Research of asteroid mining mechanism and global fairness based on TOPSIS and AHP

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Abstract. With the development of human society, earth resources are increasingly exhausted, and the importance of asteroid mining for human survival is becoming more and more prominent. In this paper, we use TOPSIS, EWM, AHP, and Correlation analysis to describe the definition and model of global equity. We also integrate and divide using the multi-group fairness model's feature selection algorithm, converting the feature selection problem of asteroid resources for N into a multi-group M individual resource allocation problem. The behavior is analyzed and processed by the multi-population fairness algorithm to provide a better allocation solution (a better subset of features), which naturally merges random search and heuristic search to decrease computing effort while achieving improved allocation accuracy. Finally, we verify the practical significance of the model, which can provide policy reference suggestions for decision-makers and is of great significance for the development of mankind in the future.

Keywords: multi-group fairness model; global equity; asteroid mining; TOPSIS; EWM.

1. Introduction

In the course of human exploration of space, people found that space is rich in available resources, such as rare earth elements and radioactive elements such as uranium. Therefore, people began to consider using existing technology to mine minerals on other planets. Most of the world's nations signed the United Nations' Outer Space Treaty of 1967, agreeing that "exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind". These laws aim to grant equal rights to all countries in the field of asteroid mining, guarantee opportunities and voluntary equitable distribution, and promote the common development of all mankind[1]. The United Nations (UN) aims to promote global peace and reduce inequities. As the foundation of international space law, the Outer Space Treaty has provided the legal underpinnings for projects that have promoted multinational access to space, such as the International Space Station and the use of satellites to browse the Internet in even the most remote locations.

At present, some developed countries have initially mastered the relevant technology, such as NASA has been able to achieve space mining and reproduction manufacturing. But at the same time, we should also be aware of the uncoordinated development of countries, especially in terms of their comprehensive and space capabilities. So we point out that global equity is not absolute fairness, but the distribution of the corresponding reward according to the contribution. We determine the indicators that affect global equity, taking the data of representative countries into consideration, and establish model 1 to measure equity using TOPSIS and EWM[2]. We examine the validity of model 1 by selecting Antarctica, which is similar to asteroid mining. we evaluated country scores to assess the impact of asteroid mining on the global equity system by comparing score changes. And then we established model 2 for evaluating country scores to assess the impact of asteroid mining on the global equity system by comparing score changes. From the perspective of the environment, we predict the resource crisis that all mankind faces, and formulate relevant laws and policies.

2. Definition of a global equity-based model on CSI

2.1 Analysis and discussion of global equity

With the development of science, technology, the economy, and other aspects, we can feel that the earth's resources are also decreasing sharply. In the face of mankind's common predicament, once such resources are excavated, they should become the commonwealth of mankind. However, in the current context, the economic, scientific, technological, and military strengths vary from country to country, and the differences between countries are also relatively obvious. Some countries are also unable to explore outer space due to their conditions, while some more technologically powerful countries are now able to master the most advanced aerospace technology. We surveyed the financial investment of various continents in the field of space exploration, and the results are as follows.

