Decision making method of human resource demand selection in cloud manufacturing environment

Baozhong Ye¹, Jian Chen¹* and Jing Zhao¹

¹School of management, Guilin University of Aerospace Technology, Guilin, Guangxi, 541004, China
*Corresponding author’s e-mail: chenjian@guat.edu.cn

Abstract. In order to solve the problem of human resource selection of demander for provider in cloud manufacturing environment, this paper proposes a selection decision method from the perspective of provider. Firstly, the evaluation index system of demander is established, and the objective weight of each index is obtained by entropy weight method according to the demander's demand information. Secondly, the subjective weight of each index is determined by improved AHP method and the comprehensive weight of each index is obtained by combining the subjective and objective weight. Then, the traditional TOPSIS method is improved to evaluate the demander and provide reference for the selection of supplier. Finally, an example is given to verify the effectiveness and practicability of the method.

1. Introduction
The development of manufacturing industry carries a big weight in comprehensive national strength and international market competitiveness of a country. In recent years, the manufacturing industry of China has developed rapidly. In order to consolidate and enhance the competitiveness of Chinese manufacturing industry, the transformation from a big manufacturing country to a powerful one is the basic way. On the foundation of advanced manufacturing models such as information manufacturing, grid manufacturing, and intelligent manufacturing, Academician Li Bohu[1] creatively proposed a new service manufacturing model—cloud manufacturing, which improves the manufacturing efficiency by making full use of the network and cloud manufacturing platform to provide manufacturing users with timely required manufacturing services through the operating mechanism of centralizing decentralized manufacturing resources and then dispersing to achieve effective sharing and optimize the allocation of manufacturing resources.

Vahideh Hayyolalam[2] has made a systematic study of service composition and selection optimizing in cloud manufacturing environment; Jafarnejad Ghomi[3] has established a new queuing network for parallel scheduling of multi-process customer orders; Jalal Delaram[4] has proposed the basic model of the task scheduling problem of cloud manufacturing system to solve the problem of operation sharing and logistics sharing in cloud manufacturing system; Yanjuan Hu[5] analyzed and solved the optimization decision-making problem of cloud manufacturing environment based on gray correlation analysis and TOPSIS method; Qi Chen[6] has explored the dynamic matching of resources in a manufacturing supply chain consisting of two independent and competing manufacturers and a resource service platform; Li Hai[7], Gong Xiaorong[8] and Yin Chao[9] have given the selecting method of machine tool equipment resources in the cloud manufacturing environment; Cheng Yuan[10] discussed the optimization of 3D printing equipment in cloud environment; Wang Xiaoyan[11] studied the service matching method of CNC equipment.
resources; Zhou Shulin[12], Wang Weixing[13] and Yi Anbin[14] discussed the service packaging method of equipment resources in cloud environment.

The above literatures have done in-depth analysis and research on cloud manufacturing and its resources and achieved important research results. Generally speaking, it mainly focuses on the research of hard resources such as machinery, machine tools and equipment at present, while the discussion of soft resources such as human resources is rare; in terms of the selection of suppliers and demanders, it also concentrates on the selection of suppliers by demanders. As the most important manufacturing resource in cloud manufacturing environment, compared with other resources, human resources has the independent characteristics such as multi-functionality, service flexibility and so on. In addition, human resource provider is an indispensable part of the cloud manufacturing mode. In the cloud environment with highly shared resources, high quality human resource provider is often favored by the demanders, so it is an objective situation that the provider faces the needs of multiple demanders at the same time. At this time, how to choose the best demander is an urgent problem to be solved for the supplier. This paper is based on this situation and from the perspective of the provider, according to the establishment of the demander’s evaluation index system and combining with the corresponding model and algorithm to evaluate the demander, which can provide the basis for the selection decision.

2. Evaluation of human resources needs and description of problem

2.1. Characteristics of human resources

Among all cloud manufacturing resources, human resources has the following independent characteristics:

1. Multi-functionality: In the process of service, hard resources only have relatively fixed functional structure attributes, however, human resources have multiple functions.
2. Flexibility: Human resource can respond flexibly according to the specific situation to ensure the effective service process while hard resources are difficult to achieve in the process of supply and demand services.
3. Non depreciation: The use of hard resources will involve depreciation, aging and other issues, but there is no such situation in human resources, and with the accumulation of experience and the growth of relevant knowledge, human resources also has value-added effect.

2.2. Principle of evaluation index selection

In the cloud manufacturing environment, when the human resource provider makes a choice decision to the demander, it needs to have reasonable evaluation index to evaluate the demander, therefore, the selection of index plays an important role. Based on the previous research, consulting and summarizing the relevant literature, we can obtain the following selection principles of evaluation index:

1. Principle of comprehensiveness: Index is to let the supplier make the best decision, so it should be able to make a comprehensive description of the demander as a whole.
2. Principle of operability: It is necessary to collect and process the corresponding index data when evaluating the demander, so the operability principle should be considered in the selection of index.
3. Principle of comparability: It means that the evaluated objects can compare with each other according to the evaluation index.

