International Journal of Fuzzy System Applications
Volume 12 • Issue 1

Bilateral Matching Decision-Making Method Considering Regret Avoidance in Second-Hand Transactions

Rui Wang, Fujian Jiangxia University, China*
Juan Liang, Fujian Jiangxia University, China

ABSTRACT

Effective methods of bilateral matching decision-making could make the second-hand transaction market and platforms more dynamic and healthier for development. However, the loss of description about the characteristics of sellers and buyers and the weight information of their inner preference can affect the matching result. By developing a method for a second-hand transaction, this paper proposes a novel approach that considers the matching parties' psychologies, which can improve the matching efficiency. A mathematical model of seller and buyer is performed, and then the price and other evaluation indicators of sellers and buyers are described by five different types. A bilateral matching multi-objective decision-making model is constructed and solved. A real case study of property trade platform is presented to illustrate how the proposed approach could be applied in practice. The results of this research indicate that the proposed approach is a useful tool for matching the sellers and buyers and has substantial practical application.

KEYWORDS

Bilateral Matching Decision-Making, Incomplete Information Weight, Multi-Type Heterogeneous Information, Regret Avoidance, Second-Hand Transactions

INTRODUCTION

With the rapid development of the domestic economy, the second-hand goods trade has become an important part of the market transaction. Effective and professional trading services are able to create value-added activities and customized solutions to satisfy the requirements of both the sellers and buyers (Wang & Li, 2017; Edmund,2020). In the real trading market, there are three players: the second-hand goods sellers (suppliers) who provide the second-hand goods to be selected, buyers (demanders) who seek the goods, and the intermediaries who match the sellers and the buyers (Zeithaml et al., 1993; Goran et al., 2021). With the popularity of e-commerce, online and offline platforms of

DOI: 10.4018/IJFSA.323564 *Corresponding Author

second-hand goods transaction intermediaries have become an important media for bilateral matching. Since the individuation of second-hand goods demand and the diversity of supply appear significantly, a proper match between the sellers and buyers has become increasingly important. As information and resources are often restricted or proprietary, it has become necessary for the second-hand goods sellers or buyers to use the expert knowledge services of intermediaries as a bridge to find suitable partners. Consequently, bilateral matching problems among sellers, intermediaries, and buyers have emerged and have been studied by many colleges (Benassi & Minin,2009; Belleflamme & Peitz, 2019; Italo & Oswaldo, 2020; Edmund, 2020; Cullen & Farronato, 2021; Yash & Daniela, 2021).

Bilateral matching problems have extensive practical backgrounds and exist widely in various bilateral matching markets. Gale and Shapley (1962) first studied renowned bilateral matching problems with ordinal preferences. After the initial study of Gale and Shapley, a large number of bilateral matching theories were proposed (Roth,1985; Rothblum, 1992; Roth et al.,1993; Sasaki & Toda, 1996; Bloch & Ryder, 2000; Manlove et al., 2002; Echenique & Oviedo,2004; Pais,2008; Hatfield & Kojima,2010; Jiang et al.,2011; Azevedo, 2014; Yu et al.,2018; Halaburda et al.,2018; Hu & Zhou,2018; Zhang et al.,2019; Liang et al.,2020; Michael & Christopher, 2021). Hence, the research on bilateral matching is meaningful in theory and valuable in practice. However, throughout the existing literature, it is well known that the prior research focused more on obtaining stable matching schemes with the preferences of both matching parties.

At present, the social environment is complex and changeable, people's cognition and judgment are more and more uncertain and fuzziness. It is increasingly difficult to express the preference information of practical problems in the form of accurate values. How to express many uncertain or fuzzy information? Obviously, this is an urgent but very interesting problem. A common assumption proposed in most prior studies was that the demanders and suppliers were able to express their opinions or perceptions using numerical values. In many realistic situations, however, people usually describe their opinions with linguistic assessments rather than numerical values (Wang & Chuu,2004; Yu et al.,2021; Yu et al., 2022; Liu,2022). Different attributes or characteristics should be expressed in different types of data forms, only that can reflect the characteristics of customers or property to the greatest extent. Customer's portrait and property characterization can be well described with heterogeneous information which was not sufficient covered in existing research.

The objective of this paper is to develop a method for second-hand transactions matching more accurate, in which the sellers and buyers' uncertain information including preference and demands is considered and the characteristics of various expressions of evaluation indicators of both the sellers and the buyers are depicted as accurately as possible. In a matching process, the income levels of sellers, buyers and intermediaries are all maximization that they desire to achieve. Due to the interests of the three parties are not consistent, a dominance function is constructed by considering their different behavior characteristics and interest needs. Meanwhile, a bilateral matching decision-making approach is proposed.

This paper contributes to the following aspects: firstly, a hybrid of decision-making methods extends the application of both bilateral matching and psychology to second-hand transactions field. This interdisciplinary study covers both transaction research and second-hand goods management, aiming to be a useful tool for knowledge and experience transfer. Secondly, the study avoids underestimation of the matching parties' characteristics, as well as considers psychological problems (e.g., uncertain weight of preference, regret avoidance). Therefore, the approach is superior to the traditional research that not fully considered these important details. Thirdly, it provides insights for second-hand transaction into facilitating more comprehensive matching parties' demand portrait by using five data types (e.g., real numbers, interval numbers, triangular fuzzy numbers, intuitionistic fuzzy sets and multi-grained linguistic variables). Lastly, it also enriches second-hand transaction literature by filling research supplement presented in this paper.

The rest of this paper is organized as follows. In Section 1, the reviews of related literature are presented. In Section 2, the multi-type heterogeneous information of matching evaluation indexes is defended. The model of sellers and buyers' regret avoidance is established. In Section 3, the perceived value of the sellers and buyers are constructed and calculated respectively. A multi-objective decision model considering regret avoidance is developed. In Section 4, the proposed model and method is specifically applied to the case of second-hand housing transactions platform. A comparison analyses are conducted. In the last Section, this paper concludes.

LITERATURE REVIEW

Bilateral matching belongs to the research branch of decision-making field, which was first introduced the Stability of Marriage problem by Gale and Shapley (1962). Gale and Shapley initially proposed a deferred acceptance algorithm, namely Gale–Shapley algorithm, to solve the marriage problem, in which men and women have preferences over each other. In their work, the concept of stable matching is proposed. After that, Roth (1984) introduced bilateral matching decision-making theory into social practice, and opened the precedent for market mechanism design. It is worth noting that Roth and Shapley won the 2012 Nobel Prize in Economics for their great contributions to bilateral stable matching theory and market design practice. Based on the Gale–Shapley algorithm, the research on bilateral matching decision-making is mainly expanded from two directions: one direction focused on matching algorithm. A number of methods and models are developed (Bertsekas,1981; Roth,1985; Rothblum,1992; Roth et al.,1993; Sasaki & Toda, 1996; Bloch & Ryder,2000; Manlove et al., 2002;Echenique & Oviedo,2004; Pais,2008; Hatfield & Kojima,2010; Jiang et al.,2011; Azevedo, 2014; Yu et al., 2021;Yu et al.,2021).Among them, some researchers studied the optimal cheating strategy and the truncation strategy in bilateral matching (Teo et al., 2001; Ehlers, 2008). Some scholars studied the bilateral matching problem focusing on preference ordinal information including incomplete and complete information (Echenique & Bumin, 2007).Meanwhile, some linear programming models are proposed to solve one-one, one-many bilateral matching problems (Munkres,1957; Echenique & Oviedo,2004), some considering the psychological features such as maximum satisfaction or minimum regret for both parties(Bell,1985;Zeithaml et al., 1993; Liu et al., 2017; Zhang et al.,2018)or dual-objective matching with maximum satisfactions and minimum individual differences (Liang et al., 2013; Liu et al., 2017; Zhang et al.,2018;Davoudabadi et al., 2020). It is worth noting that the stability of matching results has become the focus of this research direction.

Furthermore, the other direction concentrated on a comprehensive applications in different fields, such as male and female (Gale & Shapley,1962; Bloch & Ryder, 2000;Irving et al., 2008), staff and positions (Roth,1985; Azevedo, 2014), transaction suppliers and demanders (Sim & Chan, 2000; Jiang et al., 2011, 2015), students and colleges (Pais, 2008 ; Chui et al., 2020), knowledge matching (Chen et al.,2016), tasks assignment (Cullen & Farronato,2021; Kadadha et al.,2021), competition analysis (Belleflamme & Peitz, 2019; Ribeiro & Golovanova, 2020).It is noted that the research in this direction are very fruitful. In addition, recent papers explore how a platform should make matching decisions in dynamic settings (Banerjee et al., 2015; Hu & Zhou, 2018).

