Competition Evaluation of Pharmaceutical Logistics Centres Based on Combined Weight and Cumulative Prospect Theory

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Abstract. In order to evaluate the competitiveness of pharmaceutical logistics centres, promote the integration of resources and improve the management level and market competitiveness of pharmaceutical logistics enterprises, an evaluation index system for the competitiveness of pharmaceutical logistics centres is constructed, and an evaluation method based on combined weights and cumulative prospect theory is proposed. This method uses AHP and the revised entropy weight to calculate the subjective and objective weights of each index respectively, and uses game theory to carry out the weight combination. The [-1, 1] linear transformation operator is used to standardize the original decision-making matrix, and then, the positive and negative ideal solutions are obtained. The comprehensive evaluation model of pharmaceutical logistics is constructed based on the cumulative prospect theory considering the decision-maker's attitude towards the risk of profit and loss. The comprehensive prospect value of each pharmaceutical logistics centre is solved and the competitiveness sequence is determined. Finally, the feasibility of the model is verified by an example. Compared with the traditional evaluation method, the result shows that the model is scientific and reasonable and conforms to the actual decision.

1. Introduction

In recent years, the pharmaceutical circulation industry in China has developed steadily and rapidly, and the pharmaceutical logistics market has been continuously expanded. By integrating upstream and downstream enterprises in the logistics supply chain, third-party pharmaceutical logistics companies have formed some regional specialized and comprehensive pharmaceutical logistics warehousing and distribution centers, which have greatly reduced the circulation cost of pharmaceutical products, and have become an inevitable trend in the development of the pharmaceutical logistics industry [1]. But, due to the factors of high logistics cost, advanced technology and special requirements of the logistics industry, the management services level of intensive pharmaceutical logistics center is low, and the market competitiveness is weak [2]. Pharmaceutical logistics enterprises need to accurately evaluate the competitiveness of their own pharmaceutical logistics centers, boost the improvement of operation and management, and improve their core competitiveness and service level. Therefore, it is of great practical
significance to establish an index system and a scientific and reasonable evaluation model suitable for evaluating the competitiveness of pharmaceutical logistics centers.

The researches on the performance evaluation of logistics enterprises has experienced from using a single and traditional method to combination of multiple methods. The typical methods include: fuzzy analytic hierarchy process (FAHP) [3], hybrid fuzzy algorithm of analytic hierarchy process and analytic network [4], the combination of analytic hierarchy process and technique for order preference by similarity to ideal solution (TOPSIS) [5], the combination of analytic hierarchy process and grey correlation analysis [6], the combination of analytic hierarchy process and fuzzy comprehensive evaluation [7], the entropy weight combined with grey correlation analysis [8], etc. Because of the late development of modern pharmaceutical logistics center, the current researches on pharmaceutical logistics center mainly focus on site selection planning and optimization design of warehouse and distribution operations [9-13]. There are few researches in the field of competitiveness evaluation, and the methods are relatively simple. The common evaluation methods include: analytic hierarchy process, balanced score method, principal component analysis, network analysis, fuzzy comprehensive evaluation, data envelopment analysis (DEA), BP neural network, bijective soft set model [14-16], etc.

Summarizing the previous studies, it is found that there are two problems in the evaluation of pharmaceutical logistics centers: there are few researches on the evaluation index of the competitiveness of pharmaceutical logistics centers. The existing researches mainly focus on the performance evaluation of general logistics enterprises, the evaluation indicators don’t reflect some specific requirements to evaluate pharmaceutical logistics centers. Such as whether there is GSP certification, the ability of refrigeration capacity, and facilities used to control and monitor temperature throughout the vaccine distribution. In addition to, the evaluation are too dependent on subjective methods to lack the reference of objective data information. The quantitative evaluation methods are mostly based on the premise that the decision maker are absolutely rational, and the psychological preferences of decision makers facing gains and losses under uncertain conditions aren’t considered. However, this preferences often have a decisive influence on the final evaluation results.

In view of the above problems, this paper constructs an evaluation index system reflecting the competitiveness of pharmaceutical logistics centers, and combines weights on the basis of calibrating subjective and objective weights, and establishes a comprehensive evaluation model based on the cumulative prospect theory considering the decision makers’ subjective risk preferences. The combination method of subjective and objective weights based on the idea of game theory, takes into account the expert experiences considered by AHP and the objective data information embodied by the entropy weight, which makes the index weight more consistent with the reality. Due to the characteristics of uncertainty and information asymmetry, decision makers are sensitive to risk loss. The evaluation method based on the cumulative prospect theory fully considers decision-makers’ attitude towards risk in the face of gains and losses, which is more in line with their decision-making psychology and scene. Finally, the analysis and verification are carried out with examples to provide theoretical basis and technical support for the evaluation of the competitiveness of pharmaceutical logistics centers.