2.3. Construction of evaluation index system

Based on the selection principle of indicator above and combined with the characteristics of human resource supplier and demander, the evaluation index system of human resource demander is constructed by means of QoS (quality of service)[15] evaluation technology as follows.
Figure 1. Demand side evaluation index system

1. Demand dimension: Offered price ($p_1$) refers to the remuneration that the human resource demander is willing to pay for the provider; demanded time ($p_2$) means the time cycle from the beginning to the end of the service proposed by the demander; demanded quality ($p_3$) represents the quality requirement of the demander for the service. These three index values can be obtained from the demand information.

2. Enterprise dimension: Current situation ($p_5$) refers to the present business situation of the demander; potential demand ($p_6$) means the need of the same type of resource and service in the future development process of the demander. These two index values can be given by the cloud platform experts.

3. Moral dimension: Security degree ($p_7$) refers to the extent of security protection of the human resource demander to the relevant important information of the provider; reputation degree ($p_8$) means the reliability of the demander to the determined supply and demand service; settlement speed ($p_9$) represents the speed at which the demander pays the supplier. Assuming that the total number of supply and demand services traded between a demander and corresponding suppliers is $k$, in which there are $a$ times of leakage of suppliers’ important information, $b$ breaches of contract, and as the $ith$ ($i=1st, 2nd, \ldots, nth$) transaction, the payment is $c_i$ yuan, the time interval of account settlement is $d_i$ days, then $p_6 = \frac{k-a}{k}p_7 = \frac{k-b}{k}$, $p_8 = \frac{\sum_{i=1}^{k} c_i}{k}$.

Different indicators have different attribute trends, which can be divided into positive and negative types. From the perspective of human resource provider, the classification of each evaluation index is as follows.

| Index name     | Index type |
|----------------|------------|
| Offered price  | Positive   |
| Demand period  | Negative   |
| Demand quality | Negative   |
| Current situation | Positive |
Potential demand $p_S$ Positive
Security degree $p_6$ Positive
Reputation degree $p_7$ Positive
Settlement speed $p_8$ Positive

Among them, $p_4$ and $p_5$ are linguistic variables, the following linguistic evaluation set is used in this paper.

| Evaluating language variables | Triangular fuzzy number $(a^l, a^m, a^n)$ |
|-------------------------------|------------------------------------------|
| Extremely bad                 | $(0, 0, 0.1)$                             |
| Very bad                      | $(0, 0.1, 0.3)$                           |
| Bad                           | $(0.1, 0.3, 0.5)$                         |
| Common                        | $(0.3, 0.5, 0.7)$                         |
| Good                          | $(0.5, 0.7, 0.9)$                         |
| Very good                     | $(0.7, 0.9, 1)$                           |
| Extremely good                | $(0.9, 1, 1)$                             |

Assuming that the set of experts is $D = \{D_1, D_2, ..., D_c\}$ and the weight set of experts is $H = \{h_1, h_2, ..., h_c\}$, $\Sigma_{e=1}^{c} h_e = 1$, $\ p_4 = \Sigma_{e=1}^{c} h_e^4 \times \left(\frac{a_1+2a_2+a_3}{4}\right)$, $\ p_5 = \Sigma_{e=1}^{c} h_e^5 \times \left(\frac{a_1^2+2a_2^2+a_3^2}{4}\right)$. In the formula, $h_e^i$ represents the weight of expert $e$ when evaluating index $i$.

2.4. Description of the problem

Definition 1 The evaluation model of human resource demander is $r = \{p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8\}$

Definition 2 The demander of human resource set is $R = \{r_1, r_2, ..., r_n\}$

Definition 3 The attribute set of human resource demander is

$R = \begin{bmatrix}
    r_1 & p_{11} & p_{12} & \cdots & p_{1n} \\
    r_2 & p_{21} & p_{22} & \cdots & p_{2n} \\
    \vdots & \vdots & \vdots & \ddots & \vdots \\
    r_n & p_{n1} & p_{n2} & \cdots & p_{nn}
\end{bmatrix}$

The problem to be solved in this paper is that how to make decision of choosing the best demander scientifically for human resource supplier according to the index attribute set.

3. Selecting model and method

3.1. Entropy weight method to determine the objective weight of evaluation index

In this paper, entropy weight method[16] is used to determine the objective weight of each evaluation index, the specific steps are as follows.

