Research Article

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

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Sharing manufacturing is a new manufacturing mode based on sharing economy, which is one of the pillars of intelligent manufacturing. This paper proposes a two-sided matching model of shared manufacturing resources considering the psychological behavior of agents. We describe the definition of two-sided matching and introduce the concept of the cloud model. The preference information of agents is transformed to values according to the cloud model. We combine prospect theory and grey relational analysis to calculate the prospect values. Furthermore, an optimization model which aims to maximize the overall satisfaction degree of matching agents is established. A numerical example for the matching of providers and demanders is provided to verify the feasibility and effectiveness of the model.

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

in the shared manufacturing environment. At the same time, the preference information of most matching problem is based on an order value. However, most of the preference information given by the demanders and providers on the shared manufacturing platform is based on the linguistic evaluation. Meanwhile, the cloud model can use linguistic values to express the uncertainty transformation between qualitative and quantitative concepts. Also, the matching agent is usually abstract. The agent's psychological behavior in the matching process is ignored. Therefore, this paper combines prospect theory with the grey relational analysis method. According to this proposed method, we can holistically judge the degree of influence between the demanders and providers under all indicators. Then, a new calculating method of prospect value is obtained, which better reflects the psychological behavior of agents.

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 $S = \{s_1, s_2, \dots, s_n\}$, and s_j means the j th ($j = 1, 2, \dots, n$) provider in the S . The resource demander side is $D = \{d_1, d_2, \dots, d_m\}$, and d_i means the i th ($i = 1, 2, \dots, m$) demander in the D . The resource provider s_j (demander d_i) hopes to choose a satisfied demander d_i (provider s_j).

The satisfaction of the agent of two-sided matching is calculated based on the prospect theory and grey relational analysis method. Let $C = \{c_1, c_2, \dots, c_f\}$ be the set of satisfaction evaluation indicators on the quality of service from the demander d_i to the provider s_j . c_k is the k th ($k = 1, 2, \dots, f$) indicator, and each indicator is separate. The set of satisfaction evaluation C includes the following indicators: the price (c_1), technical service level (c_2), reputation (c_3), and delivery date (c_4) (the number of days required for processing and transportation). $A = \{a_1, a_2, \dots, a_g\}$ is the set of indicators on the quality of service evaluated from the provider s_j to the demander d_i . a_t

is the t th ($t = 1, 2, \dots, g$) indicator, and each indicator is separate. The set of satisfaction evaluation A includes the following indicators: the technical difficulty (a_1) ("difficult" means that it can process all tasks below "difficult" technical requirements), reputation (a_2), and payment speed (a_3) (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). ω_k is the weight corresponding to each indicator, which satisfies $\omega_k > 0$ and $\sum_{k=1}^{f/g} \omega_k = 1$. Subsequently, the demander d_i gives the expected value e_i^k and the actual measured value r_{ij}^k of each indicator of the provider s_j . 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 $C^R (A^R)$. And, the other type is an indicator that can only be evaluated by language, such as reputation. The corresponding subset is represented as $C^F (A^F)$ and $C = C^R \cup C^F$ ($A = A^R \cup A^F$). 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 be two agents; they are the demander and the provider. And, the set of provider is $S = \{s_1, s_2, \dots, s_n\}$, $n \geq 2$, where s_j is the j th provider, $j = 1, 2, \dots, n$. The set of demander is $D = \{d_1, d_2, \dots, d_m\}$, $m \geq 2$, where d_i represents the i th demander, $i = 1, 2, \dots, m$. There is a hypothesis that $m \leq n$. The basic model of two-sided matching is shown in Figure 2.

Definition 1 (see [30]). For a one-to-one mapping relationship $\mu: D \cup S \rightarrow D \cup S$, meanwhile, $\forall d_i \in D$ and $\forall s_j \in S$ satisfy the following conditions:

- (1) $\mu(d_i) \in S \cup d_i$, if $\mu(d_i) = d_i$, there is no matching agent in d_i
- (2) $\mu(s_j) \in D \cup s_j$, if $\mu(s_j) = s_j$, there is no matching agent in s_j
- (3) $\mu(d_i) = s_j$, if and only if $\mu(s_j) = d_i$, μ satisfies two-sided matching

Among them, $\mu(d_i) = s_j$ means d_i is matched with s_j in μ , which can be represented as $[d_i, s_j]$ and $\mu(s_j) = s_j$ means s_j 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 E_x , entropy E_n , and hyper-entropy H_e , called the eigenvectors of the cloud which are denoted by: $C(E_x, E_n, H_e)$. E_x is the central position of the indicator concept in the universe of

FIGURE 1: Two-sided matching model of shared manufacturing resources considering psychological behavior of agents.

