Food Supply System Analysis Method and Information System Establishment with Quantitative Analysis

Yu Chen¹*, Yanxi Zeng², Jiatao Du³

¹College of Mathematics, Sichuan University, Chengdu, China
²Sun Wah International Business School, Liaoning University, Shenyang, China
³School of Civil Engineering, Shijiazhuang Tiedao University, Shijiazhuang, China

*Corresponding author: Chenyu2019@scu.edu.cn

Abstract. Because a vast global system of national and international food producers and distributors controls the lifeblood of global food, our global food system is unstable even in well-functioning parts of the world. Therefore, it is particularly important to establish a food system that takes efficiency and profitability as the main considerations and allows for relatively cheap and efficient food production and distribution. In this paper, on the basis of the existing evaluation indicators of grain system, we establish a multi-level index system through principal component analysis. After that, we integrate the index into the grain system index through entropy weight method and coefficient of variation method, and establish a comprehensive evaluation model. On the basis of the evaluation model, the index is calculated twice, and the optimization model is established combined with the multi-objective programming algorithm. The simulation results show that the two weights of energy efficiency and per capita cultivated land area account for a large proportion in the optimized system.

Keywords: Food Security, PCA, Entropy Method, Multi-Objective Programming.

1. Introduction

Food is not only the basic necessities of life, but also the most important material basis for ensuring the sustainable development of human beings. It has an irreplaceable basic position in supporting social and economic development [1]. According to the survey results of the relevant departments of the United Nations, 821 million people in the world are still starving [2] [3]. Food insecure people do not have enough affordable nutritious food. These people who are short of food live in every continent, every country and every community. Moreover, even in rich countries, there are food shortages. The current food system has left a huge environmental footprint: "resulting in 29 per cent of greenhouse gas emissions, 0.80 per cent loss of biodiversity, 80 per cent of deforestation and 70 per cent of freshwater use. [4] ". As the population continues to grow, our managers have had a growing impact of decades of environmental abuse. While maintaining or even improving environmental health, it is very important to produce more food. Therefore, a comprehensive inspection of our current food system seems to be a reasonable and assured effort. [5].

In this paper, we first establish a grain system evaluation model, which evaluates the existing grain system. We refer to the agricultural safety evaluation model, use the principal component analysis
method to screen multi-level indicators, and then get the weight of each index through the entropy weight method, and finally establish a food system evaluation model. After that, we optimize the parameters of the model by multi-objective programming algorithm.

2. Multi-level Index system based on Principal component Analysis

Principal component analysis (PCA) is a statistical method. Through orthogonal transformation, a group of variables that may have correlation are converted into a group of linearly unrelated variables, and the converted variables are called principal components. Principal component analysis (PCA), as a basic mathematical analysis method, is widely used in many disciplines, such as demography, quantitative geography, molecular dynamics simulation, mathematical modeling, mathematical analysis and so on. It is a commonly used multivariate analysis method [6].

In PCA algorithm, we set m n-dimensional samples, \( X = (x_1, x_2, \ldots, x_m) \). Our goal is to reduce the original data to k dimensionality, which is conducive to selecting more representative indicators.

2.1. Principal Component Analysis Algorithm Steps

(1) First, the original data is formed into a n rows and m columns matrix by columns, and then the data in X each dimension is subtracted from the mean value of the dimension to obtain \( X' \).

(2) Calculate the covariance matrix of the sample \( C = \frac{1}{m} X'X'^T \).

(3) (Eigenvalue Decomposition or Singular Value Decomposition) Find the eigenvalues and corresponding eigenvectors of the covariance matrix.

(4) Arrange the eigenvectors in rows from top to bottom according to the corresponding eigenvalues to form a matrix, and take the first k rows to form a matrix p.

(5) \( Y = PX \) is the data after dimension reduction to k dimension.