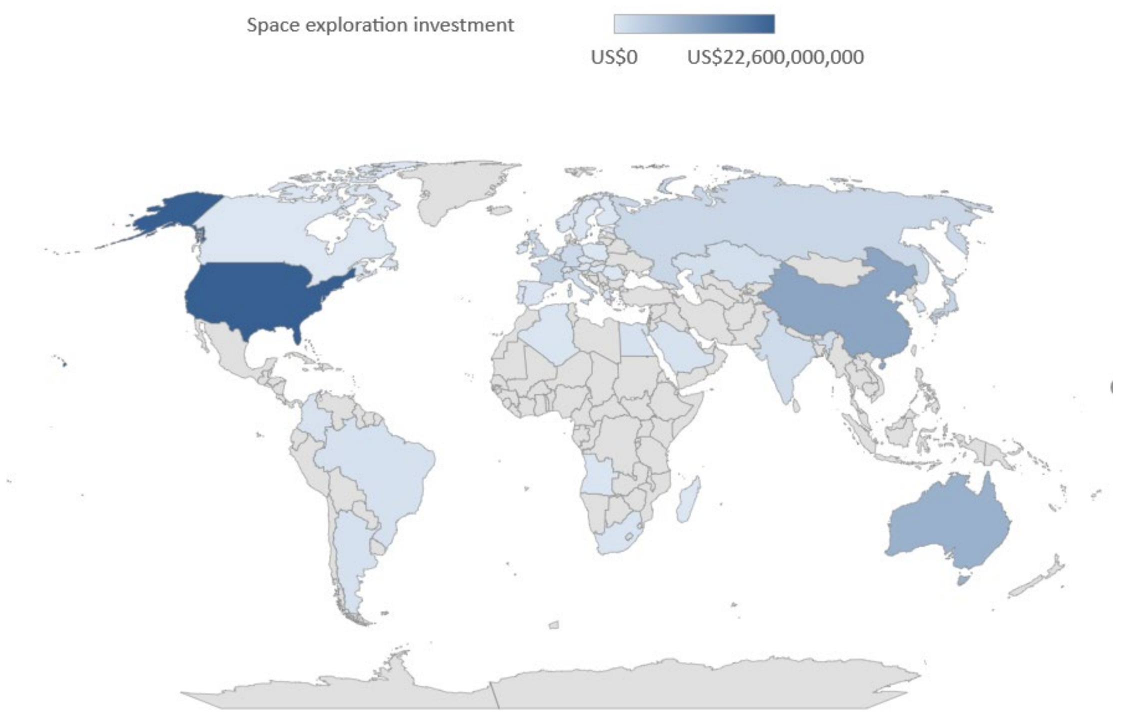


Figure 1 Global space investment

The differences between continents are huge, with North America accounting for almost half of the world's total space investment while other factors like politics and economies are not taken into account. Equity is not absolute fairness, let alone the equal allocation of opportunities and resources among countries[3]. But to give each country the minerals it deserves according to the actual input of each country and in combination with various evaluation indicators. Active cooperation is also encouraged, and even countries not involved in the core work should be compensated if they make their contributions in some way. In addition, the United Nations should store some minerals and give charitable help to some weak countries. In a word, we distribute minerals based on the principle of "reward for effort" to achieve global equity[4].

2.2 CSI model building based on TOPSIS

First, select countries that have been effective in space exploration in recent years as well as some representative countries from each continent. Then, select several indicators that can reflect the comprehensive strength (CSI) of each country including GII, GDP, EPI, POP (population), GMF, and CIP. I consider these indicators to score countries, sort them according to the final results and calculate the weight of each indicator according to the entropy weight method (EWM) [5].

Establish a numerical matrix. The number of rows (m) in the matrix is 10, and the number of columns (n) is 10. Considering that the measurement units of each indicator are not unified, we need to standardize them and transform the indicators into relative values before calculating the comprehensive indicators, to solve the dimensional problem. Among the indicators we chose, except for PWR which is a negative indicator, the other indicators are the positive indicators, and the positive indicators and the negative indicators are standardized according to formulas (1) and (2) respectively.

$$x_{ij}^{'} = \frac{x_{ij} - \min\left\{x_{1j}, \ldots, x_{nj}\right\}}{\max\left\{x_{1j}, \ldots, x_{nj}\right\} - \min\left\{x_{1j}, \ldots, x_{nj}\right\}} \tag{1}$$

$$x_{ij}^{'} = \frac{\max\left\{x_{1j}, \ldots, x_{nj}\right\} - x_{ij}}{\max\left\{x_{1j}, \ldots, x_{nj}\right\} - \min\left\{x_{1j}, \ldots, x_{nj}\right\}} \tag{2}$$

Use formula (3) to calculate the proportion of the ith value in the jth index,p_{ij} to determine the weight by entropy weight method (EWM). Then, the entropy value e_j of the jth index is calculated according to formula (4), and $e_j \geq 0$ is satisfied. The information entropy redundancy d_j is calculated by the formula (5).