1. Assuming that the number of evaluation objects and evaluation indexes are $m$ and $n$ respectively, according to the specific index information of each evaluation object, the following initial matrix $T$ can be obtained.

$$ T = \begin{bmatrix}
    t_{11} & t_{12} & \cdots & t_{1n} \\
    t_{21} & t_{22} & \cdots & t_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    t_{m1} & t_{m2} & \cdots & t_{mn}
\end{bmatrix} $$

2. The following two formulas are used to standardize the evaluation indexes.
In the two formulas, \( \max t_j, \min t_j \) represent the maximum and minimum values of the indicators in column J of the indicator attribute set. For the positive index, the formula (1) is used for standardizing, and for the negative, the formula (2) is used, then \( R = (r_{ij})_{m \times n} \) is obtained.

3. According to the following formula, the information entropy of index can be calculated.

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

There are some disadvantages in the traditional entropy weight method, that is \( p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \), and when \( p_{ij} = 0, p_{ij} \ln p_{ij} = 0 \), therefore, in order to overcome the limitations, this paper adopts the following improved formula.

\[
p_{ij} = \frac{r_{ij}+1}{\sum_{i=1}^{m} (r_{ij}+1)}
\]

4. Calculate the coefficient of variation of each index \( d_j \) according to the following formula.

\[
d_j = 1 - e_j
\]

5. Calculate the entropy weight of each index, as known as objective weight.

\[
L_j = \frac{d_j}{\sum_{j=1}^{n} d_j}
\]

3.2. Improving AHP method to determine subjective weight of evaluation index

Considering that the traditional AHP method uses 1-9 scale to compare each index to construct the judgment matrix has some limitations that the concept of 1-9 scale is not completely specific and has certain fuzziness, but the subjective judgment of experts dominates the determination of the specific scale value, so it is easy to make the results deviate from the reality to a certain extent [17]. Besides, the traditional AHP method needs consistency test. If the test fails, the judgment matrix has a lack of consistency, now it will destroy the priority function of AHP method, and it’s necessary to reconstruct the judgment matrix, which is against the original intention of experts and has a large amount of calculation work. Therefore, this paper uses the three-level scaling method to construct the comparison matrix by pairwise comparison so as to avoid the fuzziness of 1-9 scale to realize the improvement of AHP method. More than this, the calculation results do not need to be checked for consistency, which can reduce the calculation workload and improve the accuracy[18]. The specific steps of it are as follows.

1. According to the three scales adopted by the improved AHP method (as shown in the table below)

| Scale value | Implication                        |
|-------------|------------------------------------|
| 0           | Evaluation index 1 is less important than 2 |
| 1           | Evaluation index 1 and 2 are equally important |
| 2           | Evaluation index 1 is more important than 2 |

The comparison matrix \( A \) is constructed by pairwise comparison of each evaluation index, as shown below (assume the number of indexes is \( n \)).
2. Calculate the importance ranking index $r_i$.

$$r_i = \sum_{j=1}^{n} a_{ij}$$  \hspace{1cm} (7)

3. Construct judgment matrix $B$ and each element $b_{ij}$ is solved by the following formula.

$$b_{ij} = \begin{cases} \left( \frac{r_i - r_j}{r_{\text{max}} - r_{\text{min}}} \right) + 1 & r_i \geq r_j \\ \left( \frac{r_j - r_i}{r_{\text{max}} - r_{\text{min}}} \right)^{-1} + 1 & r_i < r_j \end{cases}$$  \hspace{1cm} (8)

Among them, $r_{\text{max}} = \max\{r_i\}, r_{\text{min}} = \min\{r_i\}.$

4. Find the transfer matrix $C$ of judgment matrix $B$, the elements $c_{ij}$ in $C$ are determined by the following formula.

$$c_{ij} = \log b_{ij}$$  \hspace{1cm} (9)

5. Find the optimal transfer matrix $D$ of transfer matrix $C$, and use the following formula to determine the element $d_{ij}$ in matrix $D$.

$$d_{ij} = \frac{1}{n} \sum_{k=1}^{n} (c_{ik} - c_{jk})$$  \hspace{1cm} (10)

6. Find the quasi optimal consistency matrix $B'$ of $B$, the elements of the matrix $B'$ are $b'_{ij}$.

$$b'_{ij} = 10^{d_{ij}}$$  \hspace{1cm} (11)

7. Find the product $N_i$ of elements in each row in $B'$.

$$N_i = \prod_{j=1}^{n} b'_{ij}$$  \hspace{1cm} (12)

8. Find the square root $\overline{U}_i$.

$$\overline{U}_i = \sqrt[\text{row}]{N_i}$$  \hspace{1cm} (13)

9. Find subjective weight of each index $U_i$ by normalizing $\overline{U}_i$.

$$U_i = \frac{\overline{U}_i}{\sum_{i=1}^{\text{row}} \overline{U}_i}$$  \hspace{1cm} (14)

### 3.3. Determination of comprehensive weight of evaluation index

The objective weight of each evaluation index obtained by entropy weight method is denoted by $L = (l_1, l_2, \ldots, l_n)$, the subjective weight of each evaluation index obtained by the improved AHP method is denoted by $U = (u_1, u_2, \ldots, u_n)$. Using the formula

$$W = w_j = \frac{l_j \times u_j}{\sum_{j=1}^{n} l_j \times u_j}$$  \hspace{1cm} (15)

to get the comprehensive weight of each evaluation index.

