Research Article

Application of Service Modular Design Based on a Fuzzy Design Structure Matrix: A Case Study from the Mining Industry

Xin Wang¹,² and Bo Luo³

¹School of Management, Xi'an University of Science and Technology, Xi'an, Shaanxi 710054, China
²Center for Energy Economics and Management Research, Xi'an University of Science and Technology, Xi'an, Shaanxi 710054, China
³School of Management, Xi'an Polytechnic University, Xi'an, Shaanxi 710048, China

Correspondence should be addressed to Bo Luo; luo@xpu.edu.cn

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The development of customized service is an important way to transform and upgrade China's mining industry. However, in practice, there remain problems, such as the slow market response speed of service providers and the contradiction between the large-scale development of service providers and the personalized service needs of service demanders. This paper uses the theory and method of service modular design to solve these problems and explores the process-based service modular design method. Service modular design depends largely on the determination of the relationship between service activities and the reasonable division of modules. However, previous research has rarely made use of modular design methods and modeling tools in the mining service context. At the same time, evaluations of the relationship between service activities relying on knowledge and those relying on experience have been inconclusive. Therefore, this paper proposes a service modularization design method based on the fuzzy relation analysis of a design structure matrix (DSM) that solves the optimal module partition scheme. Triangular fuzzy number and fuzzy evidence theory are used to evaluate and fuse the multidimensional and heterogeneous relationship between service activities, and the quantitative processing of the comprehensive relationship between service activities is carried out. On this basis, the service module structure is divided, followed by the construction of the mathematical programming model with the maximum sum of the average cohesion degree in the module and the average coupling degree between modules as the driving goal. The genetic algorithm is used to solve the problem, and the optimal module division result is obtained. Finally, taking the service modular design of SHD coal production enterprises in China as an example, the feasibility of the proposed method is verified.

1. Introduction

With the transformation of the global industrial structure into a service-oriented economy, all kinds of enterprises have begun to explore ways to provide customized services for customers. As early as the 1980s, in order to achieve sustainable development, the mining industry in Australia, New Zealand, Indonesia, South Africa, China, and other countries was no longer satisfied with one-time mineral product transactions, and began to provide mineral product development services for other mining enterprises, such as equipment maintenance, mine construction, mineral product transportation, mine design, and mineral product mining. This approach has since become one of the most important means to improve the income of the mining industry [1, 2]. Drawing on this literature on field investigations of mining enterprises in Northern Shaanxi, and on studies and news reports of the transformation of mining industry services in Inner Mongolia, Ningxia, and Shandong, this paper finds that the common features across mineral product development services in different countries and enterprises are that service providers take customer satisfaction as their goal and use their own redundant resources, knowledge, and technology. According to the
functional needs of the service demander, mine conditions, service content design, resource allocation, business management, and other activities within the limitations of the construction period and cost are integrated into solutions that meet the specific needs of customers, and the essence is customized service.

Because of the implementation of the supply-side reform in China, the mining volume of mineral products is limited, and the requirements for safe production and management are more stringent. The supply and demand of customized services have increased, and economic benefits have been created for enterprises. However, this study finds that the industry as a whole continues to lack norms and standards that service providers are slow in responding to the market, and that there are contradictions in service providers’ pursuit of high efficiency, low cost, and customer personalized demand design.

First of all, although the mining enterprises that provide the business call themselves service providers, the definition of the name, scope, and strategic meaning of the business is neither clear nor consistent. Different enterprises have different names for this business, such as entrusted management, outsourcing, contract mining, specialized services, coal mine trusteeship, and mining services.

Second, the supplier and demander of the service agree on the content, mode, duration, price, and responsibility for the service through negotiation, specify the form and requirements of the deliverable, and finally sign a contract. Therefore, the service scheme is characterized by a high degree of randomness. The service content can be the whole mine trusteeship, or one or more links or processes in the mine development process. Given this lack of standardized business scope, it is difficult for providers to achieve a balance between scale benefit and customer personalized demand.

Third, in each stage of mine development, customer demand continues to change. At the same time, and given the long production cycle of the mining industry, geological conditions, mining time, and other factors continue to change, as does customer demand. When demand changes significantly, service providers need to replan the service process and schedule service resources; this makes it difficult to respond to demand changes quickly.

In this study, the purpose of customization is to meet the personalized needs of customers while maintaining the production efficiency and costs of service providers to achieve rapid market response. The difficulty lies in how to transform the development process of mineral products into several technically feasible specific service tasks, maintain a relatively stable structure over a certain period of time, and combine the tasks into service projects to meet customer requirements. Baldwin and Clark, pioneers of modularity theory, argued that modularity is an effective strategy for organizing and designing complex products or processes [3, 4]. According to modularity theory, complex systems can be decomposed into semiautonomous subsystems that can be designed independently. In recent years, research on service modularization has gradually moved to the forefront of academic interest and has been applied in many industries, and previous studies have shown that the idea of service modularization is the most appropriate theory for addressing the complexities of customized service. The present study argues that we can use the theory and method of service modularization to solve existing problems.

The production object and final product of mining industry are mineral products. The production purpose and process of an enterprise is to mine underground mineral products and then transport them to ground level for processing and sales [5]. From the perspective of service modularization theory, the essence of customized service in the mining industry is the modularization design based on process. In this study, the subprocesses within the process of mineral product development are considered as service products, and process activities with specific functions are identified to form independent service modules. Each module has a deliverable, which is taken as the interface between modules. Because of the adoption of modular technology to promote the standardization of modules, the cost of suppliers can be reduced. At the same time, through the combination of service modules, diversified service products can be formed quickly to meet the needs of specific customers.

This research will help to expand the application scope of service modularization theory, improve the service modularization design research based on process, and resolve difficulties in business model innovation and enterprise transformation in the coal, oil, natural gas, and other industries. In order to achieve service modularization, the basic problems that must be addressed are the determination of the relationship between the process activities and the division of modules.

2. Research Status and Research Ideas

2.1. Literature Review. In recent years, Chinese scholars He, Zhang, Yang, and Liu have used the case study method to summarize the application modes and safeguard measures of several mining enterprises carrying out customized services according to the practice of coal enterprises [6–9]; however, their work has not fully addressed issues of fairness or included all the relevant concepts, theories, and methods. Research on the transformation of the mining industry from a producer of mineral products to a service provider thus remains in its infancy.