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, i = 1, \ldots, n \;\; j = 1, \ldots, m \tag{3}$$

$$e_j = -k \sum_{i=1}^{n} p_{ij} \ln\left(p_{ij}\right), k = \frac{1}{\ln\left(n\right)} \tag{4}$$

$$d_j = 1 - e_j, j = 1, \ldots, m \tag{5}$$

Finally, from formula (6), calculate the index weight ω_j in Table 1 and Figure 2.

$$\omega_j = \frac{d_j}{\sum_{j=1}^{m} d_j}, j = 1, \ldots, m \tag{6}$$

Table 1 Index weight of CSI indicators

Indicator	PE	PWR	GDP	HCR	GH
ω_j	0.093	0.026	0.203	0.058	0.094
Indicator	CIP	EPI	SI	SW	POP
ω_j	0.157	0.054	0.071	0.062	0.182

Determine the optional vector Z^+ and the worst vector Z^-:

$$Z^+ = \left(Z_1^+, Z_2^+, \ldots, Z_m^+\right) = \left(\max\left\{z_{i1}\right\}, \max\left\{z_{i2}\right\}, \ldots, \max\left\{z_{im}\right\}\right), 1 \leq i \leq n \tag{7}$$

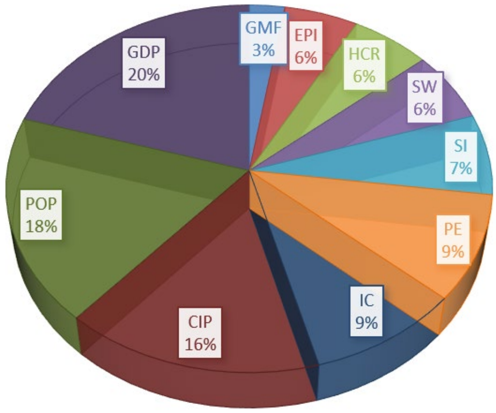
$$Z^- = \left(Z_1^-, Z_2^-, \ldots, Z_m^-\right) = \left(\min\left\{z_{i1}\right\}, \min\left\{z_{i2}\right\}, \ldots, \min\left\{z_{im}\right\}\right), 1 \leq i \leq n \tag{8}$$

Then, calculate the distance of the ith evaluation object from the optimal vector and the worst vector. Finally, calculate the final score of the ith country:

$$D_i^+ = \sqrt{\sum_{j=1}^{10} \omega_j \left(Z_j^+ - z_{ij}\right)^2}, D_i^- = \sqrt{\sum_{j=1}^{10} \omega_j \left(Z_j^- - z_{ij}\right)^2} \tag{9}$$

$$CSI_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{10}$$

Through the TOPSIS method based on entropy weight corrections, derive the CSI and its ranking for these several representative countries. The CSI evaluates a country's conditions including politics, economy, technology, society, population, and environment. On the one hand, it reflects the comprehensive strength of the country to some extent, and on the other hand, it also reflects the willingness, capacity, expected investment, and responsibility of the country to participate in affairs involving global interests.



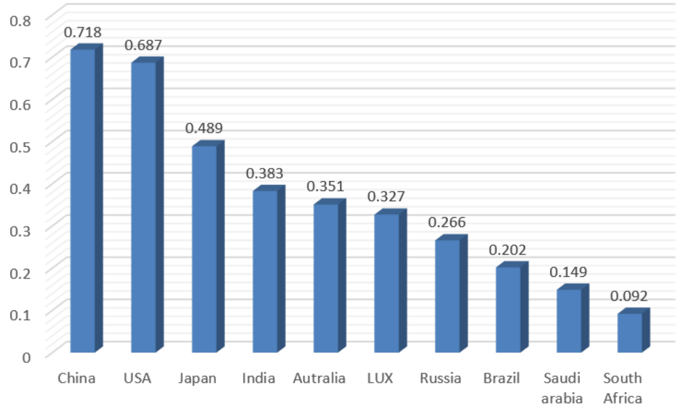


Figure 2 Index weight of CSI indicators Figure 3 CSI scores & rankings

A large CSI indicates that the country may have stronger comprehensive strength, higher participation, or insufficient effort in matters involving global interests, resulting in less investment and contribution to these affairs. Accordingly, these countries will get less return, which also shows the stronger demand for international assistance. The international community should provide some assistance so that it can also benefit from its participation in international affairs, and achieve its development.