### 3.4. Evaluation and selection based on improved TOPSIS

After getting the comprehensive weight of evaluation index, it can make up for the lack of empowerment of TOPSIS method and help to solve the problem of evaluation and decision-making. But the traditional TOPSIS method has some limitations: It is easy to affect the scientificity of the evaluation results in the process of obtaining and calculating the index data because of the linear correlation between the indexes[19]. In the face of this problem, Li Hua[20] tried to introduce Mahalanobis distance to solve it, but the application of Mahalanobis distance needs to meet a prerequisite that the number of evaluation indexes should be less than the number of evaluation objects, however, this condition can not be satisfied in many decision-making problems, including the decision-making situation involved in this paper. In view of this, this paper improves the TOPSIS method to make up for its shortcomings by introducing the cosine of the angle between vectors and calculating it between two vectors to measure the correlation through constructing the spatial
eigenvector from the corresponding data information.

Here is the basic idea of the improved TOPSIS method: Combining with the weight of the evaluation index, the decision matrix is weighted and normalized, from which the positive and negative ideal solutions can be found to obtain the optimal and worst evaluation objects, after this, calculating the cosine distance of the vector angle between each evaluation object and the optimal and worst evaluation objects respectively, and then the closeness of the evaluation object is obtained, so as to make the selection decision. The cosine of the angle between vectors is the generalization of cosine theorem in multi-dimensional space. It uses relevant data information to construct eigenvectors in space, and measures the degree of correlation by calculating the cosine of the angle between two vectors [21]. The details are as follows: The eigenvector composed of the space points determined by the indexes of the evaluation object pointed from the origin is regarded as alternative vector, and is recorded as $\overrightarrow{D_1}$, the eigenvectors formed by the origin pointing to the positive and negative ideal solutions are regarded as ideal vectors, which are respectively recorded as $\overrightarrow{D^+}, \overrightarrow{D^-}$. Thus, the distance between the evaluation object and the ideal solution calculated in the traditional TOPSIS method is transformed to the cosine value between the candidate vector and the ideal vector representing the evaluation object, which avoids the linear correlation problem and solves the limitation of using Mahalanobis distance. Here is an example of a three-dimensional spatial illustration between an alternative vector in three-dimensional space $\overrightarrow{D_1}$ and the optimal ideal vector $\overrightarrow{D^+}$.

![Figure 2. Cosine distance of vector angle](image)

In the illustration, the cosine distance of vector angle is determined by the formula $\text{sim}(\overrightarrow{D_1}, \overrightarrow{D^+}) = \cos \theta = \frac{\overrightarrow{D_1} \cdot \overrightarrow{D^+}}{||\overrightarrow{D_1}|| \cdot ||\overrightarrow{D^+}||}$. In the formula, $\overrightarrow{D_1}$ vector is the alternative vector, $\overrightarrow{D^+}$ vector is the optimal ideal vector, $\theta$ is the spatial angle between $\overrightarrow{D_1}$ and $\overrightarrow{D^+}$, $\text{sim}(\overrightarrow{D_1}, \overrightarrow{D^+})$ is the cosine distance of the vector angle between them. $||\overrightarrow{D_1}||$ and $||\overrightarrow{D^+}||$ denote the module of two vectors respectively. In the same way, the vector angle cosine distance between $\overrightarrow{D_1}$ and the worst ideal vector $\overrightarrow{D^-}$ can be calculated. The specific steps for applying the improved TOPSIS method are as follows.

1. Constructing initial matrix. Assuming the number of evaluation objects is $m$ and the number of evaluation indexes is $n$, then constructing the following initial matrix (In this paper, $n=8$).

\[
R = \begin{bmatrix}
r_1 \\
r_2 \\
\vdots \\
r_m
\end{bmatrix} = \begin{bmatrix}
p_{11} & p_{12} & \cdots & p_{18} \\
p_{21} & p_{22} & \cdots & p_{28} \\
\vdots & \vdots & \ddots & \vdots \\
p_{m1} & p_{m2} & \cdots & p_{m8}
\end{bmatrix}
\]

2. In order to eliminate the different dimensions of evaluation indexes, It is necessary to synchronize the indicators. In this paper, the reciprocal method is adopted, according to the formula

\[
p'_{ij} = \frac{1}{p_{ij}}
\]  \hspace{1cm} (16)

we can get
\[ R' = \begin{bmatrix} r'_1 \\ r'_2 \\ \vdots \\ r'_m \end{bmatrix} = \begin{bmatrix} p'_1 \\ p'_2 \\ \vdots \\ p'_m \end{bmatrix} \]

Since most own to make them have the same trend as the positive ones.