However, the existing studies have made significant contributions towards the solutions to bilateral matching problems in different research directions. However, studies ignore some important factors which commonly existing in transactions have been somewhat limited, such as the psychological behavior of intermediaries (e.g., moral hazard to the matching result), portraits of matching parties (e.g., sellers and buyers demand and expectation), full-description of property (e.g., physical and social characteristics) is seldom considered. It is necessary to develop a novel matching model considering psychological behavior of intermediaries' moral hazard and the portrait of customers and properties to improve the efficiency of matching. In the process of property transaction, the intermediary platform provides consultation, search, matching and other services, which not only saves a lot of time and energy costs for both sides of property sellers and buyers, but also reduces the problem of transaction information asymmetry. Therefore, intermediaries play a crucial role in property transactions. Due to information asymmetry, moral hazard in property platform is inevitable.

The theory of information economics shows that the essence of moral hazard is an opportunistic behavior (Balafoutas et al., 2017). The intermediary's moral hazard is an opportunistic behavior that maximizes self-interest and is not conducive to the property sellers or buyers. Studies have shown that the moral hazard was mainly concentrated in market, products, finance, credit reform (Pierce et al.,2015; Kadam & Kotowski,2018; Anton & Dam,2020; Meng et al.,2021; Goran et al., 2021; Fudge et al.,2021; Francis A.,2022) resently.

However, there are only a few studies on the moral hazard of intermediaries in the bilateral matching decision-making field. For example, Ozdenoren (2005) analyzed the functions of an invention service broker and constructed a balanced model for two-sided demand and supply matching. Benassi & Minin (2009) focused on a patent broker and discussed the importance of a broker by demonstrating how a broker can greatly reduce transaction costs. Liang & Jiang (2013) proposed a bilateral matching decision-making method considering different transaction attitudes of intermediaries. Hoppe(2005) and Liu et al. (2017) proposed a bilateral matching decision-making method for electronic intermediary buying and selling based on double reference points. Zhang et al. (2021) studied a decision-making problem about supply and demand of matching various goods among three parties in the respect of intermediary. These studies have explored more about the influencing factors of intermediary's moral hazard, but lack of consideration in revealing the impact of factors such as the payoff, risk appetite and effort of intermediaries on the bilateral matching results. Therefore, it is necessary to carry out further exploration.

Meanwhile, it is necessary to pay attention to the expression in diversity of information due to the complexity of matching information. However, due to the complexity of practical problems and the limitations of human cognition, the information of attributes or human's preference often has the characteristics of multi-type heterogeneity. For example, the attribution of distant, price, areas, floor et al. can be described as real numbers, but the others like convenience, decorate class, property management et al. may not be expressed by real numbers which can't reflect their characteristics significantly. Therefore, various fuzzy numbers, such as interval numbers, triangular fuzzy numbers, intuitionistic fuzzy sets and other types of terms are very important for the expression of different types of heterogeneous information. Many scholars have carried out researches on interval number (Kumar & Chen, 2021), fuzzy number (Jiang et al., 2014; Yu et al., 2018), language evaluation value (Wang & Chuu, 2004) and interval-dual hesitant fuzzy information (Zhang et al., 2021; Yu et al., 2021), intuitionistic fuzzy (Wang et al., 2020; Yu et al., 2022) and made many achievements. Some scholars also use it to express heterogeneous or hesitant environment, but a few was used in bilateral matching research (Wang et al., 2020). Obviously, the bilateral matching decision-making method focus on heterogeneous information environment are far from meeting the actual needs. Therefore, studying bilateral matching with heterogeneous information also has significant research significance.

PRELIMINARY

Description of Bilateral Matching Symbols

Let $S = \{S_1, S_2, \cdots, S_m\}$ $(m \geq 2)$, which represents the S party $(i = 1, 2, \cdots, m)$. Let $B = \{B_1, B_2, \cdots, B_n\}$ $(n \geq 2)$, which represents the B party $(j = 1, 2, \cdots, n)$. Let $m \leq n$, which is set to ensure that each subject of party S can be matched with a subject of party B.

Denoted μ as a bilateral $\mu(S_i) = B_j$ matching, it is essentially a one-to-one mapping (Roth, 1985; Gale & Shapley,1962) which built on the subject sets of S and B. Namely μ: $S_i \cup B_j \to S \cup B$, where $\forall S_i \in S$, $\forall B_j \in B$, which satisfies the following three conditions: (1) $\mu(S_i) \in B$; (2) $\mu(B_j) \in S \cup \{B_j\}$; (3) if and only if $\mu(B_j) = S_i$, where means that S_i and B_j are matched under

μ, both S_i and B_j are called matching bodies, and (S_i, B_j) is called μ matches the host pair, and $\mu(B_j) = B_j$ means that B_j matches itself at μ.

The Weight of Incomplete Information

In the real transaction process, the preferences of buyers and sellers of second-hand goods for various evaluation indicators are mostly given in the form of preference order rather than specific preference values. For example, when selecting buyers, a seller who is eager for cash thinks that the time of down payment and the time of final payment are the most important, followed by the down payment ratio, and pays little attention to the other evaluation indicators. At the same time, when selecting sellers, part of the buyers consider that the proportion of total price and down payment are the most important, followed by educational facilities and quality, and the importance of public transportation conditions is twice as important as that of leisure facilities. At this time, it is more realistic to express the preferences of buyers and sellers for each evaluation indicator in a sorted mathematical form.

Therefore, according to the actual needs of the seller's preference, the weight vector of the second-hand seller S_i about the evaluation index $z_{k\theta}^S$ under the evaluation index z_k^S is defined as $w^S = (w_{11}^S, w_{12}^S, \cdots, w_{1|\Theta^1|}^S, w_{21}^S, w_{22}^S, \cdots, w_{2|\Theta^2|}^S, \cdots, w_{k1}^S, w_{k2}^S, \cdots, w_{k|\Theta^k|}^S)$, $w_{k\theta}^S$ presents the weight of secondary evaluation $z_{k\theta}^S$. The seller's weight information set about the secondary evaluation index is recorded as $\widehat{\Lambda}^S$, which is expressed as:

$$\begin{aligned}\widehat{\Lambda}^S = \{&(w_{11}^S, w_{12}^S, \cdots, w_{1|\Theta^1|}^S, w_{21}^S, w_{22}^S, \cdots, w_{2|\Theta^2|}^S, \cdots, w_{k1}^S, w_{k2}^S, \cdots, w_{k|\Theta^k|}^S) \mid \\ &w_{k\theta}^S \geq 0, \textstyle\sum_{\theta=1}^{|\Theta^k|} w_{k\theta}^S = 1, k = 1, 2, \cdots, |K|\}\end{aligned} \tag{1}$$

where $\theta \in \Theta^k$. Many scholars have discussed the structural form of incomplete index weight information. This paper mainly considers that the seller's preference for evaluation index consists of two parts, weak order form and multiplicative order form, which are recorded as $\widehat{\Lambda}_1^S$ and $\widehat{\Lambda}_2^S$ respectively.

Let C_1^S and C_2^S represent two disjoint non-empty subsets in the subscript set $C^S = \{k\theta \mid k \in \{1, 2, \cdots, |K|\}, \theta \in \{1, 2, \cdots, |\Theta^k|\}\}$ of all secondary evaluation indexes, which satisfying $C_1^S \subset C^S$, $C_2^S \subset C^S$ and $C_1^S \cap C_2^S = \varnothing$. Then there are the definitions of these two forms:

Weakly ordered form:

$$\begin{aligned}\widehat{\Lambda}_1^S = \{&(w_{11}^S, w_{12}^S, \cdots, w_{1|\Theta^1|}^S, w_{21}^S, w_{22}^S, \cdots, w_{2|\Theta^2|}^S, \cdots, w_{k1}^S, w_{k2}^S, \cdots, w_{k|\Theta^k|}^S) \in \widehat{\Lambda}^S \mid \\ &w_{f_1}^S \geq w_{f_2}^S\} \qquad (f_1 \in C_1^S, f_2 \in C_2^S)\end{aligned} \tag{2}$$

Multiplicative order form:

$$\begin{aligned}\widehat{\Lambda}_2^S = \{&(w_{11}^S, w_{12}^S, \cdots, w_{1|\Theta^1|}^S, w_{21}^S, w_{22}^S, \cdots, w_{2|\Theta^2|}^S, \cdots, w_{k1}^S, w_{k2}^S, \cdots, w_{k|\Theta^k|}^S) \in \widehat{\Lambda}^S \mid \\ &w_{f_1}^S \geq \chi^S w_{f_2}^S\} \qquad (f_1 \in C_1^S, f_2 \in C_2^S)\end{aligned} \tag{3}$$

where $\chi^S > 0$. Record the weight information set of the above two evaluation indexes of seller as $\Lambda^S = \widehat{\Lambda}_1^S \cup \widehat{\Lambda}_2^S$.