### 2. Building evaluation index system

In the evaluation of the competitiveness of the pharmaceutical logistics center, in addition to the characteristics of its general logistics enterprise, it is also necessary to consider the particularity of pharmaceutical logistics. Pharmaceutical products are special commodities. The logistics requirements are complex and special. The country sets relevant qualification certification for pharmaceutical logistics suppliers. When evaluating them, it should consider whether they have GSP or not; for some pharmaceuticals, the whole process of cold chain from storage to distribution, should be strictly controlled for temperature and humidity. The strict requirements on quality and safety of pharmaceuticals have promoted the application of advanced information technology management means, and its application level also determines the level of logistics service and competitiveness. Therefore, information technology and management level should be considered in the evaluation.
Considering the above needs to pay attention to several aspects, from the two perspectives of operability and index relevance, the use of Delphi method to finally establish the evaluation index system of pharmaceutical logistics centers competitiveness is shown in Table 1.

**Table 1. Evaluation index system of competitiveness of pharmaceutical logistics centers.**

| Primary index | Secondary index | On the basis of value | Type |
|---------------|-----------------|----------------------|------|
| Assets and operating conditions | Total assets/CNY’ million | Go directly to the investigation | Benefit |
| | Annual revenue/CNY’million | Go directly to the investigation | Benefit |
| | Logistics cost rate/% | (Logistics costs/ sales)*100% | Cost |
| | Days sales of inventory/day | 365/Inventory turnover | Cost |
| Facilities and equipment | Storage area/m² | Go directly to the investigation | Benefit |
| | Capacity of refrigerated storage/m³ | Go directly to the investigation | Benefit |
| | Number of freight vehicle | Go directly to the investigation | Benefit |
| | Number of distribution terminals | Number of fixed outlets with a certain business scale | Benefit |
| Management and technology | Management system* | Expert scoring on-site/0-9 score | Benefit |
| | Prevention level of security risk* | Expert scoring on-site/0-9 score | Benefit |
| | Level of information technology* | Expert scoring on-site/0-9 score | Benefit |
| Service Level | Rate of stock-out error/% | (Number of stock-out errors/total number of stock-out)*100% | Cost |
| | Consumer Satisfaction/% | (Satisfaction /total number of services)*100% | Benefit |
| Personnel quality | middle and senior manager/% | Proportion of college degree or above and logistician certification | Benefit |
| | General logistics practitioner/% | Proportion of secondary or higher education and logistics professional qualifications | Benefit |

The score of “management system” is based on whether it has the new GSP certification, a sound quality management system, temperature monitoring and cold chain logistics operation process, and whether it has passed the ISO quality management system certification. The score of “prevention level of security risk” is based on whether there are emergency plans such as drug quality risk, heatstroke prevention and antifreeze, power failure of cold storage, and cold chain transportation, etc.; Whether to pay insurance for property, transportation and personal; whether there is safety training related to equipment, transportation and information. The score of “level of information technology” is based on whether there are warehouse management system (WMS) and transport management system (TMS); Whether there is an automatic monitoring system of temperature and humidity for drug storage; Whether there is a digital picking system; Whether the whole process of vaccine distribution is monitored by temperature control; Whether to establish automatic and manual customer query system.

3. Establishing evaluation model

3.1. Combination weighting model of subjectivity and objectivity based on game theory

3.1.1. Calibration of subjective weights based on AHP. AHP decomposes the complex problems to be evaluated into multiple influencing factors according to the nature of the evaluation objectives, and divides the influencing factors into different levels according to the subordination relationship and the coupling relationship, they are target layer, criterion layer and plan layer. According to the experience and preference of the decision makers, the importance of the factors in the same layer of the same factor is compared, and the judgment matrix is obtained. The relative weights of each factor at each level are obtained by calculating the maximum eigenvalue and eigenvector of the judgment matrix, and then the weights of each index at the lowest level relative to the target level are obtained by weighting from the bottom to the top [6]. The steps are as follows:
To construct a comparison judgment matrix: According to the connotation of evaluation of medical logistics centers, the target layer of the hierarchical structure model is the competitiveness, the first level of criterion is the primary index, the second level of criterion is the secondary index, and the medical logistics centers to be evaluated is the scheme layer. From the first level of the standard, the indexes are compared for each other, and some experts are invited to construct the comparison judgment matrix $A = (a_{ij})_{mn}$ according to the 1-9-digit scale rule.

