Two-Sided Matching Model of Shared Manufacturing Resources considering Psychological Behavior of Agents

1. Introduction

In recent years, driven by the booming mobile Internet technology, an economic model called "sharing economy" is emerging. As a new economic model, it can realize sharing of ownership of resources through the peer-to-peer market platform. The sharing economy has achieved a win-win situation among enterprises through online service and has attracted significant attention in many industries, such as tourism, trade, finance, and medical care. Especially in the transportation and hotel industries, companies such as Uber and Airbnb have achieved great success. In the era of rapid development of sharing economy, shared manufacturing has quietly emerged. The sharing of manufacturing resources which is a combination of sharing economy and manufacturing industry has become a new highlight of development.

Shared manufacturing is a new mode of social manufacturing based on the principles of sharing economy. Ellen [1] proposed the concept of “shared manufacturing” in 1990. Ari Samadhi and Hoang [2] proposed the sharing of computer-integrated manufacturing system in the complex manufacturing environment. Sheikhzadeh et al. [3] considered two types of machine sharing configuration in manufacturing systems: total flexibility and chaining. The global manufacturing industry is in a period of transformation from production-oriented manufacturing to service-oriented manufacturing. The rapid changes of the market and the diversified needs of users make manufacturers often be faced with high-efficiency and high-intensity orders, which cannot be met by their manufacturing capabilities. Simultaneously, unbalanced regional development and insufficient market demand often result in idle resources and wasteful capacity. The shared manufacturing platform is the core carrier of the shared manufacturing mode, which provides users with a platform for exchanging information, trading goods, and selling services. And, it provides manufacturing services for bilateral markets. The demanders and providers of manufacturing resources can publish capabilities and requirements on the platform at any time and place. The shared manufacturing platform acting as the interface matches the qualified demanders and providers precisely.

The shared manufacturing platform contains a large amount of manufacturing resource information. Among them, there is a large amount of shared manufacturing
service with the same or similar functions but different quality of service. The shared manufacturing service can be added and withdrawn dynamically, and the quality of service and requirements are also variable. Through aforementioned analysis, how to match demanders and providers properly in shared manufacturing becomes a key problem. On the one hand, it is vital to choose appropriate method to deal with evaluation information in shared manufacturing platform. On the other hand, in order to improve the accuracy of resource matching in the shared manufacturing platform, more psychological behavior of agents should be considered. Therefore, the problem of two-sided matching should be resolved to facilitate transactions of resources. This paper proposes a two-sided matching model of shared manufacturing resources considering psychological behavior of agents. The cloud model is used to quantify the qualitative language and deal with the quantification of preference information more objectively to embody the fuzziness and uncertainty of the cognitive degree of two agents. At the same time, based on prospect theory, the grey relational analysis method is introduced to deal with the satisfaction of matching agents as a whole, which reflects the agent’s psychological attitude.

The rest of this paper is organized as follows: In Section 2, the literature review is provided. In Section 3, it introduces the problem description and preliminaries. We propose the construction and solution of the two-sided matching model in Section 4. Numerical example using MATLAB is given in Section 5. Finally, Section 6 provides conclusions.

2. Literature Review

Two streams of the literature are relevant to this study, i.e., development of shared manufacturing and two-sided matching.

The shared manufacturing model is the application practice of using mobile Internet technology to solve the imbalance of social manufacturing resources. Yu et al. [4] presented the concept and definition of shared manufacturing on the basis of a service hierarchy and analyzed the service operations of shared manufacturing along with the trends of two significant manufacturing evolutions. He et al. [5] introduced the research status and significance of shared manufacturing in the Chinese manufacturing industry and classified the main shared manufacturing contents in detail. Yu et al. [6] proposed the blockchain-based shared manufacturing (BSM) framework in support of the application of Cyber-Physical Systems (CPS). Rozman et al. [7] presented a scalable framework for blockchain-based on shared manufacturing. Wang et al. [8] proposed a digital twin-driven service model and optimal allocation of manufacturing resources in shared manufacturing. Li et al. [9] considered the pricing strategies for the shared manufacturing model based on the cloud platform. Ayala et al. [10] studied the dynamic application of knowledge sharing in manufacturing companies depended on the type of collaboration and service object. Zhao and Du [11] analyzed the impact of information sharing through the whole supply chain on the strategies of manufacturing capability sharing under the context of Internet of Things. Bao and Cai [12] studied the intelligent production sharing and user experience based on the case of Shenyang Machine Tool. Dai et al. [13] considered the realization mechanism of sharing pattern innovation in service manufacturing enterprises by using a grounded theory analysis based on service leading logic.