FIGURE 2: Basic model of two-sided matching.

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 variables in the language evaluation set as the normal cloud model, that is, the digital features of cloud model satisfy

$$y = e^{-(x-E_x)^2/2E_n^2}. \quad (1)$$

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 $[x_{\min}, x_{\max}]$ specified by experts, five clouds can be generated. The middle cloud is

$C_0(E_{x0}, E_{n0}, H_{e0})$. The left and right neighboring clouds are, respectively, $C_{-1}(E_{x-1}, E_{n-1}, H_{e-1})$, $C_{+1}(E_{x+1}, E_{n+1}, H_{e+1})$, $C_{-2}(E_{x-2}, E_{n-2}, H_{e-2})$, and $C_{+2}(E_{x+2}, E_{n+2}, H_{e+2})$. And, the golden section can be used to generate the following digital features:

$$\begin{aligned} E_{x0} &= \frac{(x_{\min} + x_{\max})}{2}, \\ E_{x-2} &= x_{\min}, \\ E_{x+2} &= x_{\max}, \\ E_{x-1} &= E_{x0} - \frac{0.382(x_{\min} + x_{\max})}{2}, \end{aligned} \quad (2a)$$

$$\begin{aligned} E_{x+1} &= E_{x0} + \frac{0.382(x_{\min} + x_{\max})}{2}, \\ E_{n-1} &= E_{n+1} = \frac{0.382(x_{\max} - x_{\min})}{6}, \end{aligned}$$

$$\begin{aligned} E_n &= 0.618E_{n+1}, \\ E_{n-2} &= E_{n+2} = \frac{E_{n+1}}{0.618}, \end{aligned} \quad (2b)$$

$$\begin{aligned} H_{e-1} &= H_{e+1} = \frac{H_{e0}}{0.618}, \\ H_{e-2} &= H_{e+2} = \frac{H_{e+1}}{0.618}. \end{aligned} \quad (2c)$$

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,

0.013). 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_i^k of the provider's indicators is used as a reference. When the demander's actual measured value r_{ij}^k of the provider's indicators is obtained, the relationship between the two agents is compared. Meanwhile, the gain or loss value of r_{ij}^k to e_i^k 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_i^k from the demander side to the provider side to the actual measured value r_{ij}^k 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

$$d_{ij}^k = |r_{ij}^k - e_i^k|, \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n. \quad (3)$$

On this basis, the gain and loss value of r_{ij}^k relative to e_i^k is described as

$$B_{ij}^k = \begin{cases} d_{ij}^k, & r_{ij}^k \geq e_i^k \\ -d_{ij}^k, & r_{ij}^k < e_i^k \end{cases}, \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n. \quad (4)$$

When B_{ij}^k 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

$$\zeta_{ij}^k = \frac{\min_i \min_j |B_{ij}^k| + \rho \max_i \max_j |B_{ij}^k|}{|B_{ij}^k| + \rho \max_i \max_j |B_{ij}^k|}, \quad (5)$$

$$i = 1, 2, \dots, m; j = 1, 2, \dots, n.$$

Here, ρ 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

$$V_{ij}^k = \begin{cases} (1 - \zeta_{ij}^k)^\alpha, & r_{ij}^k \geq e_i^k \\ -\lambda [-(\zeta_{ij}^k - 1)]^\beta, & r_{ij}^k < e_i^k \end{cases}, \quad (6)$$

$$i = 1, 2, \dots, m; j = 1, 2, \dots, n; k = 1, 2, \dots, f.$$

Among them, $0 < \alpha < 1$, $0 < \beta < 1$, and $\lambda > 1$. The coefficient λ reflects the agent's psychological performance of being more sensitive to losses relative to gains. The larger the λ , 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

$$\bar{V}_{ij}^k = \frac{V_{ij}^k}{\max_{j=1,2,\dots,n} |V_{ij}^k|}, \quad (7)$$

$$i = 1, 2, \dots, m; j = 1, 2, \dots, n; k = 1, 2, \dots, f.$$

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

$$P_{ij} = \sum_{k=1}^f \omega_k \bar{V}_{ij}^k, \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n; k = 1, 2, \dots, f. \quad (8)$$