2.1.1. Theoretical Research on Service Modularization. In 1993, Pine et al. claimed that service modularization is feasible, and was the first to put forward the judgment that both tangible products and intangible services can realize mass customization [10]. Subsequently, Sundbo noted that service modularization is the process of standardizing service products and combining them with customers, explaining that service product standardization can secure a productivity advantage and a customer satisfaction advantage provided by customization [11, 12]. Baldwin and colleagues pointed out that mass customization of services can be realized by adopting the “architecture module”
innovation method of product development [3, 4]. Yu et al. [13–15] explored the value creation logic of service modularization, and through case studies and empirical studies in three industries found that service modularization is a new way to realize value creation of service customization. The service modularization theory has also been applied in financial services, civil aviation services, manufacturing product services, and other industries and fields [13, 16, 17]. Yan and Jiang conducted a bibliometric study on service modularization, and found that some scholars put forward that the key of service mass customization is the modularization of service process system, which is a clearer entry point for enterprises to implement service modularization [18]. Xia and Xue observed that the modular decomposition and integration of business processes to form different service products can meet different needs within the market [19]. Most recently, Yu and others conducted research from the perspective of division of labor and concluded that service process modularization can be achieved by decomposing the tightly coupled process system into sub-process modules [20].

To sum up, scholars believe that accurate module segmentation of service process can lead to service standardization and generalization, thereby achieving customized service. Nevertheless, the process is generally composed of continuous activities and is not easily divided into service modules. The case of mineral product development is particularly complex, as it consists of multiple heterogeneous activities. Each activity is composed of multiple operations, processes, and resources, and there are complex relationships in multiple dimensions, including function and resource dependence. In order to identify the service activities and their relationship in the process of mineral product development, divide them appropriately into service modules, and combine them into customized service schemes with feasible technology, shorter construction periods, lower costs, and coordinated operations, we need to explore in depth the relationship between service activities and clarify the method of process system division and combination.

2.1.2. Research on the Service Module Partition Method. Early research on the method of service module partition based on process mostly used the service blueprint and quality function methods. Through the research of service modularization literature, Yan and Jiang found that scholars use service blueprint method to form process module by merging and standardizing specific service processes [18]. Service blueprint, house of quality, critical path method (CPM), program/project evaluation and review technique (PERT), graphic evaluation and review technique (GER), and other technologies are often used to describe the elements and their relationships in the process; however, despite their suitability for serial and one-way processes, their ability to describe the coupling relationship between sub-systems is weak, and they are not appropriate for multidimensional integration analysis. Browning argued that a design structure matrix (DSM) can better describe various resources and the interdependence between them, and that it is an effective tool for solving the management problems of complex engineering, particularly in terms of calculation and analysis [21]. In recent years, however, scholars have agreed that clustering DSM to obtain a modular partition scheme is a better method [22, 23]. Yang et al. took the process of a complex R&D project as their research object, proposing a theoretical analysis framework based on DSM tools for measuring, optimizing, and clustering the dependency relationship between subprocesses [24]. Sakao et al. constructed a DSM based on the interaction relationship between service elements and studied the service module division of the customized product service system, but they did not conduct quantitative research on the strength of the interaction relationship [25]. Ying et al. used a self-organizing mapping algorithm for module clustering calculation of numerical DSM, but this has high requirements for dependency data between activities and cannot resolve situations of complex and uncertain dependency [26]. Chen et al. quantitatively calculated the relationship between subtasks on a cloud service platform and mapped it into a DSM to obtain a task composition scheme [27]. Wen and Gao introduced a DSM model to sort and quantify the service activities related to product production, and obtained the optimal functional module partition scheme of an intelligent distribution system [28]. Cheng and Luo used a DSM to express the asymmetric association between product parts, and then applied a fuzzy algorithm to cluster the parts [29]. However, they considered only the information interaction and comprehensive interaction between tasks, ignoring the differences of task interaction strength under different attributes. Jin and Geng took the product service system (PSS) as their research object and used the fuzzy design structure matrix (FDMS) as a module partition tool, but it proved necessary to artificially select the threshold to cluster process activities in order to achieve module partition [17].

In summary, previous research has a number of shortcomings. First, there are two types of research objects: manufacturing and service industries. Scholars have discussed service module partition methods based on product structure and resource types. These methods are inevitably predicated on product structure and do not consider the relationships between service activities. Therefore, they are not suitable for service module partition when the final product has no structure or where there is complex interaction between service activities. Second, module partition must clarify the relationship between the components that form the module. However, there has been little research in this area, and almost no consideration has been given to the relationship between the components of the module in different dimensions. Therefore, there are relatively few quantitative studies on building a comprehensive relationship between service activities in multiple different dimensions.

Third, previous studies have not identified the structure of the service module system or the type of service module, an oversight that is not conducive to research based on the service modularization theory. The concept of modular
composition for customized scheme designs does not address the problems of market response speed, service duration, or cost problems. Fourth, although scholars have used DSM tools to describe the complex interaction between services, they have seldom discussed the differences of interaction in different dimensions or the processing method of information fusion in multidimensional situations, and they have ignored the fuzzy evaluation information of the association relationship. However, the accuracy of the association information will directly affect the rationality of the service module partition scheme.

Fifth, in the literature on module clustering based on DSM, most studies have adopted the fuzzy clustering method and set the threshold value artificially, which leads to the subjectivity of the partition result. The common way is to first decompose DSM into a block diagonal matrix and then carry out row–column transformation. However, this method has the disadvantage of low efficiency when dealing with the clustering problem for an asymmetric DSM and a large-scale DSM with a large number of row and column elements.

2.2. Research Ideas. In view of the shortcomings of previous research, this paper takes DSM as its basic tool and uses triangular fuzzy number and evidence theory to determine the relationship between service activities and reasonable segmentation of service modules. The research process is shown in Figure 1.

The first step is to analyze the business process, identify service activities, and establish the multidimensional service activity association. Different perspectives, the degree of association between service activities is different, and the evaluation information is uncertain. In order to take account of these situations, this paper adopts DSM, uses triangular fuzzy number theory to express the quantitative results of fuzzy association strength of service activities, and models the DSM of service activities from three dimensions.

In the second step, drawing on fuzzy evidence theory, the evaluation information for different dimensions of the service activity design structure matrix (SER-DSM) is fused to form a comprehensive DSM under multiple criteria.

In the third step, based on the comprehensive DSM and according to the quantitative results of the row and column elements of the matrix, the structure of the design matrix is identified, and the service activities are divided into three types.

In the fourth step, the elements of the structure matrix are designed synthetically for the parts that need clustering calculation, and the mathematical programming model is constructed to maximize the sum of the average cohesion degree of modules and the average coupling degree between modules. The genetic algorithm is used to solve the problem, and the optimal customized service module partition scheme is obtained.

In the final step, the results are applied to the modular design process of customized service in coal mining enterprises to verify the feasibility of the proposed method.