To calculate the eigenvector: The comparison judgment matrix is standardized to obtain the judgment matrix $B = (b_{ij})_{mn}$, $w_i$ is obtained from summing each row of $B$, and it's normalized to get the eigenvector $w = (w_1, w_2, \ldots, w_n)$.

To calculate the maximum eigenvalue root:

$$\lambda_{max} = \sum_i (Aw_i) / nw_i$$

To check consistency:

$$CR = CI / RI$$

Where $CI = (\lambda_{max} - n) / (n - 1)$, when $CR < 0.1$, it indicates that the constructed judgment matrix passes the consistency test and the weight distribution is feasible; otherwise, the comparison judgment matrix is adjusted or constructed again until it passes the test.

To determine the weight of each evaluation index: Repeat the above steps, we can get the weights of the first level of criteria relative to the target level and the second level of criteria relative to the first level of criteria. The subjective weights of each evaluation index relative to the target level can be obtained by weighting:

$$c_j = w_j p_j$$

### 3.1.2. Calibration of objective weights based on modified entropy weight

Entropy weight method is an objective weighting method. Its basic idea is to reflect the importance of the index to the evaluation object from the degree of index confusion. Entropy value of each evaluation index is obtained by information entropy. Entropy value is used to express the relative importance of each evaluation index. The smaller the entropy value is, the greater the degree of difference in the index evaluation will be, the greater the information content and weight will be. The steps are as follows [8]:

1. To construct the initial evaluation matrix: Assuming that there are $n$ medical logistics centers and $m$ evaluation indexes, the initial evaluation matrix can be constructed as $S = (s_{ij})_{mn}$.

2. To obtain the dimensionless initial matrix as $T = (t_{ij})_{mn}$:

$$
\begin{align*}
    t_{ij} &= (s_{ij} - \text{min}(s_{ij})) / (\text{max}(s_{ij}) - \text{min}(s_{ij})) \\
    &\quad \text{benefit index} \\
    t_{ij} &= (\text{max}(s_{ij}) - s_{ij}) / (\text{max}(s_{ij}) - \text{min}(s_{ij})) \\
    &\quad \text{cost index}
\end{align*}
$$

3. To calculate the characteristic proportion of indicators: The medical logistics centre ($i$) under the index ($j$), the characteristic proportion of index value is $p_{ij} = t_{ij} / \sum_i t_{ij}$, the range of $p_{ij}$ is $[0,1]$. In order
to avoid that when \( t_i = 0 \), \( p_j = 0 \), the formula for calculating the characteristic proportion of indicators is meaningless, so the formula is modified:

\[
p_j = (t_j + 10^+)^{\frac{1}{\sum_{i=1}^{n} (t_i + 10^+)}}
\]  
(7)

(4) To calculate the entropy value of each index:

\[
e_j = -\frac{1}{\ln(n)} \sum_{i=1}^{n} p_j \ln p_j
\]  
(8)

(5) To determine the objective weights of each index:

\[
d_j = (1-e_j)^{\frac{1}{\sum_{j=1}^{n} (1-e_j)}}
\]  
(9)

3.1.3. Weight combination based on game theory. Analytic Hierarchy Process (AHP) can carry out hierarchical and quantitative analysis, and simplify decision-making problems by expert experience. It has obvious advantages when evaluation problems are complex and data collection is difficult. However, it relies too much on personal subjective factors and the result is poorly credible. However, it relies too much on personal subjective factors and the result is poorly credible. Entropy weight method is used to determine the weight by objective value of each index. The importance of the index depends on the difference of objective information. There will be a few relatively insignificant indexes which get a larger weight because of the greater difference of objective value, while some relatively important indexes get smaller weight because of the smaller difference of objective value, but it does not accord with the reality [17]. In order to overcome the above shortcomings, the game theory is used to combine the weights of the two methods, and a compromise is sought between the subjective and objective weights to minimize the deviation. The subjective weights calibrated by AHP are denoted as \( w_1 \), the objective weights calibrated by entropy weight method are labelled as \( w_2 \). Thus, the linear combination model of subjective and objective weights is constructed as follows:

\[
w = k_1 w_1^{\top} + k_2 w_2^{\top} = \sum_{j=1}^{n} k_j w_j^{\top}
\]  
(10)