Likewise, the weight vector of buyer B_i about secondary evaluation index $Z_{h\sigma}^B$ can be defined as $w^B = (w_{11}^B, w_{12}^B, \cdots, w_{1|\gamma^1|}^B, w_{21}^B, w_{22}^B, \cdots, w_{2|\gamma^2|}^B, \cdots, w_{h1}^B, w_{h2}^B, \cdots, w_{h|\gamma^h|}^B)$. Where $w_{h\sigma}^B$ represents the weight of the secondary evaluation index $Z_{h\sigma}^B$, $h \in \{1, 2, \cdots, |H|\}$. For the convenience of marking, the buyer's weight information set about the secondary evaluation index is recorded as $\widehat{\Lambda}^B$, which is expressed as:

$$\begin{aligned}\widehat{\Lambda}^B = \{&(w_{11}^B, w_{12}^B, \cdots w_{1|\Upsilon^1|}^B, w_{21}^B, w_{22}^B, \cdots, w_{2|\Upsilon^2|}^B, \cdots, w_{h1}^B, w_{h2}^B, \cdots, w_{h|\Upsilon^h|}^B) \mid \\ &w_{h\sigma}^B \geq 0, \textstyle\sum_{\sigma=1}^{|\Upsilon^h|} w_{h\sigma}^B = 1, h = 1, 2, \cdots, |H|\}\end{aligned} \tag{4}$$

where $\sigma \in \Upsilon^h$. This paper mainly considers that the buyer's preference for evaluation index consists of two parts, weak order form and multiplicative order form, which are recorded as $\widehat{\Lambda}_1^B$ and $\widehat{\Lambda}_2^B$ respectively. Let C_1^B and C_2^B represent two disjoint non-empty subsets in the subscript set $C^B = \{h\sigma \mid h \in \{1, 2, \cdots, |H|\}, \sigma \in \{1, 2, \cdots, |\Upsilon^h|\}\}$ of secondary evaluation indicators under all first evaluation indicators related to buyers, which satisfying $C_1^B \subset C^B$, $C_2^B \subset C^B$ and $C_1^B \cap C_2^B = \varnothing$. Then there are the definitions of these two forms:

Weakly ordered form:

$$\begin{aligned}\widehat{\Lambda}_1^B = \{&(w_{11}^B, w_{12}^B, \cdots w_{1|\Upsilon^1|}^B, w_{21}^B, w_{22}^B, \cdots, w_{2|\Upsilon^2|}^B, \cdots, w_{h1}^B, w_{h2}^B, \cdots, w_{h|\Upsilon^h|}^B) \mid \\ &w_{f_1}^B \geq w_{f_2}^B\} \qquad (f_1 \in C_1^B, f_2 \in C_2^B)\end{aligned} \tag{5}$$

Multiplicative order form:

$$\begin{aligned}\widehat{\Lambda}_2^B = \{&(w_{11}^B, w_{12}^B, \cdots w_{1|\Upsilon^1|}^B, w_{21}^B, w_{22}^B, \cdots, w_{2|\Upsilon^2|}^B, \cdots, w_{h1}^B, w_{h2}^B, \cdots, w_{h|\Upsilon^h|}^B) \mid \\ &w_{f_1}^B \geq \chi^B w_{f_2}^B\} \qquad (f_1 \in C_1^B, f_2 \in C_2^B)\end{aligned} \tag{6}$$

where $\chi^B > 0$. The weight information set of the above two evaluation indexes related to the buyer is recorded as $\Lambda^B = \widehat{\Lambda}_1^B \cup \widehat{\Lambda}_2^B$.

Expression of Heterogeneity Indicators

Let S_i $(i = 1, 2, \cdots, m)$ represent the i th S party, and the evaluation index system of the S party consists of two level evaluation indicators: the first level evaluation index z_k^S and the second level evaluation index $z_{k\theta}^S$, which all k constitute the subscript set K of the first level evaluation index, and its number is $|K|$; all the θ under the k th first level evaluation index constitute the subscript set Θ^k of its corresponding to the second level evaluation index, and its number is $|\Theta^k|$. The actual value and ideal value of the secondary evaluation index $z_{k\theta}^S$ are respectively expressed as $r_{jk\theta}^B$ and

$r_{ik\theta}^{*S}$. Due to the complexity and diversity of matching information, the expression of each evaluation index is ambiguous. Therefore, the evaluation indexes are represented by the real numbers, interval numbers, triangular fuzzy numbers, intuitionistic fuzzy numbers and granular language evaluation value. These five data types are denoted as $\Omega = \{\Omega_1, \Omega_2, \cdots, \Omega_5\}$ following:

$$r_{jk\theta}^{B} = \begin{cases} a_{jk\theta}^{B} & (z_{k\theta}^{S} \in \Omega_1) \\ [\underline{a}_{jk\theta}^{B}, \overline{a}_{jk\theta}^{B}] & (z_{k\theta}^{S} \in \Omega_2) \\ (\underline{b}_{jk\theta}^{B}, b_{jk\theta}^{B}, \overline{b}_{jk\theta}^{B}) & (z_{k\theta}^{S} \in \Omega_3) \\ < \mu_{jk\theta}^{B}, \upsilon_{jk\theta}^{B} > & (z_{k\theta}^{S} \in \Omega_4) \\ o_{jk\theta}^{B} \in O^4 & (z_{k\theta}^{S} \in \Omega_5) \end{cases}$$

and:

$$r_{ik\theta}^{*S} = \begin{cases} a_{ik\theta}^{*S} & (z_{k\theta}^{S} \in \Omega_1) \\ [\underline{a}_{ik\theta}^{*S}, \overline{a}_{ik\theta}^{*S}] & (z_{k\theta}^{S} \in \Omega_2) \\ (\underline{b}_{ik\theta}^{*S}, b_{ik\theta}^{*S}, \overline{b}_{ik\theta}^{*S}) & (z_{k\theta}^{S} \in \Omega_3) \\ < \mu_{ik\theta}^{*S}, \upsilon_{ik\theta}^{*S} > & (z_{k\theta}^{S} \in \Omega_4) \\ o_{ik\theta}^{*S} \in O^4 & (z_{k\theta}^{S} \in \Omega_5) \end{cases}$$

Denote $O^4 = \{o_0, o_1, \cdots, o_4\}$, which is the language evaluation set about the secondary evaluation index $z_{k\theta}^{S}$, where $o_i \ (i = 0,1,\cdots,4)$.

Denote $B_j \ (j = 1,2,\cdots,n)$ represent the j th B party, and the evaluation index system of party B is composed of two level evaluation indexes: the first level evaluation index z_h^B, the second level evaluation index $z_{h\sigma}^{B}$, which all h constitute the subscript set H of the first level evaluation index, and its n umber is $|H|$; all σ under the h th first level evaluation index constitute the subscript set Υ^h of its corresponding to the second level evaluation index, and its number is $|\Upsilon^h|$. The actual value and ideal value of the secondary evaluation index $z_{h\sigma}^{B}$ are respectively expressed as $r_{ih\sigma}^{S}$ and $r_{jh\sigma}^{*B}$. Due to the uncertainty of the market and the complexity and diversity of matching information, the expression of each evaluation index is ambiguous. Therefore, the evaluation indexes are represented by the real numbers, interval numbers, triangular fuzzy numbers, intuitionistic fuzzy numbers and granular language evaluation value. It can be expressed as following:

$$r_{ih\sigma}^{S} = \begin{cases} a_{ih\sigma}^{S} & (z_{h\sigma}^{B} \in \Omega_1) \\ [\underline{a}_{ih\sigma}^{S}, \overline{a}_{ih\sigma}^{S}] & (z_{h\sigma}^{B} \in \Omega_2) \\ (\underline{b}_{ih\sigma}^{S}, b_{ih\sigma}^{S}, \overline{b}_{ih\sigma}^{S}) & (z_{h\sigma}^{B} \in \Omega_3) \\ < \mu_{ih\sigma}^{S}, \upsilon_{ih\sigma}^{S} > & (z_{h\sigma}^{B} \in \Omega_4) \\ o_{ih\sigma}^{S} \in O^4 & (z_{h\sigma}^{B} \in \Omega_5) \end{cases}$$

and:

$$r_{jh\sigma}^{*B}=\begin{cases}a_{jh\sigma}^{*B} & (z_{h\sigma}^{B}\in\Omega_1)\\ [\underline{a}_{jh\sigma}^{*B},\overline{a}_{jh\sigma}^{*B}] & (z_{h\sigma}^{B}\in\Omega_2)\\ (\underline{b}_{jh\sigma}^{*B},b_{jh\sigma}^{*B},\overline{b}_{jh\sigma}^{*B}) & (z_{h\sigma}^{B}\in\Omega_3)\\ <\mu_{jh\sigma}^{*B},\upsilon_{jh\sigma}^{*B}> & (z_{h\sigma}^{B}\in\Omega_4)\\ o_{jh\sigma}^{*B}\in O^4 & (z_{h\sigma}^{B}\in\Omega_5)\end{cases}$$

PERCEIVED VALUE FUNCTION AND DECISION-MAKING MODEL

This section constructs the perceived value functions of seller and buyer respectively, which creates conditions for further constructing a bilateral matching multi-objective decision-making model considering the characteristics of regret avoidance.