Correspondingly, the satisfaction prospect matrix of the demander d_i to the provider s_j is $V_D = (P_{ij})_{m \times n}$ and in the same way, the satisfaction prospect value $\bar{P}_{ij}$ of the provider s_i to the demander d_i can be obtained. The satisfaction prospect matrix of the provider s_j to the demander d_i is $V_S = (\bar{P}_{ij})_{m \times n}$.

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 μ . And, $x_{ij} = 1$ represents that d_i and s_j match in μ . The multiobjective matching model is established by the prospect matrixes $V_D = (P_{ij})_{m \times n}$ and $V_S = (\bar{P}_{ij})_{m \times n}$ as follows:

$$\begin{cases} \max G_D = \sum_{i=1}^m \sum_{j=1}^n P_{ij} x_{ij}, \\ \max G_S = \sum_{i=1}^m \sum_{j=1}^n \bar{P}_{ij} x_{ij}, \end{cases} \quad (9a)$$

$$\text{s.t. } \sum_{j=1}^n x_{ij} = 1, \quad i = 1, 2, \dots, m, \quad (9b)$$

$$\sum_{i=1}^m x_{ij} \leq 1, \quad j = 1, 2, \dots, n, \quad (9c)$$

$$\sum_{i=1}^m \sum_{j=1}^n x_{ij} = \min\{m, n\}, x_{ij} \in \{0, 1\}, \quad i = 1, 2, \dots, m, j = 1, 2, \dots, n. \quad (9d)$$

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 ϕ_D and ϕ_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:

$$\max G = \phi_D \sum_{i=1}^m \sum_{j=1}^n P_{ij} x_{ij} + \phi_S \sum_{i=1}^m \sum_{j=1}^n \tilde{P}_{ij} x_{ij} = \sum_{i=1}^m \sum_{j=1}^n T_{ij} x_{ij}, \quad (10a)$$

$$\text{s.t.} \sum_{j=1}^n x_{ij} = 1, \quad i = 1, 2, \dots, m, \quad (10b)$$

$$\sum_{i=1}^m x_{ij} = 1, \quad j = 1, 2, \dots, n, \quad (10c)$$

$$\sum_{i=1}^m \sum_{j=1}^n x_{ij} = \min\{m, n\}, x \in \{0, 1\}, \quad i = 1, 2, \dots, m, j = 1, 2, \dots, n. \quad (10d)$$

Here, $T_{ij} = \phi_D P_{ij} + \phi_S \tilde{P}_{ij}$ and ϕ_D and ϕ_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 $\tilde{P}_{ij}$ 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 payment speed (a_3). And, the corresponding weights are 0.453, 0.504, and 0.043. Among them, c_1 and $c_4 \in C^R$ and $a_3 \in A^R$, where the indicator values c_1 , c_4 , and a_3 are negative actual numbers. The larger the c_1 and c_4 are, the lower the price is and the shorter the delivery period is, which is more beneficial for the demander. And, the larger the a_3 is, the shorter time the demander pays, which is better for the provider. For the sake of simplification, rounding and removing the dimensions, c_2 and $c_3 \in C^F$ and a_1 and $a_2 \in A^F$, this paper uses the cloud model for numerical conversion which is consistent with the description in Section 3.2.2. The expected value and actual measured value of both demanders and providers are 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 $\tilde{V}_D$ are calculated by equations (6)–(8), which can be shown in Table 11.

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

TABLE 1: Expected evaluation information of demanders to providers.

