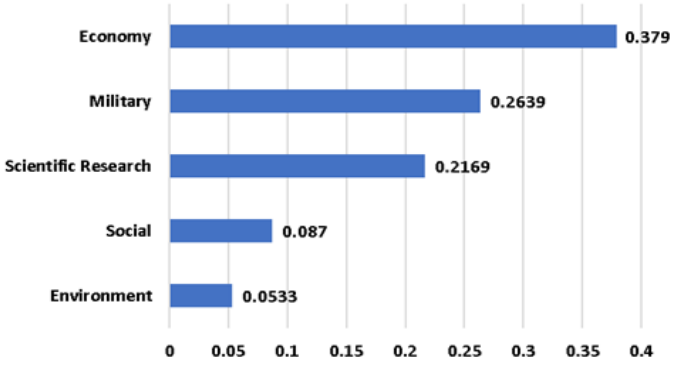


Figure. 3 Chart of weighting coefficients

Chart of weighting coefficients is shown as figure 3. From the above table, we can find that in the evaluation of the country's strength, the weight of military, economic, and scientific research are0.2639,0.3790 respec-tively0.2169, accounting for a considerable proportion, so we conclude that military, economic, and scientific research play an important role in the evaluation of the country's strength.

In the case of the military, the number of armed forces, the percentage of GDP military spending and the number of weapons were mentioned earlier, and we chose the percentage of GDP military spending as the inferior indicators because the number of armed forces and the number of weapons are more important to the military power of the country. The number of armed forces and the number of weapons to highlight the military power of the country, which has little impact on the asteroid mining in this question. For the economy, we think the indicators of GDP each country, the total income per capita and the percentage of GDP industry are important, because these can obviously reflect the economic strength of the country and the final distribution of benefits to the people, so as

to see whether the country can afford the initial research and development costs of asteroids, while the trade of goods plays an indirect role, reflected by the flow of trade. In terms of scientific research, we choose the percentage of PhD students over the 25age of the total population as inferior indicators, although the top1000 universities in the world can show the cultural and scientific research level of the country, it highlights a whole and cannot be guaranteed to individuals, because asteroid mining requires new technologies as well as equipment and highly sophisticated talents. Due to the previous weighting ratio situation, we only screened out one inferior indicator each for society and environment. Then the happiness index was chosen as inferior indicators in society, because the population size and gender equality are more about sociological content, the more or less population size and whether gender equality is not directly related to asteroid mining. We found that the happiness index actually includes people's health factors, so we will not analyze health indicators separately here for the sake of integration. For the environment, we choose CO2 emissions per capita (fossil fuel combustion) as inferior indicators, because fossil fuel combustion is related to chemical industry, and therefore industry.

To validate our model and to emphasize that global equity means the distribution of resources according to national strengths, our team selected207 one of the inferior indicators to represent5 an excellent indicator, 7which are: military spending (% of GDP), GDP (trillions of dollars), gross income per capita (dollars), industry (% of GDP), industry (% of GDP), Ph.), industry (% of GDP), PhD (% of population), happiness index, and average CO2 emissions per person (metric tons). After obtaining the indicator data, in order to quantitatively describe8 the resources obtained by each country, we use a TOPSIS model based on the entropy weight method to score the higher the score, the more resources obtained by mining, that is, the more equitable.

4. TOPSIS Method Solving Process and Results

4.1. TOPISIS model

Step 1: Calculate each element of the probability matrix P p_{ij}

$$p_{ij} = \frac{\tilde{z}_{ij}}{\sum_{j=1}^{n} \tilde{z}_{ij}} \tag{6}$$

Step 2: Calculate the information entropy of each indicator.

$$e_j = -\frac{1}{\ln n} \sum_{j=1}^{n} p_{ij} \ln p_{ij}, (j = 1, 2, \cdots, m) \tag{7}$$

Information entropy is an unordered random variable. the larger the value of information entropy e_j, the greater the amount of information its value (content) can add to you, and the smaller the amount of information you already have before knowing this value. So we define the information utility value as: $d_j = 1 - e_j$, the larger the information utility value, the more information it corresponds to.

Step 3: Calculate the entropy weight of each index.

$$W_i = \frac{d_j}{\sum_{j=1}^{m} d_j} (j = 1, 2, 3, \cdots, m) \tag{8}$$

Step 4: Construct the decision matrix.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{9}$$

Step 5: Build Standardized decision matrix.