Construction of Perceived Value Function for Sellers

In order to calculate the perceived value of the second-hand transaction sellers, we should calculate its utility value and regret-joy value according to the regret theory. First, we need to construct the utility function $U_{ijk\theta}^{S}$. The sellers will consider many aspects when choosing the buyers to avoid making mistakes. When the transaction is completed, for whatever reason, the seller may not be surprised if they find that the selling price is high. However, once it is found that the selling price is low, they will be very regretful. For this reason, most sellers are cautious.

According to the real situation, power function is often used as the utility function of seller S_i about the actual value of secondary evaluation index $\overline{\tilde{r}}_{jk\theta}^{B}$, expressed as:

$$U_{ijk\theta}^{S}=(\overline{\tilde{r}}_{jk\theta}^{B})^{\alpha_i^S} \tag{7}$$

where $\alpha_i^S\in[0,1]$ is the risk aversion coefficient of S_i. When α_i^S is larger, the risk aversion degree is lower. When α_i^S is smaller, the risk aversion is higher.

Similarly, using the same power function:

$$U_{ik\theta}^{*S}=(\overline{\tilde{r}}_{ik\theta}^{*S})^{\alpha_i^S} \tag{8}$$

the utility value $U_{ik\theta}^{*S}$ of the seller about the ideal value $\overline{\tilde{r}}_{ik\theta}^{*S}$ of the secondary evaluation index $z_{k\theta}^{S}$ can be calculated.

It should be noted that in the utility expression of sellers, the selection of risk aversion coefficient α_i^S mainly refers to the research results of the following documents: (1) Based on a large number of experimental test data analysis, Tversky and Kahneman (1992) found that the risk aversion coefficient of 0.88 is a parameter value that can express the general behavior preference of any decision makers. (2) Xu et al. (2011) and Abdellaoui (2000) also obtained the similar parameter values, based on the studied the problem of parameter selection. (3) Wakker (2010) has also adopted the above values in similar studies.

Further, the regret-joy value of the seller S_i relative to its ideal matching buyer is going to be calculated. Generally speaking, the seller wants the actual value of each index of the buyer to be as close as possible to the ideal one. When the actual value of the index is lower than the ideal value, the seller thinks that he made a mistake and will regret it. When the actual value of the index is higher than the ideal value, the seller thinks he has a good eye and will be very happy. According to the regret theory, considering the regret-joy function of seller S_i is expressed as:

$$R_{ijk\theta}^{S} = 1 - \exp\left(-\gamma_i^S (\Delta U_{ijk\theta}^S)\right) = 1 - \exp\left(-\gamma_i^S (U_{ijk\theta}^S - U_{ik\theta}^{*S})\right) \tag{9}$$

where γ_i^S is the regret avoidance coefficient of the seller S_i, $\gamma_i^S > 0$. The greater γ_i^S is, the higher the degree of loss avoidance of seller S_i. $\Delta U_{ijk\theta}^S = U_{ijk\theta}^S - U_{ik\theta}^{*S}$ represents the difference value of the utility value between the actual value of buyer B_j in the secondary evaluating indicator $z_{k\theta}^S$ and the ideal value of the seller S_i. With the increase of γ_i^S, the seller's psychological perception of loss is more sensitive than that of gain. In the real deal, the seller pays much more attention to the degree of regret that may be caused by the transaction results than to the degree of joy.

According to formulas (7)-(9), the perceived value function of seller S_i about the secondary evaluation index $z_{k\theta}^S$ of buyer B_j is constructed, which is expressed as:

$$V_{ijk\theta}^S = U_{ijk\theta}^S + R_{ijk\theta}^S \tag{10}$$

According to formula (10), the comprehensive perceived value V_{ij}^S of the seller S_i about the buyer B_j is expressed as:

$$V_{ij}^S = \sum_{k=1}^{|K|} \left(\sum_{\theta=1}^{|\Theta^k|} w_{k\theta}^S V_{ijk\theta}^S\right) \tag{11}$$

The definition of $w_{k\theta}^S$ is the same as the formula (1), representing the weight of the seller about the second-level evaluation index $z_{k\theta}^S$ under the first-level evaluation index, that is, the seller's preference for each second-level evaluation index $z_{k\theta}^S$.

Construction of Perceived Value Function of Buyers

In order to calculate the perceived value of the buyers, we should calculate its utility value and regret-joy value. First, calculate the utility value obtained when the buyer B_j matches with seller S_i. We need to construct the utility function $U_{jih\sigma}^B$ first. Since the buyer will consider many factors to avoid making mistakes when deciding which seller to choose. After the transaction, if the market price goes up gradually or the landlords of other alternative houses have different degrees of price increase, the buyer feels that the purchased goods is worth the money and will be extremely happy. If the price goes down or the landlord of other alternative one reduces the price, the buyer will feel very regretful when he finds that the price he bought is on the high side. At this time, the pain of regret is far greater than the relief brought by joy. According to the actual situation, the power function is often used as the utility function of the actual value $\tilde{\bar{r}}_{ih\sigma}^S$ of the second-level evaluation index of buyer B_j about the seller S_i, that is:

$$U^B_{jih\sigma} = (\bar{\tilde{r}}^S_{ih\sigma})^{\alpha^B_j} \tag{12}$$

$\alpha^B_j \in [0,1]$ is the coefficient of risk aversion of the buyer B_j. The greater α^B_j, the lower the risk aversion of buyer B_j. At reverse, the smaller α^B_j, the higher the risk aversion of buyer B_j.

Similarly, the same power function is used:

$$U^{*B}_{jh\sigma} = (\bar{\tilde{r}}^{*B}_{jh\sigma})^{\alpha^B_j} \tag{13}$$

We can get the utility value $U^{*B}_{jh\sigma}$ of buyer B_j about the ideal value of the secondary evaluation index $z^B_{h\sigma}$. In the utility function expression of buyer, the choice of risk aversion coefficient α^B_j is consistent with the research results referenced by seller, so we will not repeat them here.

Further, calculate the regret-joy value of the B_j relative to its ideal matching seller. Usually, the buyer wants the actual value of each indicator of the seller to be as close as possible to the ideal matching seller. When the actual value of the index is lower than the ideal value, the buyer thinks that he has not chosen the best housing, and he will feel very regretful. When the actual value of the index is higher than the ideal value, the buyer will feel gratified that he has clinched a deal with the best house. The regret-joy function of buyer B_j can be expressed as:

$$R^B_{jih\sigma} = 1 - \exp\left(-\gamma^B_j(\Delta U^B_{jih\sigma})\right) = 1 - \exp\left(-\gamma^B_j(U^B_{jih\sigma} - U^{*B}_{jh\sigma})\right) \tag{14}$$

γ^B_j is the regret avoidance coefficient of buyer B_j, $\gamma^B_j > 0$. The bigger γ^B_j is, the higher the degree of loss avoidance of buyer B_j. $\Delta U^B_{jih\sigma} = U^B_{jih\sigma} - U^{*B}_{jh\sigma}$ means the buyer B_j's difference in utility value between the actual value and the ideal value of second-level evaluation index $z^B_{h\sigma}$ about seller S_i. With the increase of γ^B_j, the buyer's psychological perception of loss is more sensitive than that of gain. It can be seen that in the real second-hand goods sale, the buyer's attention to the possible regret of the transaction result is much higher than that of joy. Therefore, in the specific calculation process, the regret value and its influence are focused on, and the joy value can be ignored.