Where, \( k = (k_1, k_2) \) are the linear combination coefficients, and \( w \) is the weight set of all possible linear combination weights of the subjective and objective weights. By referring to the idea of game theory, the decision goal is to minimize the deviation between \( w \) and \( w_j \), and the following combined weight model is proposed:

\[
\min \left\| \sum_{j=1}^{n} k_j w_j^{\top} - w_j^{\top} \right\| (j = 1, 2)
\]  
(11)

According to the differential property of matrix, the optimum first derivative condition of formula (12) is obtained as follows:

\[
\sum_{j=1}^{n} k_j w_j^{\top} w_j^{\top} - w_j^{\top} = 0 \ (j = 1, 2)
\]  
(12)

The calculated linear combination coefficients \( k = (k_1, k_2) \) are normalized to obtain the optimal combination coefficients \( k' = (k'_1, k'_2) \), and then the final combination weight (\( w' \)) is obtained.
\[ k_i^* = k_i / \sum_{i=1}^{n} k_i \]  
\[ \omega' = \sum_{i=1}^{2} k_i w_i' = k_i w_i'^T + k_j w_j'^T \]

3.2. Comprehensive evaluation model based on cumulative prospect theory
Prospect theory was proposed by Kahneman and Tversky [18]. It is considered that it is difficult for decision makers to rationally evade all risks when evaluating decision-making due to uncertainties. They prefer to choose a reference point and use the difference between the results and the reference point as the basis for judging the benefits and losses rather than the absolute number of the results. Prospect theory holds that the value of prospects is determined by value function and decision weight function. Later, cumulative prospect theory was proposed [19]. They believed that the attitude of decision makers towards gains and losses is asymmetrical. When facing with losses, they tend to pursue risks, and when facing with gains, they tend to hate risks. Under the influence of uncertainties, decision makers’ preferences for risk are non-linear in probability, and people tend to overestimate low-probability events and underestimate high-probability events, and are relatively insensitive to the change of probability in the intermediate stage. Based on cumulative prospect theory, a comprehensive evaluation model of medical logistics centers is constructed. The steps are as follows:

(1) To construct the original attribute matrix: There are several pharmaceutical logistics centers to be evaluated, a comprehensive evaluation decision set is formed as \( N = (N_1, N_2, \ldots, N_n) \). The several evaluation indexes compose the evaluation index set as \( x = (x_1, x_2, \ldots, x_m) \). Therefore, the original attribute matrix of the scheme layer to the index layer can be constructed as \( X = (x_{ij})_{mn} \).

(2) To construct the evaluation matrix: in order to eliminate the influence of index dimension, the original attribute matrix is standardized by \([-1, 1]\) linear transformation. The evaluation matrix is recorded as \( Z = (z_{ij})_{mn} \), and its calculation formula is as follows.

\[
\begin{align*}
  z_i^b &= (x_i - z_i) / \max\{\max(x_i) - z_i, z_i - \min(x_i)\} & \text{benefit index} \\
  z_i^c &= (z_i - x_i) / \max\{\max(x_i) - z_i, z_i - \min(x_i)\} & \text{cost index}
\end{align*}
\]

Where \( z_i = \sum_{i=1}^{m} x_i / n, (j = 1, 2, \ldots, m) \).

(3) To select the reference points: TOPSIS assumes that there are two ideal schemes. The optimal and the worst values of each index are selected respectively and defined as positive ideal solution and negative ideal solution. The ranking is conducted by calculating the distance between each index value of the evaluation object and the two ideal solutions. When each index is closest to the positive ideal solution and farthest from the negative ideal solution, the object is considered to be the best and vice versa [10]. Therefore, TOPSIS’s ideas can be used for reference and positive and negative ideal solutions can be selected as the reference points of prospect theory.

\[
\begin{align*}
  Z^+ &= \max\{z_i | 1 \leq i \leq n\} = \{z_1^+, z_2^+, \ldots, z_n^+\} & \text{positive ideal solutions} \\
  Z^- &= \min\{z_i | 1 \leq i \leq n\} = \{z_1^-, z_2^-, \ldots, z_n^-\} & \text{negative ideal solutions}
\end{align*}
\]

(4) To calculate the positive and negative prospect value matrix: According to cumulative prospect theory, if the positive ideal solution is taken as the reference point, then \( z_i^c \leq z_i^+ \). All the medical logistics centers in the scheme layer are worse than the positive ideal solution, so they are faced with losses for
the decision makers, who tend to have a risk preference at this time. If the negative ideal solution is used as reference point, then $z_i \geq z_a$. The medical logistics centers are superior to the negative ideal solution.