The study of two-sided matching first appeared in Gale and Shapley [14] on college enrollment and marital stability, which immediately aroused widespread concern in academia. Li et al. [15] selected service by calculating the similarity of function and quality and proposed an intelligent service searching and matching method for cloud manufacturing service based on formal description of cloud manufacturing service. Dong and Guo [16] obtained the quality of service acquisition method of cloud manufacturing through a mutual evaluation mechanism and established the trust evaluation model for cloud manufacturing service. Zhao and Wang [17] proposed a two-sided matching model for cloud service based on quality of service. Some scholars also studied the matching problem in practical situations from the perspective of preference information. Fan et al. [18] proposed a decision analysis method for two-sided satisfied matching considering stable matching conditions. Kamiyama [19] proposed an acceptable matching problem with two-sided preference lists and matroid constraints. Zhang et al. [20] developed a new method of two-sided matching decision with the fuzzy preference relation with self-confidence on the basis of the extended logarithmic least squares method and the proposed consistency improvement algorithm. Zhang et al. [21] developed a two-sided matching decision-making method with multigranularity hesitant fuzzy linguistic term sets and constructed optimization models to determine the standard weights of matching objects. Zhang et al. [22] proposed a new method of stable two-sided matching decision-making with incomplete fuzzy preference relation based on the disappointment theory. Li et al. [23] proposed a bilateral matching model based on double hesitation and ambiguity in cloud manufacturing platform. Li et al. [24] put forward a two-sided matching decision model with bidirectional projection under uncertain and fuzzy preference information. Zhang and Su [25] studied a combined fuzzy DEMATEL and TOPSIS method to estimate participants. Besides, some scholars also pay attention to the psychological behavior of the agent in two-sided matching. Zhang et al. [26] proposed a two-sided matching method considering regret aversion psychological behavior and matching aspiration of the agents. Zhao and Li [27] determined the preference of the matching agent based on the prospect theory and designed a “many-to-many” matching algorithm to obtain a stable matching result. Zhang et al. [28] considered the decision model and application of two-sided matching of uncertain information based on grey relational analysis. Bi et al. [29] studied the decision method for two-sided matching with linguistic evaluation based on cloud model and prospect theory.

Although there have studies that have solved various forms of two-sided matching problems in cloud manufacturing, few studies consider the two-sided matching
3. Problem Description and Preliminaries

3.1. Problem Description. With the development of the sharing economy and the popularization of mobile Internet technology, manufacturing enterprises tend to share production materials selectively. At this time, a third-party platform is used to integrate and release this production information and to operate and maintain the entire sharing mechanism. This paper is devoted to examining such a shared manufacturing platform that provides an accurate matching between a large number of orders and providers and helps the demanders quickly find the providers of qualified manufacturing resources and service capabilities. Also, the platform provides matching and trading services for M demanders and N providers. In the process of matching shared manufacturing resources with two-sided demand, the shared manufacturing platform provides a reasonable matching plan based on the expected level and the actual measured level of quality of service under the condition of comprehensively considering the satisfaction of both agents. The two-sided matching model of shared manufacturing resources considering psychological behavior of agents can be described in Figure 1.

The basic description of the problem about two-sided matching is set out. Let the resource provider side be S = {s1, s2, . . . , sn}, and sj means the jth (j = 1, 2, . . . , n) provider in the S. The resource demander side is D = {d1, d2, . . . , dm}, and di means the ith (i = 1, 2, . . . , m) demander in the D. The resource provider sj (provider di) hopes to choose a satisfied demander di (provider sj).