In order to construct the perceived value function of buyer B_j about seller S_i's secondary evaluation index $z^B_{h\sigma}$, that is:

$$V^B_{jih\sigma} = U^B_{jih\sigma} + R^B_{jih\sigma} \tag{15}$$

On the basis of (15), the comprehensive perceived value V^B_{ji} of the buyer B_j about the seller S_i, that is:

$$V^B_{ji} = \sum_{h=1}^{|H|} \left(\sum_{\sigma=1}^{|\Upsilon^h|} w^B_{h\sigma} V^B_{jih\sigma}\right) \tag{16}$$

The definition of $w_{h\sigma}^{B}$ is the same with (4), shows that the weight of each secondary evaluation index $z_{h\sigma}^{B}$ under the primary evaluation index, that is, the buyer's preference for each secondary evaluation index $z_{h\sigma}^{B}$.

The successful matching of the seller S_i and the buyer B_j can't be separated from the efforts of the intermediary, from which the intermediary obtains a certain percentage of the total transaction price as commission reward. Generally speaking, the more commission paid that the intermediary achieve, the greater their perceived value, in which the commission paid is recorded as π_{ij}. The perceived value of the intermediary for successfully matching the seller S_i and the buyer B_j of the second-hand transaction is recorded as V_{ij}^{M}:

$$V_{ij}^{M}=\pi_{ij} \tag{17}$$

Construction and Solution of Bilateral Matching Decision-Making Model

A bilateral matching multi-objective decision-making model with the goal of "maximizing the comprehensive perceived value of buyers and sellers and intermediary" is shown as below:

$$\max\{V^{S}\},\max\{V^{B}\},\max\{V^{M}\} \tag{18}$$

$$s.t.\begin{cases} w_{k\theta}^{S}\in\Lambda^{S} & (k\in K;\theta\in\Theta^{k}) \\ w_{h\sigma}^{B}\in\Lambda^{B} & (h\in H;\sigma\in\Upsilon^{h}) \\ \sum_{j=1}^{m}x_{ij}\le\kappa_i & (i=1,2,\cdots,m) \\ \sum_{i=1}^{n}x_{ij}\le\zeta_j & (j=1,2,\cdots,n) \\ x_{ij}\in\{0,1\} & (i=1,2,\cdots,m;j=1,2,\cdots,n) \end{cases} \tag{19}$$

where:

$$V^{S}=\sum_{i=1}^{m}\sum_{j=1}^{n}V_{ij}^{S}x_{ij}$$

$$V^{B}=\sum_{i=1}^{m}\sum_{j=1}^{n}V_{ji}^{B}x_{ij}$$

$$V^{M}=\sum_{i=1}^{m}\sum_{j=1}^{n}V_{ij}^{M}x_{ij}$$

The objective function (18) represents the maximization of the comprehensive perceived value of buyers, sellers and intermediary. The greater the comprehensive perceived value of buyers and sellers, the less likely they are to regret it. The greater the comprehensive perceived value of intermediary, it will try their best to match the most suitable partners for buyers and sellers. Constraint

(19) indicates that the seller's preference for each secondary evaluation index $z_{k\theta}^{S}$, and buyer's preference for each secondary evaluation index $z_{h\sigma}^{B}$. A buyer can match with κ_i sellers at most, and a seller can match with ζ_j buyers at most. $x_{ij} = 1$ shows that there is a match, and $x_{ij} = 0$ indicates that they have not matched.

Substituting equations (11), (16) and (17) into model (18) respectively, we can get:

$$\max\{\sum_{i=1}^{m}\sum_{j=1}^{n}[\sum_{k=1}^{|K|}(\sum_{\theta=1}^{|\Theta^k|} w_{k\theta}^{S} V_{ijk\theta}^{S})]x_{ij}\} \tag{20}$$

$$\max\{\sum_{i=1}^{m}\sum_{j=1}^{n}[\sum_{h=1}^{|H|}(\sum_{\sigma=1}^{|\Upsilon^h|} w_{h\sigma}^{B} V_{jih\sigma}^{B})]x_{ij}\} \tag{21}$$

$$\max\{\sum_{i=1}^{m}\sum_{j=1}^{n}\pi_{ij}x_{ij}\} \tag{22}$$

$$s.t.\begin{cases} w_{k\theta}^{S} \in \Lambda^{S} & (k \in K; \theta \in \Theta^{k}) \\ w_{h\sigma}^{B} \in \Lambda^{B} & (h \in H; \sigma \in \Upsilon^{h}) \\ \sum_{j=1}^{m} x_{ij} \le \kappa_i & (i = 1,2,\cdots,m) \\ \sum_{i=1}^{n} x_{ij} \le \zeta_j & (j = 1,2,\cdots,n) \\ x_{ij} \in \{0,1\} & (i = 1,2,\cdots,m; j = 1,2,\cdots,n) \end{cases} \tag{23}$$

The multi-objective decision-making model for bilateral matching of second-hand transaction constructed above belongs to the multi-objective mixed 0-1 integer programming model. Commonly used algorithms include weighting method, objective programming method, ideal point method, multi-objective evolutionary algorithm and so on. The existing research shows that the ideal point method is a common and effective method to solve multi-objective optimization problems. Therefore, the ideal point method is used in this paper, to solve models (20)-(23) from the perspective of maximizing the interests of buyers and sellers and intermediary.

Because models (20)-(23) are composed of three objective functions and have two different dimensions, that is, V^{S} and V^{B} are comprehensive perceived values, while V^{M} is related to the transaction price, it is necessary to normalize the three objective functions when solving with ideal points. In this regard, a new dimensionless objective function (24) is constructed, and the bilateral matching multi-objective decision-making model is transformed into a bilateral matching single-objective decision-making model, as shown below:

$$\min\{\rho^{S}(\frac{V^{*S} - V^{S}}{V^{*S}}) + \rho^{B}(\frac{V^{*B} - V^{B}}{V^{*B}}) + \rho^{M}(\frac{V^{*M} - V^{M}}{V^{*M}})\} \tag{24}$$

$$s.t.\begin{cases} w_{k\theta}^{S} \in \Lambda^{S} & (k \in K; \theta \in \Theta^{k}) \\ w_{h\sigma}^{B} \in \Lambda^{B} & (h \in H; \sigma \in \Upsilon^{h}) \\ \sum_{j=1}^{m} x_{ij} \leq \kappa_{i} & (i = 1,2,\cdots,m) \\ \sum_{i=1}^{n} x_{ij} \leq \zeta_{j} & (j = 1,2,\cdots,n) \\ x_{ij} \in \{0,1\} & (i = 1,2,\cdots,m; j = 1,2,\cdots,n) \end{cases} \tag{25}$$

The objective function (24) is to minimize the weighted average of the deviation between the optimal solution and the ideal solution of each objective function, where $V^{*} = (V^{*S}, V^{*B}, V^{*M})$ is the objective function value vector of the ideal point. $\rho^{S}, \rho^{B}, \rho^{M} \in [0,1]$ are the weights of the three objective functions, which reflect the importance of the roles of sellers, buyers and intermediary, which satisfying $\rho^{S} + \rho^{B} + \rho^{M} = 1$. According to the ideal point method, when ρ^{S}, ρ^{B} and ρ^{M} are not 0, the optimal solution of model (24) just corresponds to the Pareto optimal solution of models (20)-(23). For the setting of the weights, they can refer to the relevant literature, or also can according to the actual situation or experience of the transaction. Finally, the corresponding single-objective decision model (24) is solved by the optimization software package LINGO, and the optimal solution is obtained.

In summary, the specific calculation steps are as follows:

Step 1: Obtain the actual value information of the second-level evaluation index of the seller S_i and the buyer B_j, and the ideal value information of the second-level evaluation index of the buyer and the seller respectively.

Step 2: Normalize and de-fuzzification the actual value and ideal value of secondary evaluation index of seller S_i and buyer B_j respectively.

Step 3: Calculate the utility value and regret-joy value of seller S_i about the secondary evaluation index according to formulas (7)-(9).

Step 4: Calculate the utility value and regret-joy value of buyer B_j about the secondary evaluation index according to formulas (12)-(15).

Step 5: Calculate the comprehensive perceived value of seller, buyer B_j and the perceived value of intermediary's according to formulas (10)-(11) and (15)-(17).

Step 6: Build a multi-objective decision-making model (18)-(23) for bilateral matching of second-hand transaction considering regret avoidance, and use the ideal point method to solve the model (24) to get the optimal matching result.