For the decision makers, they are faced with benefits and tend to be risk-averse. Using the value function of cumulative prospect theory, the utility function of the prospect value corresponding to the indexes of each pharmaceutical logistics center are constructed.

\[
V^+(z_i) = (z_i - z_a)^\gamma \\
V^-(z_i) = -\lambda (z_i - z_a)^\delta
\]

When the negative ideal solution is taken as the reference point.

Where, $\alpha$ and $\beta$ respectively represent the degree of concavity and convexity of power function of value in the face of gain and loss, reflecting the risk preference of decision makers. $\lambda$ is the loss avoidance coefficient, $\lambda > 1$ indicates that decision makers are more sensitive to losses. Tversky and Kahneman gave the reference values of these parameters in literature [19] according to the research results, usually $\alpha = \beta = 0.88$, $\lambda = 2.25$.

Thus, the positive and negative prospect matrixes of medical logistics centers, $V^+ = (V^+(z_i))_{n \times m}$ and $V^- = (V^-(z_i))_{n \times m}$ are as follows:

\[
V^+ = \begin{bmatrix}
V^+_{11} & V^+_{12} & \cdots & V^+_{1m} \\
V^+_{21} & V^+_{22} & \cdots & V^+_{2m} \\
\cdots & \cdots & \cdots & \cdots \\
V^+_{n1} & V^+_{n2} & \cdots & V^+_{nm}
\end{bmatrix}
\quad \text{And} \quad
V^- = \begin{bmatrix}
V^-_{11} & V^-_{12} & \cdots & V^-_{1m} \\
V^-_{21} & V^-_{22} & \cdots & V^-_{2m} \\
\cdots & \cdots & \cdots & \cdots \\
V^-_{n1} & V^-_{n2} & \cdots & V^-_{nm}
\end{bmatrix}
\]

(5) To determine the function of decision weight: Another important component of the comprehensive prospect value of medical logistics center is the perceptual weight of decision makers. Combination weight based on game theory is rational. However, under the influence of uncertainty, the decision-makers’ attitudes towards gains and losses are asymmetric, and their preferences for risk are non-linear in probability. This rational combination weight will be transformed into the final decision perception weight. When the value of an index in the medical logistics center is greater than that of the negative ideal solution, the decision maker is faced with profit, and the index belongs to the profit-oriented index. On the contrary, it belongs to loss index. The cumulative prospect theory gives the weight functions of decision-making in the face of gains and losses for $\pi^+(w_j)$ and $\pi^-(w_j)$ respectively.

\[
\pi^+(w_j) = \frac{w_j^\gamma}{(w_j^\gamma + (1-w_j^\gamma)^\gamma)^\gamma} \quad \text{And} \quad \pi^-(w_j) = \frac{w_j^\delta}{(w_j^\delta + (1-w_j^\delta)^\delta)^\delta}
\]

Tversky and Kahneman gave the reference values for $\gamma$ and $\delta$. $\gamma = 0.61$, and $\delta = 0.69$ [19].

(6) To establish the comprehensive evaluation model: According to the meaning of the cumulative prospect theory, the comprehensive prospect value of each indicator of each pharmaceutical logistics center is composed of two parts: positive and negative foreground value.

\[
v(x_i) = v^+(z_i)\pi^+(w_j) + v^-(z_i)\pi^-(w_j)
\]

The comprehensive prospect value of each pharmaceutical logistics center is as follows:

\[
V_i = \sum_{j=1}^{n} v^+(z_i)\pi^+(w_j) + \sum_{j=1}^{n} v^-(z_i)\pi^-(w_j)
\]
For each pharmaceutical logistics center, when the positive prospect value is larger and the negative prospect value is smaller, the comprehensive prospect value is larger, indicating that the pharmaceutical logistics center has stronger competitiveness and the ranking is earlier. Therefore, the objective function of the comprehensive evaluation model is as follows:

\[
V_{\text{max}} = \max (V_1, V_2, \cdots, V_n) = \max \left( \sum_{j=1}^{m} \nu^+ (z_j) \pi^+ (w_j) + \sum_{j=1}^{m} \nu^- (z_j) \pi^- (w_j) \right)
\]

(21)

4. Case study
At present, \( Y \) has become a well-known domestic pharmaceutical logistics enterprise with a good momentum of development. In order to continuously expand the scope of service and enhance service capacity in the field of pharmaceutical distribution, the basic situation of the five medical logistics centers to which they belong were investigated in detail. The purpose is to evaluate the competitiveness of these logistics centers, integrate enterprise resources, and implement targeted management strategies to improve the market competitiveness of the whole enterprise. According to the survey data and the evaluation index system constructed above, the evaluation index values of five pharmaceutical logistics centers to be evaluated are detailed in Table 2.