2.2. Index System

After principal component analysis, we get the index system shown in the following table.

| First Level Indicators | Second Level Indicators | Third Level Indicators |
|------------------------|-------------------------|-----------------------|
| Food System Index      | Effectiveness           | X1: Trading           |
|                        |                         | X2: Production Index  |
|                        |                         | X3: Crop              |
|                        | Profitability           | X4: International Direct Investment |
|                        |                         | X5: Government Spending |
|                        | Sustainability          | X6: Fertilizer        |
|                        |                         | X7: Energy Use        |
|                        |                         | X8: Total Land Use    |
|                        | Equality                | X9: Per Capita Arable Land Area |
|                        |                         | X10: Population       |
|                        |                         | X11: Consumer Price Index |

3. Obtaining Index weight based on Entropy weight

In information theory, entropy is a measure of uncertainty. The greater the amount of information, the greater the uncertainty, the greater the entropy; the smaller the amount of information, the smaller the uncertainty, the smaller the entropy. Therefore, according to the characteristics of entropy, we can
judge the randomness and disorder of the event by calculating the entropy value, and we can also use the entropy value to judge the discrete degree of the index. The greater the entropy value, the greater the influence.[7]

The calculation steps of entropy weight are as follows:

1. Use the entropy method to weight m indicators in a country (or region) for n years, so as to calculate the individual's comprehensive score.

2. Carry out standardization processing: Since the measurement units of various indicators are not uniform, before using them to calculate comprehensive indicators, we must first standardize them, that is, convert the absolute value of the indicator into a relative value, and set $x_{ij} = \frac{x_{ij} - x_{j\min}}{x_{j\max} - x_{j\min}}$. So as to solve the homogeneity problem of various quality index values. Moreover, because the meanings of the positive and negative indicators are different (the higher the positive indicator value is, the better, the lower the negative indicator value is, the better), therefore, we use different algorithms for data standardization for high and low indicators. The specific method is as follows:

\[
\begin{align*}
    y_{ij} &= \frac{x_{ij} - x_{j\min}}{x_{j\max} - x_{j\min}} \\
    y_{ij}^* &= \frac{x_{ij} - x_{ij}}{x_{i\max}^* - x_{i\min}}
\end{align*}
\]

Where $y_{ij}$ the value of the j-th indicator in the i-th year of the country (or region), $x_{j\max}$ and $x_{j\min}$ are the maximum and minimum values of the evaluation value $x_j$.

3. Calculate the proportion of the i-th row under the j-th index in the index:

\[
p_{ij} = \frac{y_{ij}}{\sum_{j=1}^{m} y_{ij}}, (i = 1,2, ..., n; j = 1,2, ..., m)
\]

4. Calculate the entropy value of the j-th index.

\[
e_j = -k \sum_{i=1}^{n} p_{ij} \ln(p_{ij})
\]

among them, $k > 0$, $k = \frac{1}{\ln(n)}$, $e_j \geq 0$

5. Calculate the coefficient of variance for the j-th index. For the j-th index, the greater the difference in the index value, the greater the left and right evaluation of the program, and the smaller the entropy value. Define the coefficient of difference:

\[
g_j = \frac{1 - e_j}{m - E_e}, \text{ Where } E_e = \sum_{j=1}^{m} e_j, 0 \leq g_j \leq 1, \sum_{j=1}^{m} g_j = 1
\]

Subsequently, four comprehensive evaluation indicators are obtained: efficiency index, profitability index, sustainability index and fairness index. Hereafter, this article will be abbreviated as, and respectively. Based on these calculated weights, we have
6) Calculate the weight:
We use the coefficient of variation method to weight these four indicators, and then merge them into a comprehensive measurement indicator. Therefore, we will briefly introduce the application of the coefficient of variation method. The coefficient of variation method (CVM) uses the information of various indicators to obtain the weight of each indicator through calculation, which is an objective weighting method.