APPLICATION AND ANALYSIS

Case Introduction

With the increase of income, in order to improve the quality of life and living, some consumers will consider selling their existing houses or repurchasing a house with larger area, more convenient life, higher education quality or closer commuting distance. This section presents the calculation results and comparative analysis of some numerical problems to illustrate the application and performance of the proposed model and algorithm. The data (including the information of price, demand and attribute, etc.) comes from Beijing Lianjia Real Estate Brokerage Co., Ltd (http://bj.lianjia.com/), which is one of the largest second-hand house trading platforms in China. According to the transaction information obtained on the LinkedIn platform, we have slightly modified these data to conform to our simplified model assumptions and ensure that customer privacy is not disclosed. Then, 6 sellers and 6 buyers are selected, among which the seller corresponds to the S side and the buyer corresponds to the B side. The actual and ideal values of the second-hand house sellers and buyers are shown in Tables 1-4, the minimum acceptable price of the second-hand house sellers is shown in Table 5, the risk aversion and regret avoidance of sellers and buyers are shown in Table 6 and Table 7.

In reality, the preferences of buyers and sellers of second-hand houses for each evaluation index are mostly given in the form of preference order rather than specific preference values. For example, the total price is the most important, followed by the down payment amount, and then the down payment time, and the importance of the remaining second-level evaluation indicators does not exceed 30%. Or the total price is the most important, followed by the construction area, the third is the distance of leisure facilities, and the fourth is the property management, the orientation of the

Table 1. Actual values of secondary evaluation indexes of the second-hand house sellers (unit: 10,000 yuan)

Sellers	Total Price	Unit Price	Payment Ratio	Area	Year	Floor	Orientation
S_1	310	2.3485	30	132	1.3	1	(0.50,0.55,0.90)
S_2	320	2.2378	50	143	0.7	13	(0.55,0.60,0.90)
S_3	318	2.3382	30	136	1	7	(0.45,0.60,0.80)
S_4	305	2.3828	30	128	1	11	(0.50,0.55,0.60)
S_5	345	2.4126	40	143	0.6	5	(0.50,0.75,0.90)
S_6	310	2.2963	30	135	1	12	(0.50,0.60,0.80)
Sellers	**Decoration**	**Leisure Facilities**	**School**	**Hospitals**	**Management**	**Transportation**	**Education**
S_1	G	0.81	0.88	2.8	<0.50,0.35>	<0.65,0.20>	M
S_2	P	0.49	1.25	2.4	<0.50,0.35>	<0.40,0.50>	M
S_3	M	1.2	2.13	3.5	<0.50,0.45>	<0.70,0.20>	G
S_4	M	1.2	2.13	3.5	<0.55,0.30>	<0.65,0.30>	G
S_5	G	0.4	3.8	2.4	<0.55,0.35>	<0.55,0.40>	G
S_6	G	0.8	1.8	2	<0.50,0.40>	<0.65,0.25>	M

Table 2. Ideal values of secondary evaluation indexes of the second-hand house sellers (unit: 10,000 yuan)

Buyers	Total Price	Payment Ratio	Payment Time	Security of Procedures	Loan Method	Final Payment Time	Credit Rating
B_1	[305,320]	[30,40]	[35,40]	G	<0.2,0.5>	[55,75]	G
B_2	[315,335]	[45,55]	[20,30]	G	<0,0.55>	[40,60]	G
B_3	[310,325]	[30,40]	[30,50]	G	<0.25,0.45>	[50,80]	G
B_4	[290,315]	[30,50]	[45,55]	G	<0,0.7>	[40,60]	G
B_5	[340,360]	[30,50]	[40,50]	G	<0.2,0.5>	[30,50]	G
B_6	[305,315]	[30,40]	[25,35]	G	<0.25,0.45>	[50,70]	G

Table 3. Actual values of secondary evaluation indexes of the second-hand house buyers (unit: 10,000 yuan)

Buyers	Total Price	Payment Ratio	Payment Time	Security of Procedures	Loan Method	Final Payment Time	Credit Rating
B_1	300	30	40	G	<0.15,0.55>	60	G
B_2	310	40	30	G	<0,0.6>	40	VG
B_3	308	30	40	VG	<0.16,0.54>	80	G
B_4	288	30	45	VG	<0,0.7>	50	VG
B_5	330	40	45	G	<0,0.6>	40	VG
B_6	300	30	30	VG	<0.1,0.6>	60	G

Table 4. Ideal values of secondary evaluation indexes of the second-hand house buyers (unit: 10,000 yuan)

Sellers	Total Price	Unit Price	Payment Ratio	Area	Year	Floor	Orientation
B_1	[300,315]	[2.3,2.35]	30	[130,140]	[2011,2015]	[1,3]	(0.45,0.55,0.75)
B_2	[315,340]	[2.0,2.25]	30	[140,150]	[2005,2009]	[13,16]	(0.45,0.60,0.80)
B_3	[315,335]	[2.3,2.4]	40	[130,140]	[2008,2011]	[6,10]	(0.50,0.75,0.90)
B_4	[290,310]	[2.35,2.4]	30	[115,130]	[2008,2012]	[8,12]	(0.50,0.75,0.90)
B_5	[325,350]	[2.4,2.6]	40	[140,150]	[2004,2009]	[3,6]	(0.50,0.75,0.90)
B_6	[290,310]	[2.25,2.3]	30	[130,140]	[2009,2012]	[9,12]	(0.50,0.60,0.80)
Buyers	**Total Price**	**payment Ratio**	**Payment Time**	**Security of Procedures**	**Loan Method**	**Final Payment Time**	**Credit Rating**
B_1	M	[0,1]	[1,2]	[2,3]	<0.50,0.45>	<0.65,0.25>	M
B_2	P	[0,0.7]	[1,2]	[2,2.5]	<0.50,0.40>	<0.55,0.40>	G
B_3	G	[0,2]	[0,3]	[3,5]	<0.65,0.20>	<0.65,0.30>	M
B_4	M	[0,3]	[0,2]	[2,4]	<0.55,0.40>	<0.50,0.40>	M
B_5	M	[0,0.5]	[0,3]	[2.2,2.6]	<0.55,0.35>	<0.70,0.20>	G
B_6	G	[0,1]	[1,3]	[0,2]	<0.65,0.30>	<0.65,0.20>	M

Table 5. The minimum acceptable price of the second-hand house sellers (unit: 10,000 yuan)

	S_1	S_2	S_3	S_4	S_5	S_6
Price	305	315	310	290	340	305

house is twice as important as the construction year, and the other secondary evaluation indicators being less than 30%. The importance of the seller, buyer and real estate agency are 0.4, 0.4 and 0.2 respectively. After successfully matching, the commissions according to a certain proportion of the final transaction price and the proportion takes the industry average level as 0.03. In order to simplify the calculation, the total transaction price takes the average transaction price.

Table 6. The risk aversion and regret avoidance of the second-hand house sellers (unit: 10,000 yuan)

	S_1	S_2	S_3	S_4	S_5	S_6
α_1^S	0.85	0.6	0.75	0.88	0.9	0.87
γ_1^S	0.15	0.1	0.05	0.05	0.25	0.3

Table 7. The risk aversion and regret avoidance of the second-hand house buyers (unit: 10,000 yuan)

	S_1	S_2	S_3	S_4	S_5	S_6
α_1^S	0.86	0.79	0.9	0.88	0.88	0.71
γ_1^S	0.1	0.25	0.15	0.05	0.2	0.3

The Results and Comparative Analysis

Firstly, normalize and de-fuzzification the actual value and ideal value of secondary evaluation index of S_i and B_j. Secondly, calculate the utility value and regret-joy value of S_i and B_j about the secondary evaluation index according to formulas (7)-(9) and (12)-(14). Then, calculate the comprehensive perceived value of S_i, B_j and real estate agency according to formulas (10)-(11) and (15)-(17).The commission π obtained by the real estate agency after matching the buyers and sellers of second-hand houses is shown in Table 8.