| Index variable | Evaluation index | \( N_1 \) | \( N_2 \) | \( N_3 \) | \( N_4 \) | \( N_5 \) |
|----------------|------------------|----------|----------|----------|----------|----------|
| \( x_1 \)     | Total assets/CNY’ million | 882.94   | 841.98   | 1040.32  | 1240.44  | 367.79   |
| \( x_2 \)     | Annual revenue/CNY’million | 1965.26  | 1644.71  | 1565.94  | 1052.82  | 361.00   |
| \( x_3 \)     | Logistics cost rate/\%  | 0.529    | 0.446    | 0.776    | 0.729    | 0.779    |
| \( x_4 \)     | Days sales of inventory/day | 31       | 43       | 37       | 33       | 48       |
| \( x_5 \)     | Storage area/m²     | 11200    | 5899     | 11292    | 2590     | 3750     |
| \( x_6 \)     | Capacity of refrigerated storage/m³ | 495     | 446      | 1325     | 300      | 95       |
| \( x_7 \)     | Number of freight vehicle | 18       | 12       | 36       | 11       | 8        |
| \( x_8 \)     | Number of distribution terminals | 1306    | 843      | 1213     | 932      | 301      |
| \( x_9 \)     | Management system * | 6.57     | 6.57     | 5.03     | 8.03     | 4.03     |
| \( x_{10} \)  | Prevention level of security risk * | 6.53    | 7.13     | 8.07     | 4.17     | 6.53     |
| \( x_{11} \)  | Level of information technology * | 6.47    | 5.53     | 7.17     | 2.53     | 7.27     |
| \( x_{12} \)  | Rate of stock-out error/\% | 0.03    | 0.02     | 0.05     | 0.01     | 0.02     |
| \( x_{13} \)  | Consumer Satisfaction/\% | 95.74   | 99       | 94.17    | 97.2     | 98.33    |
| \( x_{14} \)  | middle and senior manager/\% | 12.7    | 15.7     | 80       | 4        | 19.35    |
| \( x_{15} \)  | General logistics practitioner/\% | 73.02   | 60.8     | 88       | 92.45    | 90.3     |

Using the formula mentioned above, Python3.6 is adopted to obtain the final combination weights as follows:
Table 3. Weights of index system.

| $w_i$ | $p_i$ | $c_j$ | $d_j$ | $w_i^*$ |
|-------|-------|-------|-------|---------|
| 0.3320 | 0.2857 | 0.0948 | 0.0460 | 0.0786 |
| 0.5153 | 0.1711 | 0.0479 | 0.1302 |
| 0.1225 | 0.0407 | 0.1234 | 0.0682 |
| 0.0765 | 0.0254 | 0.0555 | 0.0354 |
| 0.2043 | 0.4738 | 0.0968 | 0.0789 |
| 0.0864 | 0.0177 | 0.0836 | 0.0396 |
| 0.2994 | 0.0612 | 0.1063 | 0.0762 |
| 0.1405 | 0.0287 | 0.0463 | 0.0445 |
| 0.2191 | 0.6370 | 0.1395 | 0.1124 |
| 0.2583 | 0.0566 | 0.0447 | 0.0527 |
| 0.1047 | 0.0229 | 0.0434 | 0.0297 |
| 0.1541 | 0.2000 | 0.1233 | 0.1002 |
| 0.0905 | 0.0700 | 0.0603 | 0.0789 |
| 0.3333 | 0.0302 | 0.0502 | 0.0369 |

According to Table 2, the evaluation matrix is as follow:

$$
\begin{bmatrix}
0.016 & 0.676 & 0.597 & 0.771 & 0.976 & -0.047 & 0.053 & 0.626 & 0.260 & 0.019 & 0.207 & -0.167 & -0.422 & -0.254 & -0.392 \\
-0.065 & 0.341 & 1.000 & -0.479 & -0.240 & -0.109 & -0.263 & -0.123 & 0.260 & 0.278 & -0.081 & 0.250 & 0.777 & -0.199 & -1.000 \\
0.327 & 0.259 & -0.603 & 0.146 & 0.998 & 1.000 & 1.000 & 0.476 & -0.504 & 0.684 & 0.422 & -1.000 & -1.000 & 1.000 & 0.352 \\
0.722 & -0.277 & -0.375 & 0.563 & -1.000 & -0.293 & -0.316 & 0.021 & 0.984 & -1.000 & -1.000 & 0.667 & 0.115 & -0.417 & 0.574 \\
-1.000 & -1.000 & -0.618 & -1.000 & -0.734 & -0.551 & -0.474 & -1.000 & -1.000 & 0.019 & 0.452 & 0.250 & 0.531 & -0.130 & 0.467 
\end{bmatrix}
$$