Demander	Provider's indicator			
	c_1	c_2	c_3	c_4
d_1	-6	Satisfied	Basically satisfied	-13
d_2	-7	Basically satisfied	Basically satisfied	-8
d_3	-6	Basically satisfied	Unsatisfied	-19
d_4	-5	Very satisfied	Unsatisfied	-5

TABLE 2: Actual measured evaluation information of demanders to providers.

D	S	c_1	c_2	c_3	c_4
d_1	s_1	-6	Basically satisfied	Unsatisfied	-10
	s_2	-8	Very satisfied	Unsatisfied	-15
	s_3	-7	Satisfied	Basically satisfied	-11
	s_4	-5	Basically satisfied	Satisfied	-18
	s_5	-6	Basically satisfied	Very satisfied	-14

TABLE 2: Continued.

D	S	c_1	c_2	c_3	c_4
d_2	s_1	-6	Basically satisfied	Basically satisfied	-11
	s_2	-8	Satisfied	Unsatisfied	-7
	s_3	-7	Unsatisfied	Basically satisfied	-11
	s_4	-5	Unsatisfied	Very satisfied	-9
	s_5	-6	Satisfied	Basically satisfied	-9
d_3	s_1	-6	Unsatisfied	Very unsatisfied	-12
	s_2	-8	Basically satisfied	Unsatisfied	-20
	s_3	-7	Basically satisfied	Satisfied	-13
	s_4	-5	Very unsatisfied	Very unsatisfied	-19
	s_5	-6	Satisfied	Unsatisfied	-17
d_4	s_1	-6	Satisfied	Very satisfied	-7
	s_2	-8	Unsatisfied	Basically satisfied	-6
	s_3	-7	Very unsatisfied	Very unsatisfied	-10
	s_4	-5	Very satisfied	Basically satisfied	-5
	s_5	-6	Basically satisfied	Basically satisfied	-9

TABLE 3: Expected evaluation information of providers to demanders.

Provider	Demander's indicator		
	a_1	a_2	a_3
s_1	Average	Basically satisfied	-5
s_2	Average	Basically satisfied	-7
s_3	Hard	Satisfied	-7
s_4	Very hard	Basically satisfied	-5
s_5	Average	Basically satisfied	-5

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

S	D	a_1	a_2	a_3
s_1	d_1	Hard	Very satisfied	-7
	d_2	Average	Basically satisfied	-4
	d_3	Hard	Basically satisfied	-5
	d_4	Average	Basically satisfied	-6
s_2	d_1	Average	Satisfied	-7
	d_2	Very easy	Unsatisfied	-4
	d_3	Easy	Satisfied	-5
	d_4	Easy	Very satisfied	-6
s_3	d_1	Average	Unsatisfied	-7
	d_2	Hard	Very satisfied	-4
	d_3	Very hard	Satisfied	-5
	d_4	Hard	Basically satisfied	-6
s_4	d_1	Average	Basically satisfied	-7
	d_2	Very hard	Satisfied	-4
	d_3	Very hard	Satisfied	-5
	d_4	Hard	Basically satisfied	-6
s_5	d_1	Easy	Unsatisfied	-7
	d_2	Average	Satisfied	-4
	d_3	Easy	Satisfied	-5
	d_4	Very hard	Very 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 5: Expected values of demanders to providers.

Demander	Provider's indicator			
	c_1	c_2	c_3	c_4
d_1	-6	0.691	0.5	-13
d_2	-7	0.5	0.5	-8
d_3	-6	0.5	0.309	-19
d_4	-5	1	0.309	-5

TABLE 6: Actual measured values of demanders to providers.

D	S	c_1	c_2	c_3	c_4
d_1	s_1	-6	0.5	0.309	-10
	s_2	-8	1	0.309	-15
	s_3	-7	0.691	0.5	-11
	s_4	-5	0.5	0.691	-18
	s_5	-6	0.5	1	-14
d_2	s_1	-6	0.5	0.5	-11
	s_2	-8	0.691	0.309	-7
	s_3	-7	0.309	0.5	-11
	s_4	-5	0.309	1	-9
	s_5	-6	0.691	0.5	-9
d_3	s_1	-6	0.309	0	-12
	s_2	-8	0.5	0.309	-20
	s_3	-7	0.5	0.691	-13
	s_4	-5	0	0	-19
	s_5	-6	0.691	0.309	-17
d_4	s_1	-6	0.691	1	-7
	s_2	-8	0.309	0.5	-6
	s_3	-7	0	0	-10
	s_4	-5	1	0.5	-5
	s_5	-6	0.5	0.5	-9

coefficient matrix $T = [t_{ij}]_{4 \times 5}$ is obtained, which can be shown in Table 12.