3. Related Concepts

Scholars have defined the concept of service from different perspectives. According to Lovelock et al. and Li, service is a complete process composed of a single activity or a series of activities that has use value and a certain exchange value [30, 31]. Accordingly, this study regards service modularization as the process of modularizing all activities of the whole service process. The minimum unit studied here is service activity, which is the basic construction element of the service module. The service module is composed of a series of interrelated service activities that have more complex and complete functions than single service activities. It should be noted that in the mining industry, each service activity produces a variety of deliverable forms, including physical products, engineering projects, equipment, facilities, materials, and drawings. This paper therefore considers the service activity as having technical independence and functional integrity, including all operations or processes for completing the activity, as well as the necessary resources and services required to complete these activities. We measure the service result and service quality in terms of the deliverability of service module.

In 1981, Steward proposed DSM as a structural modeling tool to represent the elements and their interactions in a system. McCulley and Bloebaum later established a numerical DSM model, which not only quantitatively describes the dependency relationship between matrix elements but also represents the information transfer direction between elements [32]. Thus, the model has strong problem description ability. According to different application fields, DSM models can be divided into element, team, operation, and parameter types [33]. Element DSM is often used to represent the relationship between the system elements and the system structure. It describes the system structure intuitively and quantitatively but does not need to be refined to specific parameter values, which meets the needs of this study. Therefore, this paper uses an element-type numerical DSM model to describe the structural characteristics of service activities in the process of service activities and their relationships, also known as the SER-DSM. The row and column elements in the model are composed of various service activities, and the values between the row and column elements represent the relationship strength between service activities.

4. Analysis and Modeling of Association Relationships of Service Activities

Identifying all service activities and their relationships is the basis of service module division, which is very important for the design of a customized service scheme. In different dimensions, the direction and strength of service activities are different, and the quantification of their relationship often depends on the evaluations of multiple experts, which constitutes a multidimensional fuzzy fusion evaluation problem. Therefore, it is necessary to analyze the relationship of service activities in each dimension and then integrate them to build a comprehensive SER-DSM model.
4.1. Semantics of Fuzzy Association Relationships in Service Activities. As it is impossible in the mining industry to analyze the relationship of service activities according to product structure, it is very difficult to measure the relationship of service activities. Generally, this is evaluated by means of investigation and expert consultation. However, when the information is fuzzy and incomplete, experts cannot express their evaluation views with accurate values. In this study, a triangular fuzzy number is used as input for fuzzy logic deduction. For any triangular fuzzy number, the form \((n_1, n_2, n_3)\) gives the minimum, most likely, and maximum values of the elements in the triangular fuzzy number, respectively. The algorithm is as follows:

\[
\bar{a}_1 \pm \bar{a}_2 = \left( a_1^l, a_1^m, a_1^u \right) \pm \left( a_2^l, a_2^m, a_2^u \right) = \left( a_1^l \pm a_2^l, a_1^m \pm a_2^m, a_1^u \pm a_2^u \right), \\
\lambda \bar{a} = \left( \lambda a_1^l, \lambda a_1^m, \lambda a_1^u \right).
\]  

In this paper, the confidence threshold of membership degree is determined using the cut set [34]. The corresponding relationship between triangular fuzzy number and fuzzy semantics is then established and the grades are divided as in Table 1.

4.2. Identification of Service Activities and Initial DSM Matrix. The core technology and complexity of different service activities are different. In the mining industry, there is a technical and economic connection between service activities. Therefore, according to the principle of technical...
feasibility and functional independence, the process nodes on the mining business flow chart can be decomposed or merged to obtain the service activity set.

If a business process has \( n \) service activities, the whole process can be represented by an \( N \times N \) DSM matrix, as shown in Figure 2, aggregate \( s = \{ s_1, s_2, s_3, \ldots, s_n \} \). Every node \( s_i \) represents a service activity, corresponding to the \( i \)th row and \( i \)th column in SER-DSM. The element on the nondiagonal line represents the relationship strength between the activities, and is represented by \( * \). The line element indicates that the service activity corresponding to the line can support other activities, and the column element indicates the support of other activities required by the column. The 0 element is used to indicate that there is no relationship between the corresponding service activities. The diagonal element has no meaning and is set to 1.

4.3. Classification of Relationship Types among Service Activities. Previous research on service module partition has evaluated the relationship between activities on the basis of product structure, but this method is not suitable for evaluating the relationship between service processes that do not depend on product structure [24, 29, 35–39]. Extrapolating from this literature in the context of the characteristics of mining product development process, the present study describes the relationship between service activities on the three dimensions of function, resource, and time (shown in Figure 3), and measures the correlation strength.

In order to simplify the multidimensional model, this paper builds a functional SER-DSM, a resource SER-DSM, and a time SER-DSM and then establishes a comprehensive relationship.

4.3.1. Functional SER-DSM Structure Matrix. The first dimension is the functional dimension, which indicates the relevance of two service activities for achieving new functions or higher-level functions, and can be measured by the necessity or degree of collaboration between them. Taking the coal production process as an example, in order to realize the function of raw coal stripping, tunneling and coal mining must be linked. When the connection between \( s_i \) and \( s_j \) has an adverse effect on a certain function and the connection between them must be avoided, or when the connection between \( s_i \) and \( s_j \) cannot achieve other functions, the functional relationship between \( s_i \) and \( s_j \) is recorded as 0. The relationship between functional association and the triangular fuzzy number is shown in Table 2. Since the functional correlation is symmetric, the functional SER-DSM structure matrix is a symmetric matrix.

4.3.2. Resource SER-DSM Structure Matrix. The second dimension is the resource dimension, which represents the degree of resource sharing between two service activities. Based on the theory of resource dependence, resources can be classified [17, 39]. The present study divides resources into three categories: hardware resources are the materials, equipment, venues, and energy needed to carry out service activities; software resources are the knowledge, technology, data, information, and application software that support service activities; and human resources are the personnel needed for internship service activities, such as technicians, managers, and workers. The resource association relationship description and triangular fuzzy number representation for this study are shown in Table 3. If \( s_i \) and \( s_j \) do not share any resources, the resource relationship between \( s_i \) and \( s_j \) is recorded as 0. The SER-DSM structure matrix of resources is symmetrical because the type and intensity of service activities and shared resources are the same.

4.3.3. Time SER-DSM Structure Matrix. The third dimension is the time dimension, which indicates the connection between the execution time of two service activities and can be measured by their execution time and execution results. Unlike processed products, when there is a time correlation between service activities there is a sequence between the description and execution time, and the execution result can create execution conditions (such as information, site, energy, equipment, and tools); for example, the installation of coal electromechanical equipment must be executed before coal mining activities and underground production conditions for coal mining activities can be created.