Further, combined with the above calculation results, according to the model (18), a multi-objective decision-making model for bilateral matching of second-hand house sales is constructed, as shown below:

Table 8. Commission of real estate agency (unit: 10,000 yuan)

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	9.24	9	9.3	8.4	9.3	8.4
B_2	8.85	9.51	9.15	8.55	9.6	8.1
B_3	9	9.3	9.45	8.25	9.6	8.85
B_4	8.7	8.7	9	9	9	9
B_5	9	9.15	8.7	8.7	10.2	8.7
B_6	8.7	9	9	8.55	9.3	9.24

$$\max\{V^S\},\max\{V^B\},\max\{V^M\}$$

$$s.t.\begin{cases} w_{11}^S \geq w_{21}^S + 0.01 \\ w_{21}^S \geq 0.5w_{12}^S + 0.01 \\ w_{12}^S \geq 0.5w_{23}^S + 0.01 \\ w_{13}^S + w_{22}^S + w_{24}^S \leq 0.3 \\ w_{11}^B \geq w_{21}^B + 0.01 \\ w_{21}^B \geq w_{41}^B + 0.01 \\ w_{41}^B \geq w_{51}^B + 0.01 \\ w_{22}^B \geq 0.5w_{31}^B + 0.01 \\ w_{12}^B + w_{13}^B + w_{23}^B + w_{32}^B + w_{42}^B + w_{43}^B + w_{52}^B + w_{53}^B \leq 0.3 \\ w_{1\theta}^S \geq 0 & (\theta = 1,2,3) \\ w_{2\theta}^S \geq 0 & (\theta = 1,2,3,4) \\ w_{h\sigma}^B \geq 0 & (h = 1,2,4,5; \sigma = 1,2,3) \\ w_{3\sigma}^B \geq 0 & (\sigma = 1,2) \\ \sum_{j=1}^{6} x_{ij} \leq 1 \\ \sum_{i=1}^{6} x_{ij} \leq 1 \\ x_{ij} \in \{0,1\} & (i = 1,2,\cdots,6; j = 1,2,\cdots,6) \end{cases}$$

Using the ideal point method and LINGO software, $V^{*S} = 4.142$, $V^{*B} = 4.624$ and $V^{*M} = 6$ are solved.

In this case, according to the objective function (4-24), the bilateral matching multi-objective decision-making model is transformed into a bilateral matching single-objective decision-making model is shown as follow:

$$\min\{0.4(\frac{4.142 - V^S}{4.142}) + 0.4(\frac{4.624 - V^B}{4.624}) + 0.2(\frac{6 - V^M}{6})\}$$

$$s.t.\begin{cases} w_{11}^S \geq w_{21}^S + 0.01 \\ w_{21}^S \geq 0.5w_{12}^S + 0.01 \\ w_{12}^S \geq 0.5w_{23}^S + 0.01 \\ w_{13}^S + w_{22}^S + w_{24}^S \leq 0.3 \\ w_{11}^B \geq w_{21}^B + 0.01 \\ w_{21}^B \geq w_{41}^B + 0.01 \\ w_{41}^B \geq w_{51}^B + 0.01 \\ w_{22}^B \geq 0.5w_{31}^B + 0.01 \\ w_{12}^B + w_{13}^B + w_{23}^B + w_{32}^B + w_{42}^B + w_{43}^B + w_{52}^B + w_{53}^B \leq 0.3 \\ w_{1\theta}^S \geq 0 & (\theta = 1,2,3) \\ w_{2\theta}^S \geq 0 & (\theta = 1,2,3,4) \\ w_{h\sigma}^B \geq 0 & (h = 1,2,4,5; \sigma = 1,2,3) \\ w_{3\sigma}^B \geq 0 & (\sigma = 1,2) \\ \sum_{j=1}^{6} x_{ij} \leq 1 \\ \sum_{i=1}^{6} x_{ij} \leq 1 \\ x_{ij} \in \{0,1\} & (i = 1,2,\cdots,6; j = 1,2,\cdots,6) \end{cases}$$

The optimal matching results of second-hand house sellers and buyers are: $x_{16} = x_{22}=x_{31} = x_{44} = x_{55}=x_{63}=1$, and other is $x_{ij} = 0\ (i = 1,2,\cdots,6; j = 1,2,\cdots,6)$. This shows that: S_1 matches B_6, S_2 matches B_2, S_3 matches B_1, S_4 matches B_4, S_5 matches B_5, S_6 matches B_3. At this time, the perceived value of second-hand house sellers is 3.762, that of buyers is 4.394, and that of real estate agencies is 5.702. The results show that the overall value brought by this transaction to the second-hand house buyer is obviously higher than that of the seller, and the real estate agency has the highest overall value.

In order to investigate the influence of different risk aversion degrees and regret aversion degrees of second-hand house buyers and sellers on the final bilateral matching results of second-hand house transaction, different values were set for the risk preference coefficient and regret aversion coefficient of second-hand housing seller S_i and second-hand housing buyer B_j. Among them, when choosing the values of risk aversion degrees α_i^S and α_j^B, regret aversion degrees γ_i^S and γ_j^B $(i = 1,2,\cdots,6; j = 1,2,\cdots,6)$, the buyers and sellers in the same group take the endpoint values of these two parameters, which can more clearly highlight the influence of different degrees of regret aversion psychology on the choice of the final matching object for the sellers and buyers of second-hand houses. The comparative analysis results are shown in Table 9.

When $\alpha_i^S = \alpha_j^B = 0.9$ and $\gamma_i^S = \gamma_j^B = 0.1$, it shows that both buyers and sellers are risk-taking traders and have a low degree of regret for the consequences of their risky behavior. When $\alpha_i^S = \alpha_j^B = 0.1$ and $\gamma_i^S = \gamma_j^B = 0.9$, it shows that both buyers and sellers are conservative traders and try to avoid making regret decisions. From Table 9, we can see that for the second-hand house buyers and sellers, no matter they are adventurous or conservative, they have the same bilateral matching results, but the perceived value of them is significantly different. The perceived value of the conservative buyers and sellers is significantly higher than that of the adventurous buyers and sellers. Because the second-hand house is a kind of high-value commodity, the adventurous buyers and sellers often have less overall value than the conservative ones, which is consistent with the reality.

Therefore, in the different situations, when the different buyers and sellers have different risk preferences and avoidance degrees. That is, the different values of α_i^S and γ_i^S, α_j^B and γ_j^B, the bilateral matching results or the perceived values are different. we should pay attention to the influence of psychological factors on the final result.

Furthermore, in order to fully illustrate the advantage of the method proposed in this paper, the comparison of the proposed method and the existing methods (Zhang et al., 2020; Liu & Wang, 2020;

Table 9. Analysis of different values of risk preference coefficient and regret avoidance coefficient

	Risk Preference Coefficient	Regret Evasion Coefficient	Bilateral Matching Result	Perceived Value
1	$\alpha_i^S = 0.9$ $\alpha_j^B = 0.9$	$\gamma_i^S = 0.1$ $\gamma_j^B = 0.1$	$x_{11} = x_{22} = x_{33} = x_{44} = x_{55} = x_{66}=1$ Others $x_{ij} = 0$	$V^S = 3.726$, $V^B = 3.932$, $V^B = 6$
2	$\alpha_i^S = 0.1$ $\alpha_j^B = 0.1$	$\gamma_i^S = 0.9$ $\gamma_j^B = 0.9$	$x_{11} = x_{22} = x_{33} = x_{44} = x_{55} = x_{66}=1$ Others $x_{ij} = 0$	$V^S = 4.284$, $V^B = 4.588$, $V^B = 6$

Wang et al.,2022) is given. Compared with the existing literature, the differences and advantages of this paper are as follows:

1. In the information expression, Zhang et al. (2020) describes the index information with hesitant fuzzy language, and Liu and Wang (2020) expresses the satisfaction of the index and the weight of the evaluation index with intuitive fuzzy preference information. Wang et al. (2022) uses fuzzy information of probability hesitation to express evaluation index and index weight. These three kinds of language types can well reflect the uncertainty of human information expression and the fuzziness of language information. However, their calculation process is not only too complicated and cumbersome, but also causes the loss of some important information.
2. In terms of the use of weight information, Zhang et al. (2020) and Wang et al. (2022) use intuitive fuzzy preference information and probabilistic hesitant fuzzy information to express the weight of indicators respectively, both of which match the preference of decision makers for a single evaluation indicator or criterion. However, the overall preference order of all evaluation indicators is not given in these two papers, which is quite different from the actual situation. This paper uses weak order form and multiplication order form to describe the incomplete weight information of matching decision makers on evaluation indicators. This description not only highly restores the overall ranking of the preferences of decision makers for multiple evaluation indicators in reality, but also avoids complicated mathematical calculations. Therefore, this description of weight is convenient to be widely used in reality.
3. The intermediary is an indispensable subject in the process of bilateral matching, and ignoring the interests of intermediaries will affect the results of bilateral matching. However, none of the three papers considers it in Zhang et al. (2020), Liu & Wang (2020) and Wang et al. (2022), which is very important variable in the matching process. It should be emphasized that the bilateral matching method proposed in this paper considers the intermediary's benefits.
4. In the papers of Zhang et al. (2020), Liu and Wang (2020), and Wang et al. (2022), although it realized that the previous research on the preference information could not fully reflect the needs of matching parties, they only strengthen the more professional description of the degree of hesitation in human expression information. However, according to the different types of demand information of matching parties, this paper uses five data types to express them fully. Firstly, it can comprehensively describe the demand characteristics of both sides of the match and minimize the information loss caused by data expression. Secondly, it also expands the application scope of fuzzy data types in reality.