Due to the influence of different dimensions, it is difficult to directly compare the indicators, so the coefficient of variation of each indicator is needed to measure the degree of difference of each indicator. The formula for each indicator can be expressed as:

\[ V_i = \frac{\theta_i}{\bar{V}_i} \quad (1 \leq i \leq 4) \]

Where \( V_i \) is the coefficient of variation of index \( i \), \( \theta_i \) is the standard deviation coefficient, \( \bar{V}_i \) is the standard deviation of the index \( i \cdot Z_1, Z_2, Z_3, Z_4 \) represent the average of EFI, PRI, SUI and EQI respectively.

The weight of each indicator can be obtained as:

\[ W_i = \frac{V_i}{\sum_{i=1}^{n} V_i} \quad (1 \leq i \leq 4) \]

(7) Calculate the comprehensive score of each country (region): Through the above calculation, we can assign weight to each indicator without subjective impression. Finally, after the weights are obtained, a comprehensive evaluation model of the food system index can be derived.

\[ FSI = W_1 \times EFI + W_2 \times PRI + W_3 \times SUI + W_4 \times EQI \]

In this section, we obtain the weight of each index by entropy weight method, which lays a foundation for the establishment of the following optimization system.

4. System Optimization Algorithm

4.1. Food System Evaluation Model

Conversion of formulas in the evaluation model: The evaluation model does not calculate each link, but directly uses the data to calculate a comprehensive evaluation score. Although the evaluation model cannot be directly used for optimization, the fairness and sustainability indicators can be calculated twice to obtain the following formula.

\[ SUI_j = g_1 y_{1j} + g_2 y_{2j} + g_3 y_{3j} \]
\[ EQI_j = g_4 y_{4j} + g_5 y_{5j} + g_6 y_{6j} \]

Where \( g_i (i = 1, 2, \ldots, 6) \) is the weight of each indicator, and \( y_{ij} (i = 1, 2, \ldots, 6) \) is the value of each indicator.
4.2. Multi-objective Planning

Multi-objective programming is a branch of mathematical programming [8]. The optimization of more than one objective function in a given region is studied. Also known as multi-objective optimization. It is usually marked as MOP (multi-objective programming). The concept of multi-objective programming was first put forward by American mathematicians Charles and Cooper in 1961. The idea of multi-objective optimization was first put forward by the French economist Pareto in 1896. From the point of view of political economy, he considers that many goals which are incomparable in nature are transformed into the optimization problem of a single objective, which involves the problem of multi-objective programming and the concept of multi-objective.

Mathematical Model:

\[
\min F(x) = \left( f_1(x), f_2(x), \ldots, f_m(x) \right)
\]

s.t. \( x \in \Omega \)

Decision space: \( x = (x_1, x_2, \ldots, x_n) \) is in the space \( \Box \), among them \( \Omega = \{ x \in \mathbb{R}^n \mid g_i(x) \leq 0, i = 1, 2, \ldots, p \} \)

Target space: the space where the m-dimensional vector \( F(x) \) is located.

4.3. Optimization of Food system Evaluation Model based on multi-objective programming algorithm

Assign a weight \( w_i (1 \leq i \leq 4) \) to each objective function \( f_i (1 \leq i \leq 4) \), \( w_i \) is the importance of the objective function. Then the following linear combination is obtained:

\[
\mu = \sum_{i=1}^{4} \left( w_i \times f_i(x) \right)
\]

Here we will convert the multi-objective into a single objective function, which will be used as the evaluation function. However, because the goals of multi-objective function optimization problems often conflict with each other, the methods generally applicable to single-objective problems are difficult to solve multi-objective problems. Therefore, the following formula is obtained by using the idea of multi-objective planning.

\[
\min F(x) = [-(w_1 \times f_1(x)), -(w_2 \times f_2(x)), w_3 \times f_3(x), w_4 \times f_4(x)]
\]

\[\text{Figure. 1 U.S. Optimization Model Diagram}\]
5. Solution results of the model

5.1. The United States
Applying the data of relevant indicators in the United States to the above optimization model, the figure 1 can be obtained:

The optimization indicators are:

| index | X_1 | X_2 | X_3 | X_4 | X_5 | X_6 | X_7 | X_8 | X_9 | X_10 | X_11 |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|-------|
| value | 1.000 997 | 1.00 0998 | 1.00 0996 | 1.000 997 | 1.000 997 | 0.591 615 | 2.157 271 | 0.07 79 | 2.685 27 | 0.226 05 | 0.15 94 |

From the above table, we can draw the following conclusions: (1) The index values of trade, production volume index, crops, international direct investment and government expenditure are negative, indicating that optimizing fairness and sustainable development will reduce the values of these five indicators, which in turn will make the food system more efficient and profitable reduce. (2) The index values of fertilizer, energy use, total land use, per capita arable land area, population, and consumer price index are positive, indicating that optimizing fairness and sustainable development will increase the value of these six indicators, which in turn will make the food system more effective. Efficiency and profitability increase. This is the purpose of optimization, that is, the optimization model we have established has certain applicability. (3) The result of (2) shows that the optimization model we have established has certain applicability. But it still needs to be tested, and further verification of this optimization model will be launched later.

5.2. Optimized Model Result Trend Chart
Using the above optimization model, the optimization results of the United States, China, and India can be obtained, and these optimization results can be used to draw the optimization trend maps of the United States, China, and India.

5.2.1. Individual trends in the United States, China and India

As can be seen from figure 2, the US optimization model shows a trend of first decreasing and then increasing.
As can be seen from figure 3, the overall Chinese optimization model shows a trend of first increasing, then decreasing and then increasing.

It can be seen from the graph that the overall optimization of India is showing a downward trend.

5.2.2. Comparison Trend Chart of The United States, China and India. The following is a comparison chart of the optimization results of the three countries.
From the above chart, we can draw the following conclusions:

1. As can be seen from the above figure, optimizing fairness and sustainability will increase the overall results of a large food importing country like the United States.

2. In the above figure, optimizing fairness and sustainability will make the overall result of a large exporting country like China slightly lower.

3. As can be seen from the above figure, optimizing fairness and sustainability will reduce the overall results of India.

4. It can be seen from the above analysis that the difference between the optimized system and the current system is mainly reflected in the changes in indicators after optimization.

6. Conclusion

In this paper, we established a multi-level indicator system through principal component analysis and screening based on the existing food system evaluation indicators. After that, we integrated the indicators into the food system indicators through the entropy method and the coefficient of variation method, and established a comprehensive evaluation model. On the basis of the evaluation model, the index is calculated twice, combined with the multi-objective programming algorithm to establish an optimization model. The simulation results show that in the optimized system, the two weights of energy utilization rate and per capita arable land area account for a larger proportion.

References

[1] Yin Peihong, Fang Xiuqi, Ma Yuling, et al. Distribution and regional difference of food shortage in China in 21st Century[J]. Scientia Geographica Sinica, 2007, 27(4): 463—472. (in Chinese with English abstract)

[2] Food, United Nations. Retrieved from: ‘https://www.un.org/en/sections/issues-depth/food/index.html

[3] World Hunger, Poverty Facts, Statistics, 2018-World Hunger News, World Hunger News, 2018. From:https://www.worldhunger.org/world-hunger-and-poverty-facts-and-statistics/

[4] The 2021 Food Systems Summit, United Nations, 2020. Retrieved from: ‘https://www.un.org/sustainabledevelopment/food-systems-summit-2021/’

[5] An Yiming, Zhao Wenwu. Global climate change and food security: Review of the 2012 Planet under Pressure International Conference. Acta Ecologica Sinica, 2012, 32(15): 49404942.(in Chinese)

[6] Jolliffe I T . Principal Component Analysis[J]. Journal of Marketing Research, 2002, 87(4):513.

[7] Shannon C E . A mathematical theory of communication[J]. The Bell System Technical Journal, 1948, 27(4):379-423.

[8] Cohon J L . Multiobjective Programming and Planning. University of Strathclyde, 1978.