Generally, scholars agree that there are three time relationships between processes and operations: parallel, sequence, and coupling. Studies have indicated that the implementation of a complex project process has the characteristic of overlapping in time, which is consistent with the survey results of studies of coal production enterprises [24]. Research has also suggested that once activity creates resource conditions for another activity, and that multiple activities can jointly create resource conditions for another activity [40]. The present study identifies a further feature of process activities: for example, activity A may be carried out earlier in time than activity B, but instead of producing intermediate products or semifinished products, activity A only creates the execution conditions for activity B. Therefore, this study assumes that we can measure the intensity of association between activities by creating conditions for other activities.

Proceeding from the above analysis, this study divides the time relationship of service activities into parallel, sequence, overlap, cycle, and coupling, and the DSM is shown in Figure 4. A sequential relationship means that the upstream activities precede the downstream activities or create operational conditions for the downstream activities to start; a parallel relationship means that there is no execution time

| Table 1: Correspondence between triangular fuzzy numbers and fuzzy semantics. |
|---------------------------------|----------------|---------------|
| Triangular fuzzy number         | Fuzzy semantics | Grade number  |
| (0, 0.1, 0.3)                   | Weak            | 1             |
| (0.2, 0.3, 0.4)                 | Unimportant     | 2             |
| (0.4, 0.5, 0.6)                 | Common          | 3             |
| (0.6, 0.7, 0.8)                 | Important       | 4             |
| (0.8, 0.9, 1)                   | Very important  | 5             |
sequence between activities and the execution results do not affect each other; a cyclical relationship means that the upstream and downstream activities are executed in sequence and form a closed loop, and that the execution of $s_i$ needs $s_j$, and vice versa; a coupled relationship means that the upstream and downstream activities are executed

| Functional relationship                                                                 | Fuzzy semantics | Triangular fuzzy number |
|----------------------------------------------------------------------------------------|-----------------|------------------------|
| The connection between $s_i$ and $s_j$ does not hinder the normal completion of the function. | Weak            | (0, 0.1, 0.3)          |
| The connection between $s_i$ and $s_j$ is beneficial but not necessary.                  | Unimportant     | (0.2, 0.3, 0.4)        |
| The connection between $s_i$ and $s_j$ is beneficial and the synergy is average.        | Common          | (0.4, 0.5, 0.6)        |
| The connection between $s_i$ and $s_j$ is beneficial and the synergy is strong.          | Important       | (0.6, 0.7, 0.8)        |
| The connection between $s_i$ and $s_j$ is indispensable for the realization of new functions | Very important | (0.8, 0.9, 1)          |

| Functional relationship                                                                 | Fuzzy semantics | Triangular fuzzy number |
|----------------------------------------------------------------------------------------|-----------------|------------------------|
| $s_i$ and $s_j$ share only part of the software resources.                               | Weak            | (0, 0.1, 0.3)          |
| $s_i$ and $s_j$ share hardware and human resources, but the resources are sufficient and can be completely replaced. | Unimportant     | (0.2, 0.3, 0.4)        |
| $s_i$ and $s_j$ share hardware and human resources, which are limited but replaceable. | Common          | (0.4, 0.5, 0.6)        |
| $s_i$ and $s_j$ share hardware and human resources, which are important but replaceable. | Important       | (0.6, 0.7, 0.8)        |
| $s_i$ and $s_j$ share hardware and human resources, which are critical and irreplaceable. | Very important | (0.8, 0.9, 1)          |
alternately many times to create each other’s operation conditions; and an overlapping relationship means that when the upstream and downstream activities are executed in sequence, the downstream activities begin before the upstream activities are completed. When \(s_i\) and \(s_j\) have no temporal relationship and the execution results do not affect each other, the value is recorded as 0. Because of the different time relations of service activities, the time SER-DSM is an asymmetric matrix. The semantic and triangular fuzzy number expressions of time association are shown in Figure 4.

4.4. Construction of Comprehensive SER-DSM Matrix. The SER-DSM structure matrix is obtained by weighted summation of all dimensions. Although the function SER-DSM and resource SER-DSM are symmetric matrices, the time SER-DSM is asymmetric, and therefore the synthetic SER-DSM is asymmetric. In addition, because the relationship between service activities is evaluated by many experts in different fields according to their experience and understanding, the construction of a comprehensive SER-DSM is a group evaluation problem, which requires aggregation of the experts’ evaluation information. The specific methods and steps used are as follows:

Step 1: build the expert evaluation matrix. There are \(p\) experts to form a multiperson evaluation group to evaluate the dimensions of \(q\) association criteria. The evaluators’ evaluation results of service activities under each dimension are expressed by the triangular fuzzy number matrix \(\bar{R}_{ij}^{pq} = (\bar{y}_{ij}^{pq})_{non}\):

\[
\bar{R}_{ij}^{pq} = \begin{pmatrix}
\bar{y}_{11}^{pq} & \ldots & \bar{y}_{1n}^{pq} \\
\vdots & \ddots & \vdots \\
\bar{y}_{p1}^{pq} & \ldots & \bar{y}_{pn}^{pq}
\end{pmatrix},
\]

where \(\bar{y}_{ij}^{pq}\) means that under criterion \(q\), evaluator \(p\)’s evaluation value of the relationship between \(s_i\) and \(s_j\) does not need to be standardized when \(\bar{y}_{ij}^{pq} \in [0, 1]\).

Step 2: fuse expert evaluation information to obtain the SER-DSM of each dimension. Evidence theory (ET) is suitable for dealing with the uncertainty problem, as it is in line with people’s thinking habits and can solve the evaluation problem based on subjective judgment. At the same time, a triangular fuzzy number can be combined with ET to solve the problem of fuzzy information fusion, and research in different fields has verified the effectiveness of this method [41–43]. Therefore, this study uses a fuzzy evidence reasoning algorithm for expert evaluation information fusion. The fuzzy identification framework is composed of \(N\) evaluation grades, and \(G_k^q (k = 1, 2, \ldots, N)\) denotes the \(k\) evaluation grade under criterion \(q\). Its semantics are shown in Tables 1–4. \(G_k^q (i, j)\) is the confidence level of \(G_k^q\) for the correlation between \(s_i\) and \(s_j\) under criterion \(q\). According to formulas (2) and (3), the SER-DSM matrix of each dimension is obtained by fusing the evaluation values of \(s_i\) and \(s_j\) given by experts under criterion \(q\), and the elements in the matrix are \(\bar{R}_{ij}^q = (\bar{y}_{ij}^q)_{non}\):

\[
\beta_k^q (i, j) = \frac{\text{Num}(G_k^q)}{E}, \quad \beta_k^q (i, j) \in [0, 1],
\]

\[
\bar{y}_{ij}^q = \begin{cases} 
G_k^q (i, j), & i \neq j, \\
1, & i = j.
\end{cases}
\]

\(\text{Num}(G_k^q)\) is the number of experts who evaluate the relationship between \(s_i\) and \(s_j\) as \(G_k^q\) under the \(q\) criterion, and \(E\) is the number of experts who participate in the evaluation. The SER-DSM matrix representation of each dimension is shown in Table 5.

