Module partitioning study of specialized engineering services based on modular theory
——case on coal production firms

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Abstract—Outsourcing of specialized engineering services has become one of the routes to the innovation and high-quality development of the commercial model of coal production enterprises in China. Currently, although there is practice, no scale-up development has been achieved. In this paper, based on modular theory, under the condition of unknown expert weights, triangular fuzzy number method is used to construct a service unit association relationship evaluation model, and the correlation matrix is calculated. Then, a genetic algorithm is used to cluster the association matrix and obtain the results of the division of the outsourced module of engineering services. Finally, the proposed method is validated using the coal mine development process of coal producers as an example.

1 Introduction

In 2016, the tenth five coal industry development program encouraged coal enterprises to establish specialized service companies [1]. This program provides specialized engineering services to coal production firms and provides policy support for conducting business model innovations. Coal specialized engineering services are available at home and abroad [2]. According to the service demand party needs, improve mine design, resource distribution, business management and other engineering service activities. However, in practice, specialized engineering services for coal production fail to achieve scale effects because service content is formed based on negotiation between the supply and demand parties, and as a result, there is a lack of standardized service products.

Hongling Xu (2007) argues that modularity in service product design is the basis of industrialization [3]. Modular theory was proposed by Baldwin and Clark at Harvard Business School in 1997 [4]. Xia Hui (2010) considers service modularity as the modularity of service processes, thus forming a series of activities to meet the demands of different markets [5]. Gomes (2008) and Zhang Qianjun (2015) argue that appropriate task modularity has a positive effect on firm performance [6] [7]. Based on the above studies, this paper argues that the service modularity theory can guide the coal production specialty to provide services for industrialization and scale development.

The basis of service module design is module partitioning. References [8-14] have studied the problem of task module partitioning from different perspectives and methods. However, there is a lack of multidimensional analysis of association relationships, in terms of quantitative research, neglecting the effect of expert opinion on evaluation results, and often using fuzzy clustering, the accuracy of its calculation results is affected by artificially set thresholds and is not objective enough. Therefore, this paper proposes a service modularity design method based on multidimensional fuzzy association relationship analysis and solving the optimal module partition scheme.

2 MODELING THE RELATIONSHIP BETWEEN SERVICE UNITS

The smallest unit studied in this paper is the service unit. It has independently complete functions, including the operation of accomplishing active tasks. Basis of module division.

2.1 Linguistic Scale of Association Mode and Relationship Strength

Set up service unit collection \( S = \{s_1, s_2, s_3, \ldots, s_n\} \), \( s_i \) and \( s_j \) are two elements in the S. According to reference [15], the relationship between \( s_i \) and \( s_j \) can be divided into: independent, coupled and dependent, as shown in Tab.1.
The triangular fuzzy number is given by evaluator. The algorithm of value of the degree of the binary association of the lower limit, the most likely value and the upper limit of the correlation between service units is represented by trigonometric fuzzy language given by evaluator P

\[
\lambda \tilde{a} = (\lambda_a', \lambda_a^*, \lambda_a^\prime) \quad (3)
\]

(2) Consistency of expert opinions and weight of experts

Based on the evaluation information of each expert, the mean value of triangular fuzzy number of the strength of the relationship between service units is obtained

\[
\bar{\gamma}_{ij} = \frac{1}{k} \sum_{p=1}^{k} \gamma_{ij}^p \quad (4)
\]

\[1 - d(\tilde{a}_i, \tilde{a}_j)\] represents the similarity between two triangular fuzzy numbers. The larger the value is, the more consistent the two triangular fuzzy numbers are. The distance between two triangular fuzzy numbers can be measured by Euclidean distance:

\[
d(\tilde{a}_i, \tilde{a}_j) = \sqrt{\left(\tilde{a}_i' - \tilde{a}_j'\right)^2 + \left(\tilde{a}_i^* - \tilde{a}_j^*\right)^2 + \left(\tilde{a}_i^\prime - \tilde{a}_j^\prime\right)^2} / 3
\]

Average consistency of evaluation opinions of an expert D_{ij}^p:

\[
D_{ij}^p = 1 - d(\bar{\gamma}_{ij}, \gamma_{ij}^p) \quad (6)
\]

The individual weight of expert P can be normalized by (7):

\[
\omega_{ij}^p = \frac{D_{ij}^p}{\sum_{p=1}^{k} D_{ij}^p} \quad (7)
\]

(3) Service unit Association calculation

The triangular fuzzy number of the association relationship is calculated according to the expert weight.

\[
\gamma_{ij} = \frac{\gamma_{ij}^l + 2\gamma_{ij}^m + \lambda_{ij}^u}{4} \quad (9)
\]

**3 DIVISION OF SERVICE MODULES**

**3.1 Construction of Objective Function**

According to the literature [15] [16] in this paper, modularity degree is used to evaluate the module division results.

\[
Q = \sum_{j=1}^{n} (e_{ij} - e_{ij}^2) \quad (10)
\]