To sum up, the CSI model can be used to evaluate, predict and compare a country's participation in international affairs, to realize the fair and reasonable distribution of interests. It can also be used to compare national comprehensive strength, measure the possible demand for international assistance, help weak countries, prevent differentiation between the rich and poor, and realize the humanitarian fairness of common development.

2.3 Model application and verification

Much like asteroids, Antarctica is rich in geographical resources. Since humans first discovered Antarctica in 1820, many countries have sworn sovereignty over Antarctica in an attempt to occupy Antarctic resources. In 1988, the Convention on the Management of Antarctic Mineral Resource Activities came out, which allows countries with mature technology and sufficient funds to carry out mining development activities, and some enterprises are capable of developing after paying taxes and fees. The benefits that countries deserve don't require to be shared. The treaty has some incentives for countries to cooperate and share. Regrettably, for reasons of environmental protection, the international community has frozen the right to exploit Antarctic minerals. However, when our resources run out in the future, we cannot ignore what's waiting to be discovered. Therefore, it is of great practical significance to determine the model for the exploitation of Antarctic resources.

Since Antarctica has not yet been exploited, the frequency and the number of space stations of each country are selected as indicators to measure the exploration capability of these countries. Due to the high technical requirements for aerospace mining in outer space mining, there are certain differences in the technical requirements of Antarctic scientific expeditions. We do not consider the impact of technology for the time being. The correlation analysis of CSI, frequency, and number shows the following results:

Table 2 Index weight of CSI indicators

	Number	CSI	Frequency
Frequency	0.639	0.918	1.000
CSI	0.574	1.000	0.918
Number	1.000	0.574	0.639

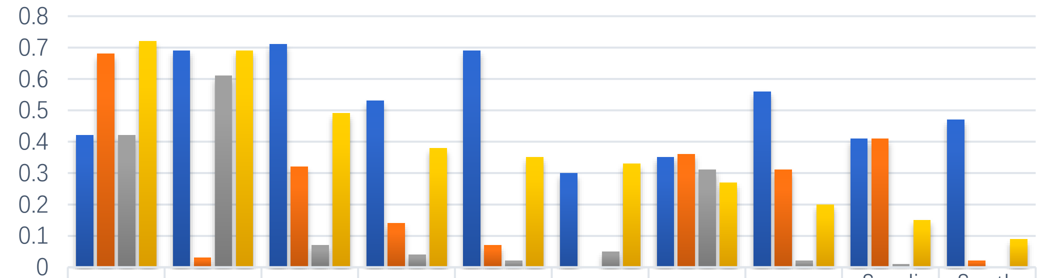
The table 2 of the correlation coefficient reflects the magnitude of the correlation. We can see that regardless of the technical differences, these three indicators still have a good correlation, especially the correlation coefficient between CSI and frequency reached 0.918, reflecting a strong correlation. This shows that the CSI we calculated by the model is basically in line with the current global context, so the model we have established is more reasonable and realistic.

3. Minerals distribution model based on CSII

3.1 CSI model building based on TOPSIS and AHP

Firstly, we collected data on each country's specific investments in the aerospace and the number of launches, which can reflect the real strength of the country in space exploration. In the initial model, we only consider the comprehensive technical strength of each country, but the core technology in actual mining greatly tested a country's aerospace strength. Additionally, given that the resources mined in the universe are mainly rare earth, the larger a country's rare earth resource reserves are, the less incentive there is for outer space resource exploration to some extent.

I first comprehensively score the aerospace strength of each country and then determine the weights of the new indicators and CSI indicator with the help of the analytic hierarchy process (AHP) [6]. Then, the TOPSIS method is used to revise the model with added indicators and re-score the countries analyzed in task1. Finally, by comparing the revised results with those in the initial model, we can roughly predict the impact of asteroid mining on global equity.