Note that the basic probability quality of the association between \(s_i\) and \(s_j\) under the \(q\) criterion is \(m_k^q (i, j)\), and its residual quality probability is \(\bar{m}_k^q (i, j)\). Then, \(m_k^q (i, j)\) is divided into residual probability \(\bar{m}_k^q (i, j)\) caused by relative importance and residual probability \(\bar{m}_k^q (i, j)\) caused by incomplete information. Let the weight of the \(q\) criterion be \(\lambda^q\) and satisfy
Table 4: Semantics of temporal relations and expression of triangular fuzzy numbers.

| Relationship       | Temporal correlation | Fuzzy semantics | Triangular fuzzy number |
|--------------------|----------------------|-----------------|-------------------------|
| Parallel           | \( s_i \) is executed before \( s_j \), but the result of execution has nothing to do with \( s_j \). | Weak            | (0, 0.1, 0.3)          |
| Overlapping        | \( s_i \) is executed before \( s_j \), and the partial execution result of the first can create conditions for the second. | Unimportant      | (0.2, 0.3, 0.4)        |
| Sequential         | \( s_i \) must precede \( s_j \) and create conditions for \( s_j \). | Common           | (0.4, 0.5, 0.6)        |
| Cycle              | \( s_i \) must precede \( s_j \) and circulate once to create conditions for each other. | Important        | (0.6, 0.7, 0.8)        |
| Coupled            | \( s_i \) and \( s_j \) go back and forth many times to create conditions for each other. | Very important   | (0.8, 0.9, 1)          |

\[
\sum_{q \in \{f,r,t\}} \lambda^q = 1, \text{ The weight of each dimension can be determined using the analytic hierarchy process (AHP) and other methods, which will not be discussed in this paper.}
\]

\[
m_k(i, j) = \lambda^3 \cdot \beta_k(i, j),
\]

\[
m_k^q(i, j) = 1 - \sum_{k=1}^{N} m_k^q(i, j),
\]

\[
m_k^q(i, j) = \frac{1}{N} \sum_{k=1}^{N} m_k^q(i, j) + \tilde{m}_k^q(i, j),
\]

\[
\tilde{m}_k^q(i, j) = \lambda^3 \cdot \left( 1 - \sum_{k=1}^{N} \beta_k(i, j) \right).
\]

Step 3: integrate the multiple criteria evaluation information to obtain the comprehensive SER-DSM. In this study, a fuzzy number analytic evidence reasoning algorithm proposed in the literature is used to fuse the consistency of expert group evaluation under multiple criteria [43]. The symbols used are defined in Table 6.

\[
K = \sum_{k=1}^{N} \prod_{q \in \{f,r,t\}} \left( m_k^q(i, j) + m_k^q(i, j) + \tilde{m}_k^q(i, j) \right) - (N - 1) \prod_{q \in \{f,r,t\}} \left( m_k^q(i, j) + \tilde{m}_k^q(i, j) \right),
\]

\[
m_k(i, j) = K^{-1} \prod_{q \in \{f,r,t\}} \left( m_k^q(i, j) + m_k^q(i, j) \right) - K^{-1} \prod_{q \in \{f,r,t\}} m_k^q(i, j),
\]

\[
\bar{m}_k(i, j) = K^{-1} \left[ \prod_{q \in \{f,r,t\}} \bar{m}_k^q(i, j) \right],
\]
5. Structure Division and Clustering Calculation of Service Activity DSM

Using the synthetic SER-DSM matrix, the clustering calculation is carried out to determine which system elements have the potential correlation to form modules, so that each module of the system contains most or even all of the mutual relationships while minimizing the mutual influence and correlation between each module.

5.1. Structure Division of Service Activity DSM. Wise and Baumgartner divided services into four parts [44]. On this basis, taking into account the relationship characteristics of row and column elements in the DSM model, service activities are divided into three categories, as shown in Figure 1.

5.1.1. Independent Activities and Modules. In the integrated SER-DSM, service activities whose row and column elements all have the value 0 are called independent activities. There is no connection between an independent service activity and other service activities, and each independent activity can form an independent module. Since there is no influence on the basic functions, construction period, cost, or market response speed of customer demand, an independent module can be selected by customers themselves and combined with other modules at will; thus, the degree of customization is general. In order to reduce the computing scale, it is not necessary to cluster.

5.1.2. Common Activities and Modules. A service activity whose all row and column elements do not have the value 0 in the comprehensive SER-DSM is called a common activity. This activity is related to all the other service activities and is a shared element in the whole system. Each common activity can form a common module separately. Common modules do not need to be customized, but they are elements that service providers need to match in order to realize or guarantee the basic functions of services, such as management and finance. A common module can be combined directly. They are poorly customized and do not need to be clustered.

5.1.3. General Activities and Modules. After removing independent activities and common activities, we can identify closely related service activities, which are called general activities. They are important factors affecting the scope, schedule, and cost of customized services. These general activities are mainly reflected in the differences of customer needs, and the customer’s mine parameters will affect the cost and duration of these service activities. Therefore, we must consider whether they can be combined quickly. Therefore, it is necessary to introduce clustering calculation and divide it into general modules.

5.2. Clustering Calculation. Clustering based on DSM involves high cohesion and low coupling between modules. Previous studies of the clustering principles of Boolean and numerical DSM have adjusted the influence of the degree of cohesion and coupling on the clustering module by setting weights [26, 45]. However, those studies used Euclidean distance to judge the closeness of the relationship and did not directly take into account the value of the relationship between the elements in the matrix; this increased the

\[
\bar{m}_{G}(i, j) = \prod_{q \in \{f, r, t\}} m_{G}^{q}(i, j) - \prod_{q \in \{f, r, t\}} m_{G}^{q}(i, j) \cdot \frac{K}{K},
\]

\[
\beta_{k}(i, j) = \frac{m_{k}(i, j)}{1 - m_{G}(i, j)}
\]

\[
\bar{y}_{ij} = \begin{cases} 
\sum_{k=1}^{N} \beta_{k}(i, j) \cdot G_{k}, & i \neq j, \\
1, & i = j,
\end{cases}
\]

\[
\gamma_{ij} = \begin{cases} 
\bar{y}_{ij} + 2\bar{y}_{ij}^{m} + \bar{y}_{ij}^{u} / 4, & i \neq j, \\
1, & i = j.
\end{cases}
\]
number of calculation steps and ignored the direction of the relationship. Accordingly, the present study adopts the principle of high cohesion within modules and low coupling between modules, taking the maximum sum of intramodule and intermodule correlations as the optimization objective.