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

TABLE 7: Expected values of providers to demanders.

Provider	Demander's indicator		
	a_1	a_2	a_3
s_1	0.5	0.5	-5
s_2	0.5	0.5	-7
s_3	0.691	0.691	-7
s_4	1	0.5	-5
s_5	0.5	0.5	-5

TABLE 8: Actual measured values of providers to demanders.

S	D	a_1	a_2	a_3
s_1	d_1	0.691	1	-7
	d_2	0.5	0.5	-4
	d_3	0.691	0.5	-5
	d_4	0.5	0.5	-6
s_2	d_1	0.5	0.691	-7
	d_2	0	0.309	-4
	d_3	0.309	0.691	-5
	d_4	0.309	1	-6
s_3	d_1	0.5	0.309	-7
	d_2	0.691	1	-4
	d_3	1	0.691	-5
	d_4	0.691	0.5	-6
s_4	d_1	0.5	0.5	-7
	d_2	1	0.691	-4
	d_3	1	0.691	-5
	d_4	0.691	0.5	-6
s_5	d_1	0.309	0.309	-7
	d_2	0.5	0.691	-4
	d_3	0.309	0.691	-5
	d_4	1	1	-6

TABLE 9: Grey relational coefficients between the expected values and the actual measured values of demanders to providers.

D	S	c_1	c_2	c_3	c_4
d_1	s_1	1	0.7236	0.6440	0.5385
	s_2	0.4286	0.6180	0.6440	0.6364
	s_3	0.6	1	1	0.6364
	s_4	0.6	0.7236	0.6440	0.4118
	s_5	1	0.7236	0.4086	0.7778
d_2	s_1	0.6	1	1	0.5385
	s_2	0.6	0.7236	0.6440	0.7778
	s_3	1	0.7236	1	0.5385
	s_4	0.4286	0.7236	0.4086	0.7778
	s_5	0.6	0.7236	1	0.7778
d_3	s_1	1	0.7236	0.5279	0.3333
	s_2	0.4286	1	1	0.7778
	s_3	0.6	1	0.4749	0.3684
	s_4	0.6	0.5	0.5279	1
	s_5	1	0.7236	1	0.6364
d_4	s_1	0.6	0.6180	0.3333	0.6364
	s_2	0.3333	0.4198	0.6440	0.7778
	s_3	0.4286	0.3333	0.5279	0.4118
	s_4	1	1	0.6440	1
	s_5	0.6	0.5	0.6440	0.4667

TABLE 10: Grey relational coefficients between the expected values and the actual measured values of providers to demanders.

S	D	a_1	a_2	a_3
s_1	d_1	0.5669	0.3333	0.4286
	d_2	1	1	0.6
	d_3	0.5669	1	1
	d_4	1	1	0.6
s_2	d_1	1	0.5669	1
	d_2	0.3333	0.5669	0.3333
	d_3	0.5669	0.5669	0.4286
	d_4	0.5669	0.3333	0.6
s_3	d_1	0.5669	0.3956	1
	d_2	1	0.4472	0.3333
	d_3	0.4472	1	0.4286
	d_4	1	0.5669	0.6
s_4	d_1	0.3333	1	0.4286
	d_2	1	0.5669	0.6
	d_3	1	0.5669	1
	d_4	0.4472	1	0.6
s_5	d_1	0.5669	0.5669	0.4286
	d_2	1	0.5669	0.6
	d_3	0.5669	0.5669	1
	d_4	0.3333	0.3333	0.6

TABLE 11: Satisfaction prospect matrix.