	China	USA	Japan	India	Autralia	LUX	Russia	Brazil	Saudi arabia	South Africa
NR	0.42	0.69	0.71	0.53	0.69	0.3	0.35	0.56	0.41	0.47
MR	0.68	0.03	0.32	0.14	0.07	0	0.36	0.31	0.41	0.02
AI	0.42	0.61	0.07	0.04	0.02	0.05	0.31	0.02	0.01	0
CSI	0.72	0.69	0.49	0.38	0.35	0.33	0.27	0.2	0.15	0.09

Figure 4 First-level indexes

Standardize the data, and then obtain SE and NL weights by the entropy weight method. Next, combine and use TOPSIS analysis to score AI of each country's aerospace strength. Then, determine the weight of first-level indexes including CSI, MR (mine reserve), NR (national reputation), and AI (aerospace indicators).

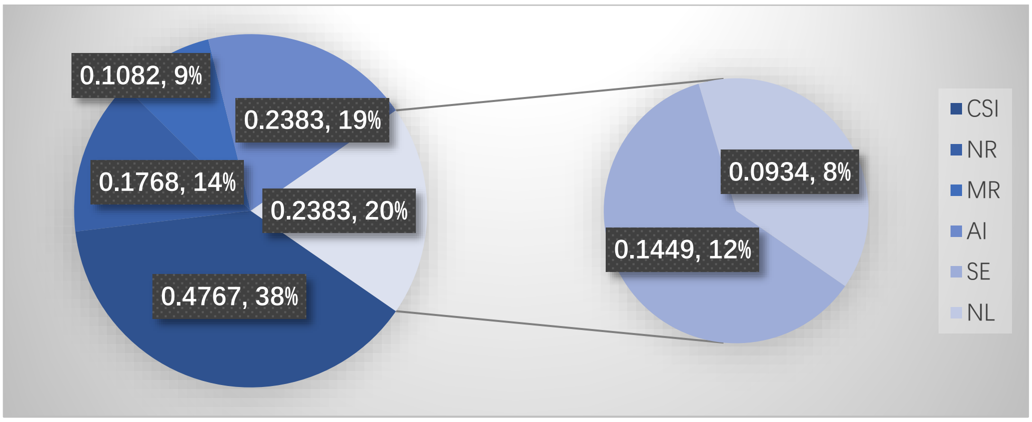


Figure 5 Total weight of the CSII model

Table 3 judgment matrix

Z	CSI	AI	MR	NR
CSI	1.0000	2.0000	4.0000	3.0000
AI	0.5000	1.0000	2.0000	1.5000
MR	0.2500	3.0000	1.0000	0.5000
NR	0.3333	0.6667	2.0000	1.0000

Based on the matrix, calculate the weight vector $\omega_i = (0.4767, 0.2383, 0.1082, 0.1768)$. The result $CR = 0.0077 < 0.1$, indicates that the result passes the consistency test.

3.2 Conclusions and analysis of the CSII model

CSII reflects the overall strength of a country to some extent, as well as the willingness, ability, expected investment, and responsibility of the country to participate in the affairs involving global interests, including asteroid mining, which is similar to the CSI indicator. The higher the CSII score, the stronger comprehensive strength the country may be of. When it comes to the interests of the global or international organizations, the country with a high score has more willingness to participate in the transaction, as well as cost more and take more responsibility. Accordingly, based on the definition of global equity, it should also have more rights and opportunities, and of course more benefit from the collective.

According to the analysis of CSII scores by various indicators and the comparison between the CSII model scores and the CSI model scores, we can draw the following conclusions: 1) The willingness, responsibility, and role of countries to participate in asteroid mining will have a limited impact on their contributions and benefits on a global scale. 2) In the CSII model, AI weights 0.2383, indicating that space power is a significant factor in the international game in the future. Besides, countries with limited development conditions of their own can consider benefiting from the form of international cooperation, as LUX did. 3) The higher a country's credit rating is, the more it will be able to act following international regulations and fulfill its commitments to international organizations. As a result, the international organization will give it more opportunities and rights to contribute more to the international organization and achieve collective development. In the case of rare earth resources, for example, the greater the country's original resource reserves, the lower the demand for the resources obtained from asteroid mining, and the lower the expected investment in asteroid mining and the lower the possible contribution[7].