Although there are many clustering methods, given that the complexity of the clustering calculation in designing the structure matrix increases sharply with the expansion of the matrix scale, this study uses heuristic methods, including the genetic algorithm. The optimization objective function constructed in this paper is expressed as follows:

$$\max F = \omega_1 F_1 - \omega_2 F_2,$$

where $F_1$ is the average cohesion degree, $F_2$ is the average coupling degree, $\omega_1$ and $\omega_2$ are the weight coefficients, and $\omega_1 + \omega_2 = 1$. In this study, $\omega_1 = \omega_2 = 0.5$.

Cohesion is the association strength among service activities within a module. The larger the association value within a module, the better the cohesion of the module. The formula is as follows:

$$F_1 = \frac{1}{N} \sum_{\mu_1=1}^{N} \sum_{\mu_2=1}^{N} \frac{f_{\text{in}}}{N_{\mu_1} N_{\mu_2}},$$

$$F_2 = \frac{1}{N} \sum_{\mu_1=1}^{N-1} \sum_{\mu_2=\mu_1+1}^{N} \frac{f_{\text{out}}}{2 N_{\mu_1} N_{\mu_2}},$$

Following analysis methods used in the literature [46], this paper constructs the fitness function by using the lower bound construction method:

$$\text{fit}(F) = \frac{1}{1 + c - F},$$

where $c$ is the conservative estimate of the bound of the objective function, $C \geq 0$, and the fitness function must be positive. Let $c = 0.5$.

In this study, integer coding is used, and the gene values of each individual in the initial population are generated using uniformly distributed random numbers. The selection operator is roulette selection, and the crossover operator is single-point crossover and the basic bit mutation. In order to determine the value of the parameters, the orthogonal experiment of parameters is designed to obtain the optimal combination [47, 48].

The coupling degree is the connection between modules. The higher the value, the smaller the connection between modules and the stronger the independence of modules. Suppose $N$ modules; $\mu_1, \mu_2$ are any two modules; $s_i^{\mu_1}$ is any service activity in module $\mu_1$; $s_j^{\mu_2}$ is any service activity in module $\mu_2$. $N_{\mu_1}, N_{\mu_2}$ are the number of service units in module $\mu_1$ and module $\mu_2$, respectively; $y_{ij}^{\mu_1, \mu_2}$ is the correlation value of service unit $s_i^{\mu_1}$ in module $\mu_1$ to service activity $s_j^{\mu_2}$ in module $\mu_2$; $s_{ij}^{\mu_1}$ is the correlation value of service unit $s_j^{\mu_2}$ in module $\mu_2$ to service activity $s_i^{\mu_1}$ in module $\mu_1$; $f_{\text{in}}$ represents the relationship between modules $\mu_1$ and $\mu_2$; and $f_{\text{out}}$ represents the average relationship between modules. The larger the value of $f_{\text{in}}$, the closer the relation within the module and the better the cohesion of the module. The formula is as follows:

$$f_{\text{in}} = \sum_{i=1}^{N} \sum_{j=1}^{N} y_{ij}^{\mu_1, \mu_2}, \quad (i, j = 1, 2, L \ldots, n, \mu_1 = 1, 2, L \ldots, N),$$

$$F_1 = \frac{1}{N} \sum_{\mu_1=1}^{N} \frac{f_{\text{in}}}{N_{\mu_1}^2},$$

$$F_2 = \frac{1}{N} \sum_{\mu_1=1}^{N-1} \sum_{\mu_2=\mu_1+1}^{N} \frac{f_{\text{out}}}{2 N_{\mu_1} N_{\mu_2}},$$

(14)

6. Case Analysis

SHD is a large-scale coal production enterprise located in China’s energy-rich areas. Its main business is coal development, production, and operation. The company has the world’s top equipment and great technical strength. In recent years, in accordance with the national requirements of coal production reduction and production limits, some equipment and personnel have remained idle. In order to revitalize these idle resources and increase enterprise efficiency, since 2016 the company has introduced technology and equipment aimed at internal services to the market, going on to provide coal machinery and equipment transportation, coal washing, equipment repair, and maintenance for many coal production enterprises in Inner Mongolia, Shanxi, and other locations, as well as a coal production enterprise in Northern Shaanxi to provide coal mine hosting.
services. As of the first half of 2020, the service revenue of SHD accounts for about 20% of its total revenue. However, the profit margin is low; there are no systematic service products, and the service items are limited, making it difficult to respond quickly to customer needs.

6.1. Service Unit Identification. Based on the literature [49] and research into SHD, a total of 23 service activities of SHD are identified (see Table 7).

6.2. Calculation of Synthetic SER-DSM Matrix. Five SHD enterprise technical experts and university coal experts were organized to evaluate the relationship between the above service activities on the dimensions of function, resource, and time, and the SER-DSM matrix of each dimension was constructed. The weight was calculated using the analytic hierarchy process, which is not discussed in this paper. The weight of each dimension was set as function weight $\lambda_f = 0.39$, resource weight $\lambda_r = 0.24$, and time weight $\lambda_t = 0.37$. For reasons of space, this paper takes service activities 8 and 9 as examples to illustrate the evaluation semantics and triangular fuzzy numbers reached by the experts according to the multiple criteria given in Tables 2–4. The results are shown in Tables 8–10.

According to formula (3), the evaluation level belief degree for each dimension of service activities 8 and 9 was obtained by integrating expert evaluation information, as shown in Table 11. In the table, $q = (f, r, t)$ represents function dimension, resource dimension, and time dimension.

Then, according to formula (4) and Table 5, the evaluation information from the fusion experts in the functional dimension was calculated, and the evaluation results and confidence of all service activities in the functional dimension were obtained. For reasons of space, this paper shows only part of the content of the functional association relationship evaluation matrix (Table 12).

Similarly, the resource SER-DSM, time SER-DSM, and function SER-DSM were calculated. The complexity of the calculation process makes it difficult to present it here, and the calculations used to support the findings of this study are available from the corresponding author upon request.

According to formulas (6)–(12), the evaluation matrix of function, resource, and time dimensions was fused to obtain a clear and comprehensive SER-DSM, as shown in Table 13.