The satisfaction of the agent of two-sided matching is calculated based on the prospect theory and grey relational analysis method. Let C = {c1, c2, . . . , cf} be the set of satisfaction evaluation indicators on the quality of service from the demander di to the provider sj. Ck is the kth (k = 1, 2, . . . , f) indicator, and each indicator is separate. The set of satisfaction evaluation A includes the following indicators: the technical difficulty (a1) ("difficult" means that it can process all tasks below "difficult" technical requirements), reputation (a2), and payment speed (a3) (how many days do you want to pay 95% of the full amount after the order task is placed, and 5% is the warranty deposit). aWk = the weight corresponding to each indicator, which satisfies aWk > 0 and fKk=1 aWk = 1. Subsequently, the demander di gives the expected value Eki and the actual measured value rki of each indicator of the provider sj. The provider’s expected value and actual measured value of the demander’s indicators can be obtained in the same way.

Combined with reality, indicators can be described as numerical values or evaluation phrases. One type is an indicator that can be measured with actual numbers such as price, and the corresponding subset is denoted as CEx(A). And, the other type is an indicator that can only be evaluated by language, such as reputation. The corresponding subset is represented as CEx(A) and C = CEx(A) ∪ CEx(A). In this paper, the cloud model is used to convert the indicators of language evaluation into quantitative standard values.

3.2. Preliminaries

3.2.1. Definition of the Two-Sided Matching. Suppose there are two agents; they are the demander and the provider. And, the set of provider is S = {s1, s2, . . . , sn}, n ≥ 2, where sj is the jth provider, j = 1, 2, . . . , n. The set of demander is D = {d1, d2, . . . , dm}, m ≥ 2, where di represents the ith demander, i = 1, 2, . . . , m. There is a hypothesis that m ≤ n. The basic model of two-sided matching is shown in Figure 2.

Definition 1 (see [30]). For a one-to-one mapping relationship µ: D ∪ S → D ∪ S, meanwhile, ∀di ∈ D and ∀sj ∈ S satisfy the following conditions:

(1) µ(di) ∈ S ∪ d, if µ(di) = di, there is no matching agent in di

(2) µ(sj) ∈ D ∪ s, if µ(sj) = sj, there is no matching agent in sj

(3) µ(di) = sj, if and only if µ(sj) = di, µ satisfies two-sided matching

Among them, µ(di) = sj means di is matched with sj in µ, which can be represented as [d, s] and µ(sj) = sj means sj is matched with itself, that is, it does not be matched.

3.2.2. Concept of the Cloud Model. For the indicators that can only be evaluated in language, this paper adopts the cloud model to transform. The cloud model (Li et al. [31]) is an uncertain transformation that deals with qualitative concepts and quantitative numerical descriptions. The overall characteristics of the concepts described by the cloud model can be represented by three digital attributes of the cloud, expectation EEx, entropy EEx, and hyper-entropy HEx, called the eigenvectors of the cloud which are denoted by: C(EEx, EEx, HEx). EEx is the central position of the indicator concept in the universe of
discourse and is the value that best represents the qualitative concept; $E_n$ is the measure of the randomness of the qualitative concept, reflecting the degree of dispersion of the qualitative concept of cloud drops; and $H_e$ is a measure of the uncertainty of entropy, which is determined by the randomness and ambiguity of entropy. Due to the general applicability of normal cloud, this paper expresses the language variable in the language evaluation set as the normal cloud model, that is, the digital features of cloud model satisfy

$$y = e^{-\left(x-E_e\right)^2/2E_e^2}.$$  

In the process of matching shared manufacturing resources, reviews are generally divided into five levels. Therefore, the phrase evaluation of each indicator is also divided into five groups which, respectively, represent "very satisfied/very difficult, satisfied/difficult, basically satisfied/fair, dissatisfied/easy, very dissatisfied/very easy." According to the right domain $[x_{\text{min}}, x_{\text{max}}]$ specified by experts, five clouds can be generated. The middle cloud is $C_0\left(E_{x0}, E_{n0}, H_{e0}\right)$. The left and right neighboring clouds are, respectively, $C_1\left(E_{x-1}, E_{n-1}, H_{e-1}\right)$, $C_{-1}\left(E_{x+1}, E_{n+1}, H_{e+1}\right)$, $C_2\left(E_{x-2}, E_{n-2}, H_{e-2}\right)$, and $C_{-2}\left(E_{x+2}, E_{n+2}, H_{e+2}\right)$. And, the golden section can be used to generate the following digital features:

$$E_{x0} = \frac{x_{\text{min}} + x_{\text{max}}}{2},$$

$$E_{x-2} = x_{\text{min}},$$

$$E_{x+2} = x_{\text{max}},$$

$$E_{x-1} = E_{x0} - 0.382\left(x_{\text{max}} - x_{\text{min}}\right)/2,$$

$$E_{x+1} = E_{x0} + 0.382\left(x_{\text{max}} - x_{\text{min}}\right)/2,$$

$$E_{n-1} = E_{n+1} = 0.382\left(x_{\text{max}} - x_{\text{min}}\right)/6,$$

$$E_n = 0.618E_{n+1},$$

$$E_{n-2} = E_{n+2} = E_{n+1}/0.618,$$

$$H_{e-1} = H_{e+1} = H_{e0}/0.618,$$

$$H_{e-2} = H_{e+2} = H_{e+1}/0.618.$$  

Let the effective universe interval be $[0, 1]$ and the value of $H_{e0}$ is generally 0.005. "Very satisfied/very hard" corresponds to the cloud model $(1, 0.104, 0.013)$, and "satisfied/difficult" corresponds to the cloud model $(0.691, 0.064, 0.008)$; "basically satisfied/average" corresponds to the cloud model $(0.5, 0.039, 0.005)$ and "unsatisfied/easy" corresponds to the cloud model $(0.309, 0.064, 0.008)$. And, "very unsatisfied/very easy" corresponds to the cloud model $(0, 0.104,
The cloud model can effectively represent qualitative language variables. The expected value of the cloud model of each language variable is used as the satisfaction value of the matching agents to construct the preference matrix, respectively.

4. Construction and Solution of the Two-Sided Matching Model

4.1. Calculation of Satisfaction Based on Prospect Theory and Grey Relational Analysis. The prospect theory uses the gap between the actual measured value and the reference point as the basis for measuring gains and losses and evaluating the quality. In this paper, taking the demander side as an example, the demander’s expected value \( e^k_i \) of the provider’s indicators is used as a reference. When the demander’s actual measured value \( r^k_{ij} \) of the provider’s indicators is obtained, the relationship between the two agents is compared. Meanwhile, the gain or loss value of \( r^k_{ij} \) to \( e^k_i \) is obtained. When making decisions in prospect theory, people care more about the gap between the actual measured value and the reference point. Therefore, this paper introduces the grey relational analysis method. The grey relational coefficient is used to judge the closeness of expected value \( e^k_i \) from the demander side to the provider side to the actual measured value \( r^k_{ij} \) under each indicator, so as to improve the value function in the prospect theory. The provider side uses the same calculation method for the demander side.

The distance between the actual measured value and the reference point is denoted as

\[
d^k_{ij} = |r^k_{ij} - e^k_i|, \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n. \tag{3}
\]

On this basis, the gain and loss value of \( r^k_{ij} \) relative to \( e^k_i \) is described as

\[
B^k_{ij} = \begin{cases} 
    d^k_{ij}, & r^k_{ij} \geq e^k_i \\
    -d^k_{ij}, & r^k_{ij} < e^k_i, 
\end{cases} \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n. \tag{4}
\]

When \( B^k_{ij} \) is positive, it is called gain and when it is negative, it is called loss. On the basis of the gain and loss value, the grey relational coefficient between the demander \( d_i \) and the provider \( s_j \) under the indicator \( c_k \) is defined as

\[
\zeta^k_{ij} = \frac{\min_{j} \min_{i} B^k_{ij} + \rho \max_{i} \max_{j} B^k_{ij}}{\max_{i} \max_{j} B^k_{ij}}. \tag{5}
\]

Here, \( \rho \) is the resolution coefficient and \( \rho \in [0, 1] \), which is generally 0.5.