Figure 6 Comparison between CSI and CSII

4. Multi-group fairness model based on a feature selection algorithm

4.1 Model Description

All the space resources with limited human detection are integrated, and the value of all the resources is judged to arrive at a total value, for example, the resources of asteroids are divided into two major categories: one is their scientific resources, and the other is their mineral resources. The total value of all the detected asteroids in space is calculated according to their value, and they are divided according to the principle of global equity[8]. They can be integrated and divided according to a feature selection algorithm based on a multi-group model.

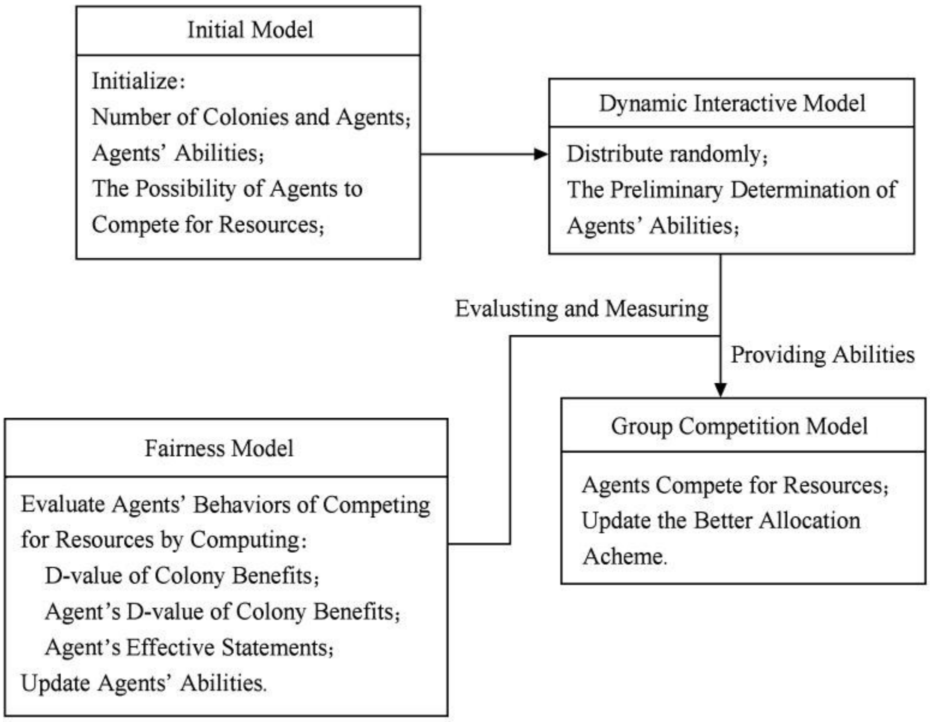


Figure 7 Evolution process of MCFA

The multi-population fairness algorithm judges and process the behavior to obtain a better assignment, which organically integrates random search and heuristic search, and combines the filter and wrapper methods to reduce the computational effort while obtaining higher classification accuracy.

Feature selection is a discrete optimization problem, which can be described as a known dataset that has m features and all the m features are used to classify the dataset, one is to reduce the classification efficiency and the other is to reduce the classification accuracy if there are some interference features among them features. For a feature set with m features, the entire search space is optimized for all feature subsets, and the size of the entire search space is: $O = C_m^0 + C_m^1 + \cdots + C_m^{m-1} + C_m^m = 2^m$

One of the difficulties in the feature selection process is that the length of feature subsets cannot be determined. In this paper, the general feature selection problem model is converted into a parallel feature subset selection problem model with m fixed lengths, as shown in the following figure.