3. After synchrof the evaluation indexes in this article are positive, when synchronizing, the negative ones will be counted dionizing, according to the following formula to standardize the data

\[ p_{ij}^* = \frac{p_{ij}}{\sum_{i=1}^{m}(p_{ij})} \]  

and obtain

\[ R^* = \begin{bmatrix} r'_1 \\ r'_2 \\ \vdots \\ r'_m \end{bmatrix} = \begin{bmatrix} p'_1 \\ p'_2 \\ \vdots \\ p'_m \end{bmatrix} \]

4. Establishing the weighted normalization ma trix. Combining the comprehensive weight \( w_j \) of each evaluation index to obtain the weighted normalization matrix according to the following.

\[ D = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{18} \\ d_{21} & d_{22} & \cdots & d_{28} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m1} & d_{m2} & \cdots & d_{m8} \end{bmatrix} = \begin{bmatrix} w_1p_{11} & w_2p_{12} & \cdots & w_8p_{18} \\ w_1p_{21} & w_2p_{22} & \cdots & w_8p_{28} \\ \vdots & \vdots & \ddots & \vdots \\ w_1p_{m1} & w_2p_{m2} & \cdots & w_8p_{m8} \end{bmatrix} \]

5. Determining the optimal and worst evaluation objects.

Optimal evaluation object \( \overrightarrow{D^+} = (d^+_{i1}, d^+_{i2}, \ldots, d^+_{i8}) \)

Worst evaluation object \( \overrightarrow{D^-} = (d^-_{i1}, d^-_{i2}, \ldots, d^-_{i8}) \)

In the two formulas above, \( d^+_{ij} \) and \( d^-_{ij} \) respectively represent the maximum and minimum values of each evaluation index column in the weighted normalization matrix.

6. Calculating the cosine distance of vector angle from the evaluation object to the optimal and worst evaluation object according to the following formulas.

\[ \text{sim}_i^+ (\overrightarrow{D_i}, \overrightarrow{D^+}) = \cos \theta = \frac{\overrightarrow{D_i} \cdot \overrightarrow{D^+}}{\|\overrightarrow{D_i}\|\|\overrightarrow{D^+}\|} \]

\[ \text{sim}_i^- (\overrightarrow{D_i}, \overrightarrow{D^-}) = \cos \theta = \frac{\overrightarrow{D_i} \cdot \overrightarrow{D^-}}{\|\overrightarrow{D_i}\|\|\overrightarrow{D^-}\|} \]

7. Calculating the closeness from the following formula and make a choice.

\[ C_i^* = \frac{|\text{sim}_i^+|}{|\text{sim}_i^+| + |\text{sim}_i^-|} \]

At this time, the value of closeness \( C_i^* \) is between 0 and 1, the closer \( C_i^* \) is to 1, the closer the evaluation object is to the optimal level; the closer \( C_i^* \) is to 0, the closer the evaluation object is to the worst level, therefore, the side with the largest \( C_i^* \) value is selected.

4. Example verification and analysis

In this paper, a car enterprise F is taken as an example. Supposing car enterprise F has first-class production capacity, it also has idle period under the premise of meeting the production needs of itself. In order to make full use of its advantages to obtain more benefits, it provides corresponding production and supply service in the cloud platform. Assuming the supply service of F is selected by the demand-side enterprises A, B, C, D, E at the same time, all five demander enterprises hope that F can provide their own corresponding service, and through different data collection channels such as telephone consultation, network search and expert evaluation in related fields, demand information of the five enterprises are obtained as follows. In the table below, the unit of offered price is RMB 10,000 and the unit of demand time is day(s).
Table 4. Demand information of demander

| Demander | Offered price | Demand period | Demand quality | Current situation | Potential demand | Security degree | Reputation degree | Settlement speed |
|----------|---------------|---------------|----------------|------------------|------------------|-----------------|------------------|-----------------|
| A        | 65            | 23            | 0.85           | 0.57             | 0.68             | 0.77            | 0.84             | 2700            |
| B        | 54            | 18            | 0.89           | 0.62             | 0.64             | 0.82            | 0.87             | 2500            |
| C        | 68            | 25            | 0.78           | 0.77             | 0.72             | 0.91            | 0.91             | 3200            |
| D        | 57            | 17            | 0.74           | 0.73             | 0.53             | 0.92            | 0.78             | 2800            |
| E        | 60            | 20            | 0.81           | 0.82             | 0.58             | 0.68            | 0.85             | 2200            |

In order to let F choose the best demand-side enterprise from the five ones, the following analysis and decision are made.