Taking into account the different risk attitudes of the agent to gains and losses, the grey relational coefficient is substituted into the utility value function and the indicator prospect value is denoted as

\[
V^k_{ij} = \begin{cases} 
    (1 - \zeta^k_{ij})^{\alpha}, & r^k_{ij} \geq e^k_i \\
    -\lambda \left[ (r^k_{ij} - 1)^{\beta} - 1 \right], & r^k_{ij} < e^k_i, 
\end{cases} \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n; k = 1, 2, \ldots, f. \tag{6}
\]

Among them, \( 0 < \alpha < 1, 0 < \beta < 1, \) and \( \lambda > 1 \). The coefficient \( \lambda \) reflects the agent’s psychological performance of being more sensitive to losses relative to gains. The larger the \( \lambda \), the greater the degree of loss aversion. Referring to He and Zhou [32], it is taken as \( \alpha = \beta = 0.88 \) and \( \lambda = 2.25 \).

Before the weighted summation, the foreground value of the indicator needs to be de-dimensionalized to truly reflect the weight relationship of each indicator. The prospect value is normalized as

\[
V^k_{ij} = \frac{V^k_{ij}}{\max_{j=1,2,\ldots,n} V^k_{ij}}, \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n. \tag{7}
\]

The satisfaction prospect value of the demander \( d_i \) to the provider \( s_j \) is denoted as

\[
P_{ij} = \sum_{k=1}^{f} \omega_k V^k_{ij}, \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n; k = 1, 2, \ldots, f. \tag{8}
\]

The satisfaction prospect matrix of the provider \( s_j \) to the demander \( d_i \) can be obtained.

4.2. Construction of the Model. In the process of matching the agents in shared manufacturing, there are one-to-one, one-to-many, and many-to-many situations. And, only one-to-one situation is considered here. Let \( x_{ij} \) represent a 0-1 variable where \( x_{ij} = 0 \) represents that \( d_i \) and \( s_j \) do not match in \( \mu \). And, \( x_{ij} = 1 \) represents that \( d_i \) and \( s_j \) match in \( \mu \). The multiobjective matching model is established by the prospect matrices \( V_D = (P_{ij})_{m \times n} \) and \( V_S = (P_{ij})_{m \times n} \) as follows:

\[
\begin{align}
\text{max } G_D &= \sum_{i=1}^{m} \sum_{j=1}^{n} P_{ij} x_{ij}, \\
\text{max } G_S &= \sum_{i=1}^{m} \sum_{j=1}^{n} P_{ij} x_{ij}, \\
\text{s.t. } \sum_{j=1}^{n} x_{ij} &= 1, \quad i = 1, 2, \ldots, m, \\
\sum_{i=1}^{m} x_{ij} &\leq 1, \quad j = 1, 2, \ldots, n.
\end{align} \tag{9a,b,c}
\]
\[
\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} = \min\{m, n\}, x_{ij} \in \{0, 1\}, \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n.
\]  
\hspace{2cm} (9d)

The meaning of the objective functions is to maximize the sum of the prospect value of the demander side to the provider side and to maximize the sum of the prospect value of the provider side to the demander side. The meaning of equation (9b) is that each demander must be matched with only one provider. And, equation (9c) indicates that each provider can only be matched with at most one demander. Equation (9d) is the constraint on the number of two-sided matching, which guarantees the maximum number of successful matches and the platform’s interests.

4.3. Solution to the Model. In order to solve the multi-objective optimization model, let \(\phi_D\) and \(\phi_S\) denote the weights of \(G_D\) and \(G_S\), respectively, and satisfy \(0 < \phi_D, \phi_S < 1\) and \(\phi_D + \phi_S = 1\). The linear weighting method is used to convert the multiobjective model into the single-objective model:

\[
\max G = \phi_D \sum_{i=1}^{m} \sum_{j=1}^{n} P_{ij}x_{ij} + \phi_S \sum_{i=1}^{m} \sum_{j=1}^{n} \bar{P}_{ij}x_{ij} = \sum_{i=1}^{m} \sum_{j=1}^{n} T_{ij}x_{ij},
\]  
\hspace{2cm} (10a)

s.t. \[\sum_{j=1}^{n} x_{ij} = 1, \quad i = 1, 2, \ldots, m,\]  
\hspace{2cm} (10b)

\[\sum_{i=1}^{m} x_{ij} = 1, \quad j = 1, 2, \ldots, n,\]  
\hspace{2cm} (10c)

\[
\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} = \min\{m, n\}, x \in \{0, 1\}, \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n.
\]  
\hspace{2cm} (10d)

Here, \(T_{ij} = \phi_D P_{ij} + \phi_S \bar{P}_{ij}\) and \(\phi_D\) and \(\phi_S\) reflect the importance of two agents. Generally, the fairness of the two agents is considered, and let \(\phi_D = \phi_S = 0.5\).