According to the analysis in Section 5.1, the numbers of the independent service activities in the comprehensive SER-DSM matrix are 7, 15, 17, 18, 20, 21, 22, and 23. There are no common service activities. For convenience in subsequent calculations, the general service activities were renumbered as shown in Table 14.

6.3. Module Clustering. Through orthogonal experiment, the results show that the optimal parameter combination scheme is population size $n = 100$, crossover probability $PC = 0.65$, and mutation probability $PM = 0.01$. In this study, the number of iterations (set to 1,000) was taken as the condition for the genetic algorithm to stop running. In the parameter combination scheme, in order to obtain the optimal solution of module partition, 10 experiments were carried out. The hardware configuration for the experiment consisted of an Intel Core i3 processor with 200 GB memory, and the software configuration consisted of Windows 7 operating system and MATLAB version 2016a. The experimental results are shown in Table 15.

The optimal service module partition of general service activity was obtained by taking the calculation result corresponding to the maximum fitness value through several iterative experiments, which is the result of Experiment 9.

Figure 5 shows the iteration curve of the fitness function of the process with the highest fitness value. The approximation curve at the lower end of the graph represents the mean value of the fitness function, while the step curve at the upper end of the graph represents its maximum value. Because of the low mutation rate, the convergence image is gentle but the maximum value is obtained quickly.

The service module division scheme of SHD is shown in Table 16.

From the above results, it is clear that the general activities of SHD can be divided into four modules: mine design (Module 1); environmental protection engineering (Module 2); administrative engineering (Module 3); and activities 4–14 in Table 14, involving the main production business of coal mining systems, such as ground setting and construction, coal mining and tunneling, underground transportation, supply of materials, and maintenance of equipment (Module 4). In SHD, there were only two services: moving and face down services, and coal mine overall trusteeship. The results of this study show that Module 4 categorizes the processes closely related to coal mining into a
single module, instead of providing moving and face down services alone, which improves personnel safety.

6.4. Customized Service Model and Application to SHD. After the preliminary division of modules, it was necessary to separate, replace, delete, and add modules to form a structured module system [50]. The necessary operation of the independent public module partition scheme was carried out, and the maintenance services and Module 4 were separated; two independent consulting service activities were merged into one module. Ultimately, there are seven independent modules and five general modules. The customized service model system for SHD is formed as shown in Table 17, and there are five general modules that need to be customized according to customer needs. At the same time, they can be combined according to the personalized needs of customers to form a customized service scheme.

Because of capacity constraints, SHD had a variety of idle equipment, with a net value of nearly 110 million yuan. In October 2019, SHD learned that SW coal mine was planning to develop a new coal face and contacted them in the hope of providing the necessary equipment. Due to its large capital occupation, SW intends to rent equipment; the company also has equipment maintenance, installation, and other needs. SHD has thus responded quickly to the market and accepted orders from customers. The independent leasing module and the customized maintenance module have been quickly combined to organize staff to carry out business. SW has leased 149 sets of equipment, with a rental fee of 99.94 million yuan and a maintenance fee of 58.3 million yuan. The feasibility of responding to the market using the above research results is thus confirmed.

Table 8: Experts’ evaluations of the functional relationship between service activities 8 and 9.

| Expert | Fuzzy semantics | Triangular fuzzy number |
|--------|-----------------|------------------------|
| 1      | Coal mining and drivage are indispensable for the completion of coal stripping. | (0.8, 0.9, 1) |
| 2      | Coal mining and drivage are indispensable for the completion of coal stripping. | (0.8, 0.9, 1) |
| 3      | Coal mining and drivage are indispensable for the completion of coal stripping. | (0.8, 0.9, 1) |
| 4      | Coal mining and drivage are indispensable for the completion of coal stripping. | (0.8, 0.9, 1) |
| 5      | Coal mining and drivage are indispensable for the completion of coal stripping. | (0.8, 0.9, 1) |

Table 9: Experts’ evaluations of the resource correlation between service activities 8 and 9.

| Expert | Fuzzy semantics | Triangular fuzzy number |
|--------|-----------------|------------------------|
| 1      | Coal mining and drivage share part of the equipment and energy resources, which are critical and sufficient. | (0.8, 0.9, 1) |
| 2      | Coal mining and drivage share part of the equipment and energy resources, which are critical and sufficient. | (0.8, 0.9, 1) |
| 3      | Coal mining and drivage share part of the equipment and energy resources, which are abundant. | (0.4, 0.5, 0.6) |
| 4      | Coal mining and drivage share part of the equipment and energy resources, which are critical and sufficient. | (0.8, 0.9, 1) |
| 5      | Coal mining and drivage share part of the equipment and energy resources, which are critical and sufficient. | (0.8, 0.9, 1) |
Table 10: Experts’ evaluations of the time correlation between service activities 8 and 9.

| Expert | Fuzzy semantics                                           | Triangular fuzzy number          |
|--------|-----------------------------------------------------------|----------------------------------|
| 1      | Coal mining should not precede drivage.                   | (0, 0.1, 0.3)                    |
| 2      | Coal mining cannot precede drivage, but both of them circulate many times. | (0.8, 0.9, 1)                    |
| 3      | Coal mining should not precede drivage.                   | (0, 0.1, 0.3)                    |
| 4      | Coal mining cannot precede drivage, but both of them circulate many times. | (0.8, 0.9, 1)                    |
| 5      | Coal mining cannot precede drivage, but both of them circulate many times. | (0.8, 0.9, 1)                    |

Table 11: Evaluation of belief degree for each dimension of service activities 8 and 10.

| β | k = 1 | k = 2 | k = 3 | k = 4 | k = 5 |
|---|-------|-------|-------|-------|-------|
|   |       |       |       |       |       |
| Functional dimension | 0     | 0     | 0     | 0     | 1     |
| Resource dimension   | 0     | 0     | 0     | 0.6   | 0.4   |
| Time dimension       | 0.4   | 0     | 0     | 0     | 0.6   |

Table 12: Evaluation matrix of functional relationship between service activities.

| Service activity number | 1 | 8 | 9 | 10 | 11 | 12 |
|-------------------------|---|---|---|----|----|----|
| 1                       |   |   |   |    |    |    |
| 8                       |   |   |   |    |    |    |
| 9                       |   |   |   |    |    |    |
| 10                      |   |   |   |    |    |    |
| 11                      |   |   |   |    |    |    |
Table 13: Integrated SER-DSM matrix.