Matrix	s_1	s_2	s_3	s_4	s_5
V_D	-0.5701	-0.6662	-0.1806	0.2161	0.3717
	0.1041	-0.6160	-0.1121	0.3874	0.1688
	-0.6814	-0.2228	0.0706	-0.5604	0.0632
	-0.1783	-0.2580	-1.0000	0.1775	-0.1604
$\tilde{V}_D$	0.3389	0.1671	-0.8139	-0.4960	-0.7288
	0.0274	-0.9140	0.3207	0.2514	0.2514
	0.2013	0.0940	0.2926	0.5040	0.0510
	-0.0430	-0.0188	-0.4849	-0.4960	0.5215

TABLE 12: Coefficient matrix.

Demander	Provider				
	s_1	s_2	s_3	s_4	s_5
d_1	-0.1156	-0.2496	-0.4973	-0.1400	-0.1785
d_2	0.0658	-0.7650	0.1043	0.3194	0.2101
d_3	-0.2401	-0.0644	0.1816	-0.0282	0.0571
d_4	-0.1107	-0.1384	-0.7424	-0.1592	0.1805

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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References

- [1] B. Ellen, "A vision for shared manufacturing," *Mechanical Engineering*, vol. 112, pp. 52–55, 1990.
- [2] T. M. A. Ari Samadhi and K. Hoang, "Shared computer-integrated manufacturing for various types of production environment," *International Journal of Operations & Production Management*, vol. 15, no. 5, pp. 95–108, 1995.
- [3] M. Sheikhzadeh, S. Benjaafar, and D. Gupta, "Machine sharing in manufacturing systems: total flexibility versus chaining," *International Journal of Flexible Manufacturing Systems*, vol. 10, no. 4, pp. 351–378, 1998.
- [4] C. Yu, X. Xu, S. Yu, Z. Sang, C. Yang, and X. Jiang, "Shared manufacturing in the sharing economy: concept, definition and service operations," *Computers & Industrial Engineering*, vol. 146, Article ID 106602, 2020.
- [5] J. He, J. Zhang, and X. Gu, "Research on sharing manufacturing in Chinese manufacturing industry," *International Journal of Advanced Manufacturing Technology*, vol. 104, no. 1–4, pp. 463–476, 2019.
- [6] C. Yu, X. Jiang, S. Yu, and C. Yang, "Blockchain-based shared manufacturing in support of cyber physical systems: concept, framework, and operation," *Robotics and Computer-Integrated Manufacturing*, vol. 64, Article ID 101931, 2020.
- [7] N. Rozman, J. Diaci, and M. Corn, "Scalable framework for blockchain-based shared manufacturing," *Robotics and Computer-Integrated Manufacturing*, vol. 71, Article ID 102139, 2021.
- [8] G. Wang, G. Zhang, X. Guo, and Y. Zhang, "Digital twin-driven service model and optimal allocation of manufacturing resources in shared manufacturing," *Journal of Manufacturing Systems*, vol. 59, pp. 165–179, 2021.
- [9] K. Li, W. Xiao, and X. Zhu, "Pricing strategies for sharing manufacturing model based on the cloud platform," *Control and Decision*, 2021.
- [10] N. F. Ayala, C. A. Paslauskis, A. Ghezzi, and A. G. Frank, "Knowledge sharing dynamics in service suppliers' involvement for servitization of manufacturing companies," *International Journal of Production Economics*, vol. 193, pp. 538–553, 2017.
- [11] D. Zhao and Q. Du, "The impact of demand information updating on sharing of manufacturing capacity in the supply chain," *Journal of Systems & Management*, vol. 26, no. 2, pp. 374–380, 2017.
- [12] S. Bao and R. Cai, "Intelligent production sharing and user experience: a case study of Shenyang Machine Tool," *Industrial Engineering and Management*, vol. 22, no. 3, pp. 77–82, 2017.
- [13] K. Dai, W. Chen, and R. Cai, "Realization mechanism of sharing pattern innovation in service manufacturing enterprises-A grounded theory analysis based on service leading logic," *Industrial Engineering and Management*, vol. 24, no. 3, pp. 124–129, 2019.
- [14] D. Gale and L. S. Shapley, "College admissions and the stability of marriage," *The American Mathematical Monthly*, vol. 69, no. 1, pp. 9–15, 1962.
- [15] H. Li, X. Dong, and C. Song, "Intelligent searching and matching approach for cloud manufacturing service," *Computer Integrated Manufacturing Systems*, vol. 18, no. 7, pp. 1485–1493, 2012.
- [16] Y. Dong and G. Guo, "Evaluation and selection approach for cloud manufacturing service based on template and global trust degree," *Computer Integrated Manufacturing Systems*, vol. 20, no. 1, pp. 207–214, 2014.
- [17] J. Zhao and X. Wang, "Two-sided matching model of cloud service based on QoS in cloud manufacturing environment," *Computer Integrated Manufacturing Systems*, vol. 22, no. 1, pp. 104–112, 2016.
- [18] Z. Fan, M. Li, and Q. Le, "Decision analysis method for two-sided satisfied matching considering stable matching condition," *Chinese Journal of Management Science*, vol. 22, no. 4, pp. 112–118, 2014.
- [19] N. Kamiyama, "Popular matchings with two-sided preference lists and matroid constraints," *Theoretical Computer Science*, vol. 809, pp. 265–276, 2020.
- [20] Z. Zhang, X. Kou, W. Yu, and Y. Gao, "Consistency improvement for fuzzy preference relations with self-confidence: an application in two-sided matching decision making," *Journal of the Operational Research Society*, vol. 72, no. 8, pp. 1914–1927, 2021.
- [21] Z. Zhang, J. Gao, Y. Gao, and W. Yu, "Two-sided matching decision making with multi-granular hesitant fuzzy linguistic