The reference points of the value function are selected as follows:

$$Z^+ = (0.72, 0.34, 1.00, 0.56, 1.00, 1.00, 0.48, 0.98, 0.68, 0.45, 0.67, 0.78, 1.00, 0.57)$$

$$Z^- = (-1.00, -1.00, -0.62, -1.00, -1.00, -0.55, -0.47, -1.00, -1.00, -1.00, -1.00, -1.00, -0.42, -1.00)$$

The positive and negative prospect matrix of each index of the pharmaceutical logistics center obtained by using the formula (17) are as follows:

$$
\begin{bmatrix}
1.014 & 1.576 & 1.187 & 1.653 & 1.821 & 0.548 & 0.568 & 1.534 & 1.225 & 1.017 & 1.180 & 0.852 & 0.617 & 0.202 & 0.645 \\
0.943 & 1.295 & 1.527 & 0.563 & 0.785 & 0.488 & 0.254 & 0.891 & 1.225 & 1.241 & 0.928 & 1.217 & 1.659 & 0.262 & 0.000 \\
1.282 & 1.225 & 0.024 & 1.127 & 1.838 & 1.472 & 1.407 & 1.408 & 0.540 & 1.582 & 1.365 & 0.000 & 0.000 & 1.359 & 1.304 \\
1.613 & 0.752 & 0.288 & 1.481 & 0.000 & 0.304 & 0.197 & 1.018 & 1.828 & 0.000 & 0.000 & 1.568 & 1.100 & 0.000 & 1.490 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.312 & 0.000 & 0.000 & 0.000 & 1.017 & 1.389 & 1.217 & 1.454 & 0.332 & 1.401 \\
-1.655 & 0.000 & -1.012 & 0.000 & -0.075 & -2.343 & -2.145 & 0.000 & -1.694 & -1.571 & -0.653 & -1.916 & -2.640 & -2.747 & -2.183 \\
-1.820 & -0.859 & 0.000 & -2.738 & -2.715 & -2.464 & -2.764 & -1.745 & -1.694 & -1.018 & -1.293 & -1.041 & 0.000 & -2.639 & -3.353 \\
-0.993 & -1.043 & -3.409 & -1.488 & 0.000 & 0.000 & 0.000 & -0.425 & -3.192 & 0.000 & -0.105 & -3.527 & -3.732 & 0.000 & -0.597 \\
0.000 & -2.158 & -2.978 & -0.566 & -4.136 & -2.821 & -2.865 & -1.446 & 0.000 & -3.559 & -3.124 & 0.000 & -1.566 & -3.057 & 0.000 \\
-3.620 & -3.545 & -3.436 & -3.720 & -3.647 & -3.312 & -3.165 & -3.452 & -4.112 & -1.571 & 0.000 & -1.041 & -0.656 & -2.506 & -0.315 
\end{bmatrix}
$$

The comprehensive prospect value of each pharmaceutical logistics center is as follows:

$$V = (V_1, V_2, V_3, V_4, V_5) = (-0.352, -0.637, -0.376, -1.039, -2.056)$$

So,

$$V_{max} = \max(V_1, V_2, V_3, V_4, V_5) = V_1 = -0.352$$
5. Results and discussions

5.1. Analysis of the evaluation results

The five pharmaceutical logistics centers are ranked as N1 > N2 > N3 > N4 > N5, according to the comprehensive prospect value. It is obvious that N1 has the strongest competitiveness and N5 is the worst. In addition, the comprehensive prospects of the five pharmaceutical logistics centers are all negative, which indicates that there is a great room for improvement of their overall competitiveness. In particular, N5 urgently need to fully enhance their competitiveness.