4.1. Determination of objective weight of evaluation index

For the demand information of five demand enterprises, the following table is standardized by Formula (1) and (2),

Table 5. Demand information of demander after standardization

| Demander | Offered price | Demand period | Demand quality | Current situation | Potential demand | Security degree | Reputation degree | Settlement speed |
|----------|---------------|---------------|----------------|------------------|------------------|-----------------|------------------|-----------------|
| A        | 0.786         | 0.250         | 0.267          | 0.000            | 0.789            | 0.375           | 0.462            | 0.500           |
| B        | 0.000         | 0.875         | 0.000          | 0.200            | 0.579            | 0.583           | 0.692            | 0.300           |
| C        | 1.000         | 0.000         | 0.733          | 0.800            | 1.000            | 0.958           | 1.000            | 1.000           |
| D        | 0.214         | 1.000         | 1.000          | 0.640            | 0.000            | 1.000           | 0.000            | 0.600           |
| E        | 0.429         | 0.625         | 0.533          | 1.000            | 0.263            | 0.000           | 0.538            | 0.000           |

The objective weight vector \( L \) of each index calculated from the formula (3) ~ (6) is

\[
L = (0.135, 0.135, 0.135, 0.135, 0.135, 0.135, 0.135, 0.135)^T
\]

4.2. Determination of subjective weight of evaluation index

According to the evaluation index system shown in Figure 1, relevant experts are invited to compare each dimension of the index system between each other to determine their relative importance, and the comparison matrix \( A \) is obtained as follows.

\[
A = \begin{bmatrix}
0 & 1 & 1 \\
2 & 0 & 0 \\
1 & 2 & 1
\end{bmatrix}
\]

Weight vectors for each dimension can be derived from the formulas (7) ~ (14).

\[
U_w = (0.444, 0.444, 0.444)^T
\]

Similarly, the weights of each index under each dimension are compared to construct comparison matrices. The comparison matrices of indexes under demand dimension, enterprise dimension and moral dimension are as follows.

\[
\text{Demand dimension} A_c = \begin{bmatrix}
1 & 0 & 0 \\
2 & 1 & 0 \\
2 & 2 & 1
\end{bmatrix}
\]

\[
\text{Enterprise dimension} A_q = \begin{bmatrix}
1 & 1 \\
1 & 1 \\
1 & 2 \\
0 & 2 \\
0 & 0 & 1
\end{bmatrix}
\]

And the weights are calculated from the formulas (7) ~ (14).

\[
\text{Demand dimension} A_c = (0.105, 0.258, 0.637)^T
\]

\[
\text{Enterprise dimension} A_q = (0.500, 0.500)^T
\]

\[
\text{Moral dimension} A_f = (0.637, 0.258, 0.105)^T
\]

Hence, the subjective weight vector \( U \) of each evaluation index relative to the total evaluation objective is

\[
U = (0.047, 0.114, 0.283, 0.056, 0.056, 0.283, 0.114, 0.047)^T
\]
4.3. Determination of comprehensive weight of evaluation index
Based on the above, the comprehensive weight vector $W$ of each evaluation index is obtained from formula (15).

$$W = (0.051, 0.124, 0.276, 0.062, 0.057, 0.293, 0.095, 0.042)^T$$

4.4. Evaluation and selection based on improved TOPSIS
The supply information of each demander is processed by formulae (16) and (17) with synchronization and standardization and we get the following table.

Table 6. Demand information of demander after synchronization and standardization

| Demander | Offered price | Demand period | Demand quality | Current situation | Potential demand | Security degree | Reputation degree | Settlement speed |
|----------|---------------|---------------|----------------|------------------|------------------|----------------|------------------|-----------------|
| A        | 0.476         | 0.388         | 0.426          | 0.360            | 0.480            | 0.417          | 0.441            | 0.447           |
| B        | 0.396         | 0.496         | 0.406          | 0.392            | 0.452            | 0.445          | 0.457            | 0.414           |
| C        | 0.498         | 0.357         | 0.464          | 0.486            | 0.508            | 0.493          | 0.478            | 0.530           |
| D        | 0.418         | 0.525         | 0.489          | 0.461            | 0.374            | 0.499          | 0.410            | 0.464           |
| E        | 0.440         | 0.447         | 0.447          | 0.518            | 0.409            | 0.369          | 0.447            | 0.364           |

Combine the comprehensive weight of each evaluation index, the weighted normalized matrix table is constructed by formula (18).

Table 7. Weighted normalized matrix table of demander's demand information

| Demander | Offered price | Demand period | Demand quality | Current situation | Potential demand | Security degree | Reputation degree | Settlement speed |
|----------|---------------|---------------|----------------|------------------|------------------|----------------|------------------|-----------------|
| A        | 0.024         | 0.048         | 0.117          | 0.022            | 0.027            | 0.122          | 0.042            | 0.019           |
| B        | 0.020         | 0.062         | 0.112          | 0.024            | 0.026            | 0.130          | 0.043            | 0.017           |
| C        | 0.025         | 0.044         | 0.128          | 0.030            | 0.029            | 0.145          | 0.045            | 0.022           |
| D        | 0.021         | 0.065         | 0.135          | 0.029            | 0.021            | 0.146          | 0.039            | 0.019           |
| E        | 0.022         | 0.055         | 0.123          | 0.032            | 0.023            | 0.108          | 0.042            | 0.015           |

The optimal and worst ideal evaluation objects are determined by formulas (19) and (20) as follows.