The process of two-sided matching of shared manufacturing resources is depicted in Figure 3 and is described as follows:

Step 1: by using the numerical values and evaluation phases, the expected values and actual measured values of the indicator of the demander \(d_i\) to the provider \(s_j\) and the provider \(s_j\) to the demander \(d_i\) are obtained.

Step 2: through the cloud model, the evaluation phrases are converted into numerical values.

Step 3: the grey relational coefficients between expected values and actual measured values of the demander \(d_i\) to the provider \(s_j\) and the provider \(s_j\) to the demander \(d_i\) are calculated.

Step 4: by applying equations (3)–(8), the satisfaction prospect matrix \(P_{ij}\) of \(d_i\) to \(s_j\) and \(\bar{P}_{ij}\) of \(s_j\) to \(d_i\) is obtained.

Step 5: the multiobjective model in (9a)–(9d) is established.

Step 6: by using linear weighting, the multiobjective model is transformed into the single-objective one (10a)–(10d).

Step 7: by solving the single-objective model, the matching results are obtained.

5. Numerical Example Analysis

In this paper, a numerical example of automobile mold parts is given and the historical data of the last year are obtained from the Mustard Network, a shared manufacturing platform, which includes 1081 orders and 23 providers. This paper extracts four demanders and five providers to match in the platform. The evaluation information is obtained by the preliminary processing and analysis of the related data of the shared manufacturing platform. The two-sided matching and verification processes are as follows.

In the two-sided matching of shared manufacturing resources considering psychological behavior of agents, the demander side evaluates the satisfaction to the provider side through four indicators: price \((c_1)\), technical service level \((c_2)\), reputation \((c_3)\), and delivery date \((c_4)\). And, the corresponding weights are 0.250, 0.231, 0.512, and 0.007. Meanwhile, the provider side evaluates the satisfaction to the demander side through three indicators: technical difficulty \((a_1)\), reputation \((a_2)\), and delivery date \((a_3)\). And, the corresponding weights are 0.453, 0.504, and 0.043. Among them, \(c_1\) and \(c_4\) are \(C^B\) and \(A_3\), respectively, and \(a_1\) and \(a_3\) are \(A^R\) and \(A^S\), respectively. The expected value and actual measured value of both demanders and providers is shown in Tables 1–4.

According to equations (2a)–(2c), the indicators of the five-level language evaluation in Tables 1–4 are represented by the cloud model and the expected value of the five cloud models is used as the preference values of two matching agents, as shown in Tables 5–8.

Besides, the grey relational coefficients between the expected value under each indicator and the actual measured value are calculated by equations (3)–(5), which can be shown in Tables 9 and 10.

The grey relational coefficient is put into the utility value function of prospect theory, and the prospect matrices \(V_D\) and \(\bar{V}_D\) are calculated by equations (6)–(8), which can be shown in Table 11.
The evaluation matrixes of expected values and actual measured values by the demander and the provider side

The evaluation phases are converted into numerical values through cloud model

The grey correlation coefficient between expected values and actual measured values are calculated

The satisfaction prospect matrixes are obtained by applying the Eqs. (3)–(8)

The multi-objective decision model (9a)–(9d) is established

The multi-objective model (9a)–(9d) is converted into a single-objective one (10a)–(10d)

The matching results are obtained by solving the model (10a)–(10d)

Figure 3: Two-sided matching process of shared manufacturing resources.

| Demander | Provider’s indicator |
|----------|----------------------|
|                      | c₁ | c₂ | c₃ | c₄ |
| d₁        | −6 | Satisfied | Basically satisfied | −13 |
| d₂        | −7 | Basically satisfied | Basically satisfied | −8 |
| d₃        | −6 | Basically satisfied | Unsatisfied | −19 |
| d₄        | −5 | Very satisfied | Unsatisfied | −5 |

Table 1: Expected evaluation information of demanders to providers.