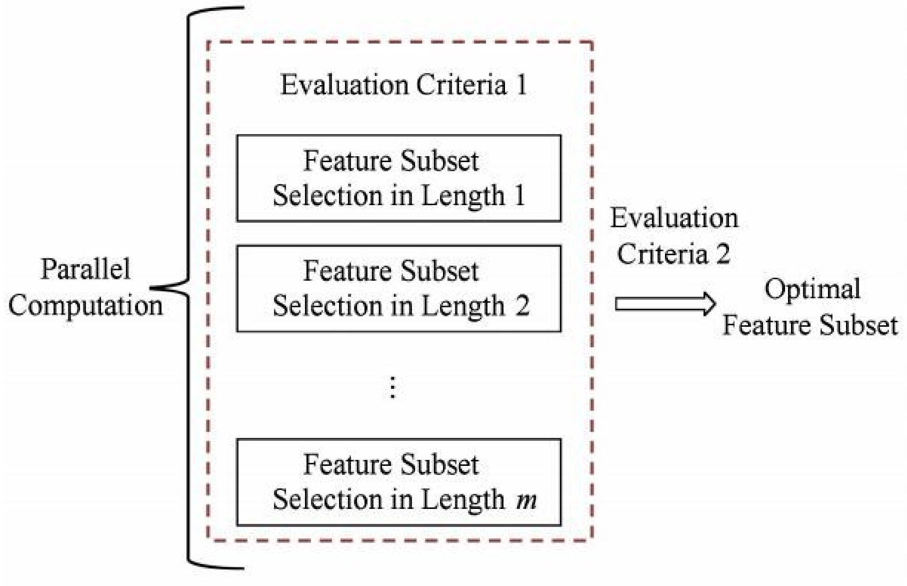


Figure 8 Feature subset selection model

The feature selection problem of fixed length n is converted into a multi-population M individual resource allocation problem, with the number of initialized populations N, the ith population labeled C_i(ability value), and the jth individual labeled P_j(individuals), where M is the total number of features in the feature dataset[9].

Definition I. Resource ownership state, whether the resources owned by individual P_j in population C_i are self-sufficient state S_{ij}(self-sufficient status of resources). If $S_{ij} = 1$, individuals do not engage in resource competition; if $S_{ij} = 0$, individuals are likely to engage in resource competition.

Definition II. Ability value of individual P_j in population C_{ij} ($C_{ij} \in [0,1]$). The larger the value of C_{ij}, the greater the ability of individual P_j will not have the ability to engage in competitive resource behavior.

Definition III. The probability of resource competition behavior. The likelihood that an individual P_j in a group C_i will adopt resource contention behavior, P_{ij} is determined by the individual's resource possession status and the individual's ability value and is calculated as in the equation, if $C_{ij} \geq \varepsilon$, $P_{ij} = (1 - S_{ij}) \times C_{ij} \times e^{C_{ij}-1}$; if $C_{ij} < \varepsilon$, $P_{ij} = 0$.

The number N of initialized resulting populations is determined, and the size of the population is determined by the complexity of the specific problem (the feature dimension of the dataset in which feature selection is performed); the number of individuals in each population is also the same for all features of the dataset.

4.2 Dynamic Interaction Model

Multi-group evolution in the dynamic interaction stage mainly completes the basic stereotypes of ability values of individuals of the same species in different groups and lays the foundation for the intra-group competition stage of each group.

If $S_{ij} = 1$, it means that individual P_j in group C_i is getting resources (feature r_j is selected into feature subset). If $S_{ij} = 0$, it means that P_j in population C_i lacks resources (feature r_j is not selected into the feature subset), and the value of feature subset evaluation function is calculated based on the feature subset of selected features: $F_i = fit(s_i) = DFS_i$ where fit is the feature subset evaluation function[10].