Table 8. The optimal and worst ideal evaluation object

| Demander | Offered price | Demand period | Demand quality | Current situation | Potential demand | Security degree | Reputation degree | Settlement speed |
|----------|---------------|---------------|----------------|------------------|------------------|----------------|------------------|-----------------|
| $D^{+}$  | 0.025         | 0.065         | 0.135          | 0.032            | 0.029            | 0.146          | 0.045            | 0.022           |
| $D^{-}$  | 0.020         | 0.044         | 0.112          | 0.022            | 0.021            | 0.108          | 0.039            | 0.015           |

The distances and their proximity from each demander to the optimal and worst ideal evaluation objects are calculated and sorted as follows.

Table 9. The distance between the demander and the best and the worst ideal evaluation objects and the order of their closeness

| Demander | $|sim^{+}_i|$ | $|sim^{-}_i|$ | $C^*_i$ | Order |
|----------|--------------|--------------|--------|-------|
| A        | 0.9984       | 0.9989       | 0.4999 | 4     |
| B        | 0.9987       | 0.9943       | 0.5011 | 1     |
| C        | 0.9960       | 0.9958       | 0.5001 | 3     |
| D        | 0.9987       | 0.9960       | 0.5007 | 2     |
| E        | 0.9946       | 0.9970       | 0.4994 | 5     |

Based on the results of the table above, demand-side B has the closest degree, so it is the best demander, F should choose B.

In addition to choosing the best demand side, the method above can also make a more detailed comparison of the demand sides, then analyze the shortcomings of the unselected demand sides and make corresponding improvements. Based on the corresponding data in the weighted normalized matrix table, a comparison chart of the demand sides weighted evaluation data can be drawn as shown below.
Figure 3. Comparison chart of demand side weighted evaluation data

In the figure above, the larger the peak value represents the better. From the graph, we can see that although demander B is not in the best indicators, it has a balanced development, and compared with other demanders, each of its indexes is at a better level. The unselected demanders A, C, D, E are more or less inferior in one or more indicators, they can find their own shortcomings based on the diagram and improve themselves to enhance the competitiveness.

4.5. Provider satisfaction ratio analysis

Definition 4  The human resource supplier's satisfaction rate is the ratio of the number of satisfied matches to the total number of matches, it can be described as follows.

\[
\text{supplier's satisfaction rate} = \frac{\text{the number of satisfied selected matches}}{\text{total number of selected matches}} \times 100\%
\]

Based on the current selection methods[22], the satisfaction rate of the suppliers under three different selection methods are compared and analyzed experimentally. Here are the three different selection methods:① Undifferentiated selection method, in which each indicator has the same weight; ② Subjective selection method, in other words, the method of selecting only according to the weight of the subjective index; ③ The method in this paper, that is to say, the selection method considers both the objective weight and the subjective weight of the index. Ten different matching simulations of human resource suppliers and demanders are conducted through experiments. 300 human resource providers are arranged to select the demanders each time. The change of satisfaction rate of the suppliers with the results under different selection methods and the comparison are shown below.

Figure 4. Change and comparison of supplier satisfaction rate under different selection methods
As we can see from the above figure, with the increase of the number of tasks, compared with the existing selection methods, because the method in this paper considers the subjective and objective weights of the evaluation indexes on the basis of taking more reasonable evaluation indexes into account, and improves the AHP method and TOPSIS method to avoid the corresponding limitations, the satisfaction rate of the suppliers for the results is improved, and the stability is getting better and better.

5. Conclusion
In the cloud manufacturing environment, both the supply and demand sides of human resource are making mutual selection and matching all the time, therefore, how to choose the best object from a large number of supply and demand groups is an urgent problem for both sides. From the perspective of human resource provider in this article, firstly, according to the demand information of thequirer, the objective weight of each index is obtained by entropy weight method; secondly, the improved AHP method is used to determine the subjective weight of each indicator; then the comprehensive weights of the indexes are obtained by combining the subjective and objective weights; finally, the TOPSIS method is improved to evaluate the demander, so as to provide the basis for the selection decision-making of the provider. This method can better solve the problem of choosing the human resource demander by the provider in cloud manufacturing environment and ensure the satisfaction of the provider with the result to some extent. Future research will combine the corporate culture information of both sides of human resource to further study and explore their optimal decision-making in the cloud environment.