| D       | S       | c₁ | c₂       | c₃       | c₄ |
|---------|---------|----|----------|----------|----|
| d₁      | s₁      | −6 | Basically satisfied | Unsatisfied | −10 |
|         | s₂      | −8 | Very satisfied | Unsatisfied | −15 |
|         | s₃      | −7 | Satisfied | Basically satisfied | −11 |
|         | s₄      | −5 | Basically satisfied | Satisfied | −18 |
|         | s₅      | −6 | Basically satisfied | Very satisfied | −14 |

Table 2: Actual measured evaluation information of demanders to providers.
Table 3: Expected evaluation information of providers to demanders.

| Provider | Demander’s indicator | \(a_1\) | \(a_2\) | \(a_3\) |
|----------|----------------------|--------|--------|--------|
| \(s_1\)  | Average              | \(-6\) |        |        |
| \(s_2\)  | Average              | \(-8\) |        |        |
| \(s_3\)  | Hard                 | \(-7\) |        |        |
| \(s_4\)  | Very hard            | \(-5\) |        |        |
| \(s_5\)  | Average              | \(-6\) |        |        |

Table 4: Actual measured evaluation information of providers to demanders.

| S | D     | \(a_1\) | \(a_2\) | \(a_3\) |
|---|-------|--------|--------|--------|
| \(s_1\) | Hard | Very satisfied | \(-7\) |        |
| \(s_2\) | Average | Basically satisfied | \(-7\) |        |
| \(s_3\) | Hard | Basically satisfied | \(-5\) |        |
| \(s_4\) | Average | Basically satisfied | \(-6\) |        |
| \(s_5\) | Average | Satisfied | \(-6\) |        |

From the satisfaction prospect matrix, this paper constructs a multiobjective optimization model, taking \(\phi_D = \phi_S = 0.5\) and converting the multiobjective optimization model to a single-objective optimization model, and the

Table 6: Actual measured values of demanders to providers.

| D | S | \(c_1\) | \(c_2\) | \(c_3\) | \(c_4\) |
|---|---|--------|--------|--------|--------|
| \(s_1\) | \(d_1\) | \(-6\) | 0.5 | 0.309 | \(-10\) |
| \(s_2\) | \(d_2\) | \(-8\) | 1 | 0.309 | \(-15\) |
| \(s_3\) | \(d_3\) | \(-7\) | 0.691 | 0.5 | \(-11\) |
| \(s_4\) | \(d_4\) | \(-5\) | 0.5 | 0.691 | \(-18\) |
| \(s_5\) | \(d_5\) | \(-6\) | 0.5 | 1 | \(-14\) |

The software package Matlab R2018b can be used to solve the above model, the objective value is 0.5660, and the matching result is \(\mu = \{[d_1, s_1], [d_2, s_4], [d_3, s_3], [d_4, s_5]\}\); that is, the demander 1 matches the provider 1, the demander 2 matches the provider 4, the demander 3 matches the

Coefficient matrix \(T = [t_{ij}]_{4 \times 5}\) is obtained, which can be shown in Table 12.
provider 3, and the demander 4 matches the provider 5. The provider 2 has not obtained the demander.

6. Conclusions

Shared manufacturing resources are different from traditional manufacturing resources. The complexity of the transaction process and the characteristics of the manufacturing industry determine the particularity of service matching options. A two-sided model of shared manufacturing resources considering psychological behavior of agents is proposed in this paper. The cloud model is
used to realize the conversion from qualitative evaluation to quantitative evaluation, which can solve the fuzziness of the linguistic evaluation. In accordance with preference information extracted by using the cloud model, the satisfaction prospect matrix is constructed through the combination of prospect theory and grey relational analysis. Based on it, the satisfaction prospect values of both agents are comprehensively considered. The model of two-sided matching for maximizing satisfaction prospect values from both agents is constructed. For the sake of obtaining the matching results, the solution is given. Meanwhile, the validity and rationality of the model are verified through a numerical example. Subsequently, the model is applied to solve the matching problem for shared manufacturing resources.

The future research of this research is as follows. First, it can be used to consider the intelligent optimization algorithm for shared manufacturing resource allocation. Second, the supply chain capability between agents of shared manufacturing will be investigated. Third, the application of implementing the one-to-many and many-to-many matching for shared manufacturing resources will be another work.

**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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