For the $l(l \geq 2)$ class classification problem, assume that the size of the training sample set is G and the dimension of the sample space is m, i.e., the training sample set is $x_k \in R^m$ (m-dimensional real space), $m \geq 0$, $y_k \in \{1, \cdots, l\}$, $l \geq 2$ where the sample size of the jth category is G_j. Then the discriminant DFS_i of the feature subset containing i ($i = 1, \cdots, m$) feature is defined as:

$$DFS_i = \frac{\sum_{i=1}^{l} \left\| x^{(j)} - x \right\|^2}{\sum_{j=1}^{l} \frac{1}{G_j - 1} \sum_{k=1}^{G_j} \left\| x_k^{(j)} - x^{(j)} \right\|^2} \tag{11}$$

where x and $x^{(j)}$ are the mean vectors of the subset of features containing the current i features on the whole data set and the mean vector on the data set of class j, respectively; $x_k^{(j)}$ is the eigenvector of the kth sample in class j corresponding to the current i features. The numerator in equation (4) represents the sum of the squares of the distance between the sample centroid vectors of each category corresponding to the subset of features containing the current i features and the centroid vectors of the whole sample set corresponding to the subset of features containing the current i features, and the smaller the variance, the more clustered the inter classes. Therefore, the defined DFS_i represents the ratio of inter-class distance and intra-class variance of the subset of features containing the current i features, and the larger the value, the stronger the class discrimination of the subset of features containing the current i features.

At the current stage, the mean group benefit is calculated as $A_{Fit} = \frac{1}{N} \times \sum_{i=1}^{N} F_j$.

To make the whole group (group) more adaptable to the survival environment, that is to make the whole group obtain greater group benefits, this question introduces the proportional distribution, effective statement, and factors in the fairness algorithm to judge and deal with the competition behavior of individuals in the group resource allocation, which is more beneficial to the group development.

The proportional allocation mechanism introduced in the fairness algorithm is mainly reflected in the proportional allocation of the group benefit difference. Especially, after quantifying the pre-allocation of group C_i resources with probability P_j satisfying the condition $B_{ij} = 0$ and $C_{ij} > \varepsilon$ will compete for resources with probability $P_{ij} = (1 - B_{ij}) \times C_{ij} \times e^{C_{ij} - 1}$, and the group benefit difference obtained at the end of the process will be proportionally allocated to all individuals according to their ability values. The group benefit difference is assigned to all individuals with $O_{ij} = 1$, and the group benefit difference is obtained as follows: if $O_{ij} = 1, d_{ij} = \frac{D_i \times C_{ij}}{\sum_{j=1}^{M} C_{ij} \times O_{ij}}$; if $O_{ij} = 0, d_{ij} = 0$.

To more equitably reflect the different group benefits of different individuals, a proportional allocation is introduced in the fairness algorithm to assign the group benefits to each individual proportionally.

Results: Global equity means equality for the entire planet, equality for all nations, equality for all people. We measure global equity with the above model, and we demonstrate the effectiveness of the fairness algorithm model to solve the feature selection problem in two ways.

1) Demonstrate that the ability value of individuals (features) that contribute little to the evaluation criterion-characteristic subset differentiation (group benefit value) becomes smaller, eventually converging to 0.
2) To prove that the ability value of individuals (features) contributing to the differentiation (group benefit value) of the evaluation criterion-feature subset becomes larger and larger, and eventually tends to 1.

5. Conclusion

We develop a definition of global equity, build a scoring model, and revise it. In the absence of a definition and associated indicators, we comprehensively surveyed the development of several representative countries, built the model using the TOPSIS method, and corrected the weights using the EWM method. The countries were scored comprehensively and the corresponding allocation principles were determined based on their scores. To justify the model, we apply the model to Antarctic scientific data and prove the model's validity. In this paper, we develop several models that CSI models can be used to assess, predict, and compare a country's participation in international affairs to achieve a fair and reasonable distribution of benefits. Also, they can be used to compare the combined power of countries. From our perspective, these models and the data analysis ideas contained in them can also be used to assess the contribution of each individual in a team, such as the distribution of wages in a company, thus promoting equity and motivating individuals to contribute to the collective.

Due to the limitation of acquiring data, it is not possible to expand the sample size of countries and consider more influencing factors. And the AHP model approach is somewhat subjective, although the current model fit level is high, and in the future, we hope to obtain further data to optimize the model so that it can be better applied to global equity issues in several fields.

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