Acknowledgments
Fund project of Guangxi Aviation Logistics Research Center（2018KFJJHKWL01）
Research on the innovation mode of system and mechanism of higher vocational colleges based on social service（GXGZJG2018B150）

References
[1] LI B H,ZHANG L,WANG S L, et al. Cloud manufacturing:a new service-oriented networked manufacturing model[J]. Computer integrated manufacturing system, 2010,16(01):1-7+16.
[2] Vahideh Hayyolalam,Behrouz Pourghhebleh,Ali Asghar Pourhaji Kazem, et al. Exploring the state-of-the-art service composition approaches in cloud manufacturing systems to enhance upcoming techniques[J]. Springer London,2019,105(1-4).
[3] Jafarnejad Ghomi,Masoud Rahmani,Nasih Qader. Service load balancing, task scheduling and transportation optimisation in cloud manufacturing by applying queuing system[J]. Enterprise Information Systems,2019,13(6).
[4] Jalal Delaram,Omid Fatahi Valilai. A Mathematical Model for Task Scheduling in Cloud Manufacturing Systems focusing on Global Logistics[J]. Procedia Manufacturing,2018,17.
[5] Yanjuan Hu,Lizhe Wu,Chao Shi, et al. Research on optimal decision-making of cloud manufacturing service provider based on grey correlation analysis and TOPSIS[J]. International Journal of Production Research,2020,58(3).
[6] Qi Chen,Qi Xu,Cui Wu, et al. Dynamic Matching in Cloud Manufacturing considering Matching Costs[J]. Hindawi,2019,2019.
[7] LI H,WANG W,FAN L. Selection method of machine tool resources in cloud manufacturing environment[J]. Acta Aeronautica ET Astronautica Sinica,2020,41(07):54-65.
[8] GONG X R,LI X B,YIN C. Optimization Decision Method of Machine Tool Resources Based on Bayesian Network under Cloud Manufacturing Environments[J]. China Mechanical Engineering,2018,29(20):2438-2445.
[9] YIN C,LUO P,LI X B, et al. Optimal selection method for machine tool resource based on multi-agent[J]. Computer integrated manufacturing system,2016,22(06):1474-1484.
[10] CHENG Y,SHENG B Y,ZHANG C L. Optimization Method of 3D Printing Device Resources in
Cloud Manufacturing Environment[J]. Machinery Design & Manufacture, 2019(02):95-99.

[11] WANG X Y, LIU S C, WANG Z X, et al. Research on matching method of CNC equipment resource service in cloud manufacturing environment[J]. Manufacturing Technology & Machine Tool, 2018(03):27-32.

[12] ZHOU S L, YIN H K. A service encapsulation method of production equipment resources for cloud manufacturing[J]. Modern Manufacturing Engineering, 2017(09):46-51.

[13] WANG W X, LIU F, SHEN A M. A Service Encapsulation Method of Equipment Resources for Cloud Manufacturing[J]. Laser Journal, 2016, 37(12): 87-90.

[14] YI A B, ZHOU H F. Service Encapsulation Method of Equipment Resources in Cloud Manufacturing Environment[J]. Combined machine tool and automatic machining technology, 2016(05): 151-154+160.

[15] HU Y F, TAO F, ZHOU Z D. Manufacturing grid resource Trust-QoS evaluation and application[J]. Journal of Mechanical Engineering, 2007(12): 203-211.

[16] YAN X X, YUAN Z Z, MAO S J, et al. Coordination Evaluation of Non-motorized Traffic and Urban Design Based on Entropy Weight-TOPSIS Model[J]. Journal of Highway and Transportation Research and Development, 2018, 35(09): 107-114.

[17] SUN X, CHEN Y Z, YUAN S S, et al. Fire safety assessment for the fire-prone units based on the renovated hierarchical analysis process[J]. Journal of Safety and Environment, 2017, 17(04): 1253-1257.

[18] MA J Q, CUI B F, LIU L, et al. Application of fuzzy comprehensive evaluation based on improved analytic hierarchy process in optimization of irrigation scheme[J]. Water saving irrigation, 2017(08): 34-37+43.

[19] WANG X J, WANG L. Applications of TOPSIS improved based on Mahalanobis distance in supplier selection[J]. Control and Decision, 2012, 27(10): 1566-1570.

[20] LI H, HE Z K, LI Q, et al. Applications of the Improved TOPSIS Decision-Making Method in the Supplier Selection[J]. Mathematics in Practice and Theory, 2016, 46(16): 93-101.

[21] CHEN W G, WANG H H, YAN H, et al. Competency Evaluation of Construction Project Manager Based on Vector Angle Cosine[J]. Journal of Civil Engineering and Management, 2018, 35(02): 32-38+84.

[22] MA W L, ZHU L N, WANG W L. Cloud service selection model based on QoS-aware in cloud manufacturing environment[J]. Computer Integrated Manufacturing System, 2014, 20(05): 1246-1254.