|   | w1   | w2    | w3    | w4    | w5    | w6    | w7    | w8    | w9    | w10   | w11   | w12   | w13   | w14   | w15   | w16   | w17   | w18   | w19   | w20   | w21   | w22   | w23   |
|---|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| w1| 1    | 0.0267| 0     | 0.0383| 0.027 | 0.0182| 0     | 0     | 0     | 0     | 0     | 0.03  | 0.03  | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w2| 0.018| 1     | 0     | 0     | 0     | 0     | 0     | 0     | 0.03  | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w3| 0.018| 0     | 1     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w4| 0.01315| 0 | 0.018 | 0 | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w5| 0.018 | 0     | 0     | 0     | 0.1   | 0     | 0     | 0     | 0     | 0     | 0     | 0.1   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w6| 0.018 | 0     | 0     | 0     | 1     | 0.048 | 0     | 0     | 0.06  | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w7| 0     | 0     | 0     | 0     | 0     | 1     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w8| 0     | 0     | 0.0115| 0     | 0     | 1     | 0.101 | 0.1   | 0.05  | 0.04  | 0.03  | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w9| 0.018 | 0     | 0     | 0     | 0     | 0.2   | 1     | 0.2   | 0.15  | 0.1   | 0.11  | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w10| 0.018 | 0     | 0     | 0.0391| 0     | 0     | 0.1   | 1     | 0.118 | 0.1   | 0.2   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w11| 0.018 | 0     | 0     | 0     | 0     | 0.138 | 0.1   | 0     | 0.13  | 0.1   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w12| 0.018 | 0     | 0     | 0.0741| 0     | 0.1   | 0.13  | 0.1   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w13| 0.018 | 0     | 0     | 0.076 | 0     | 0.1   | 0.1   | 0.12  | 0.12  | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w14| 0     | 0     | 0     | 0     | 0     | 0     | 0.113 | 0     | 0     | 1     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w15| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w16| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0.029 | 0     | 0.03  | 0.03  | 0     | 0     | 0     | 1     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w17| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w18| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| w19| 0     | 0     | 0     | 0     | 0     | 0     | 0.066 | 0     | 0.06  | 0.1   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 0     | 0     | 0     |
| w20| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1     |
| w21| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 0     |
| w22| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 0     |
| w23| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1     |
Table 14: General service activities.

| No. | Service unit                           |
|-----|----------------------------------------|
| 1   | Mine design                            |
| 2   | Environmental protection engineering   |
| 3   | Administrative engineering             |
| 4   | Hoisting engineering                   |
| 5   | Power supply engineering               |
| 6   | Ventilation engineering                |
| 7   | Mining                                 |
| 8   | Drivage                                |
| 9   | Support and installation of equipment  |
| 10  | Lifting system                         |
| 11  | Ventilation and drainage               |
| 12  | Power supply                           |
| 13  | Moving upside down                     |
| 14  | Provisioning                           |
| 15  | Equipment maintenance                  |

Table 15: Optimal module division.

| Test | Module | Objective | Objective mean/STD | Fitness | Fitness mean/STD |
|------|--------|-----------|--------------------|---------|------------------|
| 1    | 4      | 0.427823212 | 0.426725267/0.001449 | 0.93268201 |
| 2    | 4      | 0.428067727 | 0.93289476         |         |
| 3    | 6      | 0.426723442 | 0.9317263          |         |
| 4    | 4      | 0.427064527 | 0.9320225          |         |
| 5    | 4      | 0.425964327 | 0.93106777         |         |
| 6    | 5      | 0.426322041 | 0.93137797         | 0.93173/0.001257 |
| 7    | 4      | 0.42476842  | 0.9303221          |         |
| 8    | 4      | 0.428227725 | 0.93303403         |         |
| 9    | 4      | 0.428422832 | 0.93320391         |         |
| 10   | 3      | 0.42386842  | 0.92925439         |         |

Table 16: Optimal scheme of service module division in coal enterprises.

| Module | Service unit                                      |
|--------|--------------------------------------------------|
| 1      | Mine design                                      |
| 2      | Environmental protection engineering             |
| 3      | Administrative engineering                       |
| 4      | Hoisting engineering, power supply engineering, mining, drivage, support and installation of equipment, lifting system, ventilation and drainage, power supply, moving upside down, provisioning, equipment maintenance |

Table 17: Service module system for SHD.

| Module type | Module name                      | Service activity                                      |
|-------------|----------------------------------|-------------------------------------------------------|
| Independent | Construction of auxiliary facilities | Auxiliary engineering                               |
|             | Logistics                         | Coal transportation                                   |
|             | Lease                             | Equipment leasing                                    |
|             | Technical consultation            | Mine construction and technical consultation          |
|             | Training                          | Training                                              |
|             | Coal washing and processing       | Coal preparation                                     |
| General     | Design                            | Mine design                                          |
|             | Environmental engineering         | Environmental protection engineering                  |
|             | construction infrastructure       | Administrative engineering                           |
|             | Coal production                   | Hoisting engineering, power supply engineering, ventilation engineering, mining, drivage, support and installation of equipment, lifting system, ventilation and drainage, power supply, moving upside down, provisioning |
|             | Repair                            | Equipment maintenance                                 |
7. Conclusion

Using DSM, this study analyzes the modular system architecture modeling and clustering of customized services in the mining industry with a view to resolving the problems of determining service activity correlation and reasonable segmentation of service modules. A number of general conclusions can be drawn.

(1) There has been little research on the application of service modularization theory and methods in the mining industry, which is technologically complex and has a single-product structure. The present study helps to expand the application scope of service modularization theory and promote business model innovation in the coal, oil, and natural gas industries.

(2) Focusing on the problem of determining the association relationship of service activities in the process of service modular design, and drawing on DSM, the association relationship model between service activities can be constructed from multiple dimensions. Here, the fuzzy measurement of the comprehensive association relationship of service activities in multiple dimensions and with uncertain information was constructed using triangular fuzzy number and fuzzy ET methods.

(3) According to the information characteristics of row and column elements in the design structure, the structure of service modules can be divided. On this basis, the mathematical programming model with the maximum sum of average cohesion and coupling degree was constructed, and a genetic algorithm was used to carry out a clustering calculation to obtain the best service module partition scheme. The disadvantage of this method is that the clustering method does not achieve the optimal degree of cohesion and coupling. However, the proposed method does not need prior information (such as clustering center or module partition granularity); after the clustering analysis, it can divide the service modular architecture, thereby determining the boundaries of contract, performance, and responsibility division for customized services in the mining industry. At the same time, it helps service providers to determine the business scope of customized services and to improve the efficiency of their customized service scheme design. It also helps customers to clarify their outsourcing business content and to focus on their own competitive business processes.

(4) Taking the SHD coal company as an example, the feasibility of the proposed method has been verified. There are two kinds of service items in SHD. The calculations in this study yield 11 service modules, which can form a variety of customized service items according to customer needs, and solve the problem of rapid market response.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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