- term sets and incomplete criteria weight information,” *Expert Systems with Applications*, vol. 168, Article ID 114311, 2021.
- [22] Z. Zhang, X. Kou, I. Palomares, W. Yu, and J. Gao, “Stable two-sided matching decision making with incomplete fuzzy preference relations: a disappointment theory based approach,” *Applied Soft Computing*, vol. 84, Article ID 105730, 2019.
  - [23] B. Li, Y. Yang, J. Su, N. Zhang, and S. Wang, “Two-sided matching model for complex product manufacturing tasks based on dual hesitant fuzzy preference information,” *Knowledge-Based Systems*, vol. 186, Article ID 104989, 2019.
  - [24] B. Li, Y. Yang, J. Su, Z. Liang, and S. Wang, “Two-sided matching decision-making model with hesitant fuzzy preference information for configuring cloud manufacturing tasks and resources,” *Journal of Intelligent Manufacturing*, vol. 31, no. 8, pp. 2033–2047, 2020.
  - [25] X. Zhang and J. Su, “A combined fuzzy DEMATEL and TOPSIS approach for estimating participants in knowledge-intensive crowdsourcing,” *Computers & Industrial Engineering*, vol. 137, Article ID 106085, 2019.
  - [26] D. Zhang, H. Dai, and X. Liu, “Intuitionistic fuzzy two-sided matching method considering regret aversion and matching aspiration,” *Operations Research and Management Science*, vol. 29, no. 10, pp. 132–139, 2020.
  - [27] D. Zhao and R. Li, “Two-sided matching mechanism with agents’ expectation for cloud manufacturing resource,” *Control and Decision*, vol. 32, no. 5, pp. 871–878, 2017.
  - [28] Y. Zhang, J. Wu, P. Li, Y. Sheng, and Q. Shi, “Decision model and application of two-sided matching of uncertain information based on grey correlation,” *Science and Technology Management Research*, vol. 16, pp. 253–259, 2017.
  - [29] A. Bi, Z. Luo, Z. Sun, and X. Zhang, “Decision method for two-sided matching with linguistic evaluation based on cloud model and prospect theory,” *Statistics & Information Forum*, vol. 35, no. 11, pp. 42–48, 2020.
  - [30] D. Gale, “Two-sided matching problem: origin, development and current issues,” *International Game Theory Review*, vol. 3, no. 2-3, pp. 237–252, 2001.
  - [31] D. Li, H. Meng, and X. Shi, “Membership clouds and membership cloud generators,” *Computer Research and Development*, vol. 32, no. 6, pp. 16–21, 1995.
  - [32] X. D. He and X. Y. Zhou, “Portfolio choice under cumulative prospect theory: an analytical treatment,” *Management Science*, vol. 57, no. 2, pp. 315–331, 2011.