Row (or column) a_i = \sum_{j=1}^{n} e_{ij} Denotes the number of edges connected to the vertex [15]. Edges are between vertices, expressed as e_{ij} = a_i \cdot a_j.
optimal module partition scheme should have the maximum value of modularity [15]. Suppose there are n attributes. Firstly, the modularity of each attribute is calculated \( Q_m \) (m=1, ……n), weight \( \mu_n \), and \( \sum_{n=1}^{n} \mu_n =1 \). Calculation of integrated modularity \( Q_{\text{total}} \).

\[
Q_{\text{total}} = \sum_{n=1}^{n} \mu_n Q_m
\]  

(11)

Targeting comprehensive modularity.

\[
F(Q) = \max(Q_{\text{total}})
\]  

(12)

3.2 Others

This paper uses integer coding, and gene values for each individual in the initial population are generated by uniformly distributed random numbers. Chromosomes were selected by the disk selection method using single point crossover with pc set to [0.25, 0.75], pm was set at [0.01, 0.2]. The number of iterations was set to 100-5000 times.

4 CASE ANALYSIS

4.1 Identification Of Specialized Service Units Of Coal Production Enterprises

Based on the principle of technology behavior, combined with field investigation in coal production enterprises, this paper forms a list of service units as in Tab.3.

| Service unit          | No. |
|-----------------------|-----|
| Mine design           | 1   |
| Administrative        | 3   |
| Power-supply          | 5   |
| Auxiliary             | 7   |
| Drivage               | 9   |
| Lifting system        | 11  |
| Power supply          | 13  |
| Coal Preparation      | 15  |
| Coal transportation   | 17  |
| Equipment maintenance | 19  |
| Mine construction     | 21  |
| Training              | 23  |

Table3. LIST OF SPECIALIZED SERVICE UNITS

4.2 Relationship Measurement of Professional Service Unit

Based on [2] and [17-19], this paper reviews the relationship between service units in three dimensions, safety, function and economy. Space is limited, only some of the results of this review are truncated, as summarized in Table4.

| Service unit          | \( s_{m} \) | \( s_{o} \) |
|-----------------------|-------------|-------------|
| Mine                  | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Administrative        | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Power-supply          | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Auxiliary             | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Drivage               | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Lifting system        | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Power supply          | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Coal Preparation      | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Coal transportation   | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Equipment maintenance | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Mine                  | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Training              | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |

Table4. SEVICE UNITS SECURITY RELATIONSHIP EVALUATION

| Service unit          | \( s_{m} \) | \( s_{o} \) |
|-----------------------|-------------|-------------|
| Mine                  | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Administrative        | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Power-supply          | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Auxiliary             | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Drivage               | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Lifting system        | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Power supply          | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Coal Preparation      | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Coal transportation   | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Equipment maintenance | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Mine                  | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |
| Training              | 1, 0.8, 0.9, 1 | 0, 0, 0, 0   |

The security association matrix of service unit is obtained by calculation \( R^{\text{p}}_{ij} = \left( \gamma^{\text{p}}_{ij} \right)_{23x23} \)

\[
\gamma^{\text{p}}_{ij} = \begin{pmatrix}
0.1 & 0.2 & 0.1 \\
0.2 & 0.1 & 0.2 \\
0.1 & 0.2 & 0.1
\end{pmatrix}
\]

Similarly, we can calculate the economic relation matrix \( R^{\text{e}}_{ij} = \left( \gamma^{\text{e}}_{ij} \right)_{23x23} \), function relation matrix \( R^{\text{f}}_{ij} = \left( \gamma^{\text{f}}_{ij} \right)_{23x23} \) (get it from 463906442@qq.com).

4.3 Division Scheme Solution and Result Analysis of Coal Specialized Service Module

In this paper, the parameters of the GA were set as follows: \( n = 60 \), \( pc = 0.45 \), \( pm = 0.01 \). Calculations were performed using MATLAB 2016a version. The results showed that it could be divided into 14 modules, as shown in Table 5.
Table5. SEVICE UNITS SECURITY RELATIONSHIP EVALUATION

| Modules | Service unit | Modules | Service unit |
|---------|--------------|---------|--------------|
| 1       | Technical consultation | 2       | Coal Preparation |
| 3       | Sales | 4       | Environmental protection engineering |
| 5       | Administrative engineering | 6       | Equipment leasing |
| 7       | Provisioning | 8       | Mine construction technical consultation |
| 9       | Equipment maintenance | 10      | Auxiliary engineering |
| 11      | Training | 12      | Coal transportation |
| 13      | Mining, Drivage, Transportation and hoisting, Ventilation and drainage, Power supply, Supporting and installation of equipment , moving upside down | 14      | Mine design, Ventilation engineering, Power supply engineering, Administrative engineering |

5 CONCLUSION

This paper presents the division method of engineering specialized service module and practices in combination with coal production enterprises. In cases where the expert weights were unknown, a triangular fuzzy number method was adopted to evaluate the association relationship and calculate the expert weights. And genetic algorithm is employed to calculate the optimal service module partitioning scheme. The research results of this paper provide the foundation for the development of the professional division of labour and professional service industrialization of coal enterprises.

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