The comprehensive prospect value matrix of the index of medical logistics centers using formula (19) is as follow:

\[
V = \begin{bmatrix}
-0.048 & 0.151 & 0.005 & 0.049 & 0.121 & -0.065 & -0.105 & 0.045 & -0.054 & -0.029 & 0.012 & -0.036 & -0.174 & -0.172 & -0.052 \\
-0.064 & 0.033 & 0.083 & -0.070 & -0.153 & -0.071 & -0.164 & -0.028 & -0.054 & 0.006 & -0.011 & 0.003 & 0.126 & -0.161 & -0.111 \\
0.012 & 0.007 & -0.199 & -0.014 & 0.128 & 0.049 & 0.084 & 0.028 & -0.251 & 0.068 & 0.032 & -0.114 & -0.312 & 0.084 & 0.021 \\
0.099 & -0.157 & -0.159 & 0.026 & -0.316 & -0.090 & -0.174 & -0.015 & 0.154 & -0.164 & -0.084 & 0.047 & -0.047 & -0.205 & 0.046 \\
-0.243 & -0.375 & -0.202 & -0.119 & -0.257 & -0.117 & -0.206 & -0.107 & -0.381 & -0.029 & 0.035 & 0.003 & 0.056 & -0.148 & 0.033
\end{bmatrix}
\]

Figure 1. Comprehensive prospect values radar map of evaluation index.

The radar map drawn by \( V \) is shown in Figure 1. The analysis shows that: the comprehensive prospect values of all indicators in N1 is relatively large, and the overall competitiveness is the strongest. However, the comprehensive prospect values of \( x_{i1}, x_{i3} \) and \( x_{i5} \) are -0.174, -0.172 and -0.052 respectively, which are all at a low level. Therefore, N1 should comprehensively strengthen the introduction of high-quality talents, strictly enforce the operation process, and strive to improve customer satisfaction. For N2, the comprehensive prospect values of \( x_{i1} \) and \( x_{i4} \) are -0.011 and -0.111, N2 should speed up the introduction and use of advanced information technology systems and equipment, raise the threshold for employees, and strengthen personnel training. For N3, the comprehensive prospect values of \( x_{i1}, x_{i5} \) and \( x_{i13} \) are -0.199, -0.251 and -0.312 respectively. Therefore, N3 should strictly implement quality management requirements, improve the operational efficiency of equipment and facilities, promote cost reduction and improve service level. \( x_{i2}, x_{i5}, x_{i10}, x_{i11} \) and \( x_{i4} \) of N4 are far lower than those of other centers. N4 should give full play to the advantages of assets and management system, actively explore the market, expand the storage area, accelerate the construction of information technology, improve all kinds of safety emergency plans, broaden the channels for talent introduction, and attract high-quality management personnel. Except that the level of informatization is slightly better than others, the
comprehensive prospects of the other indicators in $N_i$ are at a low level, especially for $x_i$, $x_2$, $x_3$, $x_4$, $x_6$ and $x_8$. Therefore, pharmaceutical logistics enterprises can consider gradually withdrawing $N_5$ from the market and integrating resources for the development and construction of several other centers.

5.2. Comparison of evaluation results
The evaluation result in this paper is compared with those of traditional evaluation methods such as AHP, Entropy weight method, TOPSIS and AHP-TOPSIS, as shown in Table 4.

Table 4. Comparison of evaluation results.

| Methods                        | Evaluation results |
|-------------------------------|--------------------|
| AHP                           | $N_i > N_2 > N_3 > N_4 > N_5$ |
| Entropy weight method         | $N_1 > N_i > N_2 > N_3 > N_5$ |
| TOPSIS                        | $N_1 > N_2 > N_3 > N_4 > N_5$ |
| AHP-TOPSIS                    | $N_1 > N_2 > N_3 > N_4 > N_5$ |
| Combined Weight and Cumulative Prospect Theory | $N_1 > N_2 > N_3 > N_4 > N_5$ |

Except that the results of AHP and AHP-TOPSIS are consistent, the results of other evaluation methods are different. AHP and entropy weight method rely too much on expert experience and differences of objective value of indicators when calculating weights, and neither consider the risk psychology of the decision makers. TOPSIS ignores the index weight. Although AHP-TOPSIS considers the index weight and the deviation degree from the ideal solution, it still ignores the risk attitude of decision makers.

The comprehensive evaluation method of this paper not only reflects the expert experience but also the objective data information of each index in the combination of subjective and objective weights. The most important is to introduce the cumulative prospect theory considering the decision maker when facing gains and losses of risk attitudes. It is different from the absolute optimum concept of traditional methods.

6. Conclusion
Because of uncertainty and information asymmetry, it is often difficult for decision makers to have a comprehensive understanding of the competitiveness of pharmaceutical logistics centers, especially when making major decisions, they are sensitive to risk losses. Therefore, this paper proposes a comprehensive evaluation model based on cumulative prospect theory, which fully considers the risk attitudes of decision makers in the face of gains and losses. In addition, the combination weighting method based on game theory is used to determine the weights of indicators, taking into account both expert experience and objective data information. Finally, the case analysis shows that the model has practical significance.

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