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{10}$$

Step 6: Define the maximum and minimum values.

$$\begin{aligned} Z^+ &= (Z_1^+, Z_2^+, \cdots Z_m^+) = (\max\{z_{11}, z_{21}, \cdots, z_{n1}\}, \max\{z_{12}, z_{22}, \cdots z_{n2}\}, \cdots, \max\{z_{1m}, z_{2m}, \cdots, z_{nm}\}) \\ Z^- &= (Z_1^-, Z_2^-, \cdots Z_m^-) = (\min\{z_{11}, z_{21}, \cdots, z_{n1}\}, \min\{z_{12}, z_{22}, \cdots z_{n2}\}, \cdots, \min\{z_{1m}, z_{2m}, \cdots, z_{nm}\}) \end{aligned} \tag{11}$$

Step 7: Calculate the distance

$$\begin{aligned} D_i^+ &= \sqrt{\sum_{j=1}^{m} (Z_j^+ - z_{ij})^2} \\ D_i^- &= \sqrt{\sum_{j=1}^{m} (Z_j^- - z_{ij})^2} \end{aligned} \tag{12}$$

Step 8: Calculate the score of unnormalization

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{13}$$

Step 9: Normalize the score.

$$\widetilde{S}_i = \frac{S_i}{\sum_{i=1}^{n} S_i} \tag{14}$$

The final scores for 8 each country is shown in the table4.

Table 4 Ranking table based on TOPSIS method.

Country	Military spending(% of GDP)	GDP (trillions of dollars)	Total income percapita (USD)	Industry (% of GDP)
United States	3.74	20.89	64500	18
China	1.75	14.72	10600	37.8
Canada	1.42	1.643	43500	25
United Kingdom	2.25	2.76	39700	16.9
Australia	2.06	1.33	53700	25.7
France	2.07	2.6	39500	16.4
New Zealand	1.54	0.211	41500	20
Netherlands	1.42	0.914	51100	17.8

Table 5 Continued Table Ranking table based on TOPSIS method.

Country	PhD (of total population)	Happiness Index	Average CO2 emissions per person (metric tons)	Score	Ranking
United States	2.14	69	17.4	0.1954	1
China	0.003	52	7.32	0.1375	2
Canada	1.5	70	14.7	0.1041	7
United Kingdom	1.2	72.1	5.34	0.1255	3
Australia	1.31	71.4	16.7	0.1045	6
France	0.901	66.8	4.9	0.1175	4
New Zealand	1.042	73.4	6.64	0.1084	5
Netherlands	0.64	74.6	6.1	0.107	8

Continued table ranking table based on TOPSIS method is shown as table5.The score means that when the total weight of the eight countries from asteroid mining is10000 tons, then the United States can get 1954tons of minerals. China can get1375 tons of minerals, Canada can get 1041tons of minerals, and so on.

4.2. Verification of Solution Results

To make the results more accurate, we used the SPSS software to perform cluster analysis on the data in the table and came up with the following pedigree chart.**P**edigree chart based on cluster analysis is shown as figure 4.

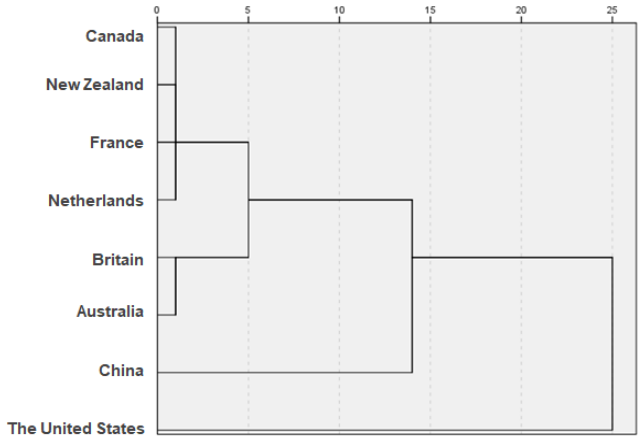


Figure. 4 Pedigree charts based on cluster analysis.

Through the graph we verify that the United States and China are at the top, and they are both merged together at the end, which is consistent with the results of our score ranking, so the above TOPSIS model for scoring can more correctly reflect the strength of each country, and thus reflect global equity.

5. Model Evaluation

Our team shifts the definition of global equity to the evaluation of national strength. Equity we define is not the average sharing of resources, but ac-cording to the national strength, the higher the national strength, the more re-sources it gets corresponding to, that is, the more equitable. First of all, this pa-per adopts a hierarchical analysis method to evaluate national strength at the macro level. Hierarchical analysis method has greater professionalism according to experts' opinions, simple and practical decision-making method, and less data requirement; in order to avoid excessive subjectivity, then entropy method which is less subjective and can make full use of data characteristics is used to assign weights to the inferior indicators in the evaluation system, so as to get the weight of each indicator in the evaluation system.

In terms of data sources, this paper selects data from several national statistical office databases to ensure the reliability and richness of data sources. The data visualization technology is fully utilized, and the results are displayed more intuitively and clearly with the help of graphic visualization methods

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