CONCLUSION

This paper presents a novel method for solving the bilateral matching problem. In the method, a model is first to be established to exhibit the mechanism of regret psychology. In this model, we can fully understand the important factors that affect the regret avoidance can be demonstrated clearly. Then, the perceived utility of evaluation indicators to each matching party is built respectively. Further, by the perceived utility of matching parties, the method of bilateral matching decision-making considering the regret avoidance characteristics is built and the final matching result is determined by ideal point method. Finally, a realistic example is shown using the real data collected from the second-hand house transaction. The major contributions of this paper are discussed as follows.

First, this paper focuses on bilateral matching decision-making considering regret avoidance psychology, which is a new research topic with a lot of practical backgrounds. In the problem, the matching parties' behavioral characteristics and psychological demands are fully considered.

Second, this paper presents a method for solving the bilateral matching decision-making considering psychological characteristics and the application in the second-hand transaction platform. This method is superior to the existing methods in the following aspects: 1. It fully characterizes the matching parties' demand portrait with five data types, which including real numbers, interval numbers, triangular fuzzy numbers, intuitionistic fuzzy numbers and multi-grained linguistic variables. 2. It develops a method of establishing the perceived utility of the matching parties' and second-hand goods by game theory. 3. Not only considering maximum payoff of the sellers and buyers, but also taking account into the maximum satisfaction of intermediary .This calculation design is more fit in with the reality and the matching result is more reasonable.

It is important to highlight that, since the proposed method is new and different from the existing methods, it can give the transaction operators one more choice for selecting the appropriate method for solving the bilateral matching problem. In addition to supplementing the existing methods, the proposed method is also important for developing and enriching theories and methods of bilateral matching decision-making.

REFERENCES

Abdellaoui, M. (2000). Parameter-free elicitation of utility and probability weighting functions. *Management Science*, *46*(11), 1497–1512. doi:10.1287/mnsc.46.11.1497.12080

Azevedo, E. M. (2014). Imperfect competition in two-sided matching markets. *Games and Economic Behavior*, *83*(1), 207–223. doi:10.1016/j.geb.2013.11.009

Bell, D. E. (1982). Regret in decision-making under uncertainty. *Operations Research*, *30*(5), 961–981. doi:10.1287/opre.30.5.961

Bell, D. E. (1985). Disappointment in decision making under uncertainty. *Operations Research*, *33*(1), 1–27. doi:10.1287/opre.33.1.1

Belleflamme, P., & Peitz, M. (2019). Managing competition on a two-sided platform. *Journal of Economics & Management Strategy*, *28*(1), 5–22. doi:10.1111/jems.12311

Benassi, M., & Minin, A. D. (2009). Playing in between: Patent brokers in markets for technology. *R & D Management*, *39*(1), 68–86. doi:10.1111/j.1467-9310.2008.00537.x

Bertsekas, D. P. (1981). A new algorithm for the assignment problem. *Mathematical Programming*, *21*(1), 152–171. doi:10.1007/BF01584237

Bloch, F., & Ryder, H. (2000). Two-sided search, marriage and matchmakers. *International Economic Review*, *41*(1), 93–115. doi:10.1111/1468-2354.00056

Chen, X., Li, Z., Fan, Z. P., Zhou, X., & Zhang, X. (2016). Matching demanders and suppliers in knowledge service: A method based on fuzzy axiomatic design. *Information Sciences*, *346*, 130–145. doi:10.1016/j.ins.2016.01.096

Connors, R. D., & Sumalee, A. (2009). A network equilibrium model with travellers' perception of stochastic travel times. *Transportation Research Part B: Methodological*, *43*(6), 614–624. doi:10.1016/j.trb.2008.12.002

Cullen, Z., & Farronato, C. (2021). Outsourcing tasks online: Matching supply and demand on Peer-to-Peer internet platforms. *Management Science*, *67*(7), 3985–4003. doi:10.1287/mnsc.2020.3730 PMID:35001975

Davoudabadi, R., Mousavi, S. M., & Mohagheghi, V. (2020). A new last aggregation method of multi-attributes group decision making based on concepts of TODIM, WASPAS and TOPSIS under interval-valued intuitionistic fuzzy uncertainty. *Knowledge and Information Systems*, *62*(4), 1371–1391. doi:10.1007/s10115-019-01390-x

Echenique, F., & Oviedo, J. (2004). Core many-to-one matchings by fixed-point methods. *Journal of Economic Theory*, *115*(2), 358–376. doi:10.1016/S0022-0531(04)00042-1

Edmund, Z. (2020). A longitudinal analysis of the effect of public rail infrastructure on proximate residential property transactions. *Urban Studies (Edinburgh, Scotland)*, *57*(8), 1620–1641. doi:10.1177/0042098019836564

Engelbrecht, W. R., & Katok, E. (2008). Regret and feedback information in first-price sealed-bid auctions. *Management Science*, *54*(4), 808–819. doi:10.1287/mnsc.1070.0806

Fan, Z. P., Li, M. Y., & Zhang, X. (2017). Satisfied two-sided matching: A method considering elation and disappointment of agents. *Soft Computing*, *15*(1), l-15.

Fudge, K. D. K., Honoré, F., & Nistor, C. (2021). When the weak are mighty: A two-sided matching approach to alliance performance. *Strategic Management Journal*, *42*(5), 917–940. doi:10.1002/smj.3275

Gale, D., & Shapley, L. S. (1962). College admissions and the stability of marriage. *The American Mathematical Monthly*, *69*(1), 9–15. doi:10.1080/00029890.1962.11989827

Halaburda, H., Jan, P. M., & Yıldırım, P. (2018). Competing by restricting choice: The case of search platforms. *Management Science*, *64*(8), 3574–3594. doi:10.1287/mnsc.2017.2797

Hu, M., & Zhou, Y. (2022). Dynamic Type Matching. *Manufacturing & Service Operations Management*, *24*(1), 125–142. doi:10.1287/msom.2020.0952

Irving, R. W., Manlove, D. F., & Scott, S. (2008). The stable marriage problem with master preference lists. *Discrete Applied Mathematics*, *156*(15), 2959–2977. doi:10.1016/j.dam.2008.01.002

Jiang, Z. Z., Ip, W. H., Lau, H. C. W., & Fan, Z. P. (2011). Multi-objective optimization matching for one-shot multi-attribute exchanges with quantity discounts in e-brokerage. *Expert Systems with Applications*, *38*(4), 4169–4180. doi:10.1016/j.eswa.2010.09.079

Jiang, Z. Z., Zhang, R., Fan, Z. P., & Chen, X. (2015). A fuzzy matching model with Hurwicz criteria for one-shot multi-attribute exchanges in E-brokerage. *Fuzzy Optimization and Decision Making*, *14*(1), 77–96. doi:10.1007/s10700-014-9189-x

Kadadha, M., Otrok, H., Singh, S., Mizouni, R., & Ouali, A. (2021). Two-sided preferences task matching mechanisms for blockchain-based crowdsourcing. *Journal of Network and Computer Applications*, *191*. doi:10.1016/j.jnca.2021.103155

Kumar, K., & Chen, S. M. (2021). Multi-attribute decision making based on interval-valued intuitionistic fuzzy values, score function of connection numbers, and the set pair analysis theory. *Information Sciences*, *551*, 100–112. doi:10.1016/j.ins.2020.11.032

Li, M. Y., & Fan, Z. P. (2014). Method for stable two-sided matching considering psychological behavior of agents on both sides. *Systems Engineering Theory & Practice*, *34*(10), 2591–2599.

Liang, D. C., He, X., & Xu, Z. S. (2020). Multi-attribute dynamic two-sided matching method of talent sharing market in incomplete preference ordinal environment. *Applied Soft Computing*, *93*(1), 1–18. doi:10.1016/j.asoc.2020.106427

Liang, K. R., & Li, D. F. (2022). A bi-objective biform game approach to optimizing strategies in bilateral link network formation. *IEEE Transactions on Systems, Man, and Cybernetics. Systems*, *52*(3), 1653–1662. doi:10.1109/TSMC.2020.3034480

Liu, S. Q., & Wang, B. W. (2020). Method for two-sided matching decision considering regret behavior in hesitant fuzzy environment. *Journal of Mathematics in Practice and Theory*, *50*(7), 97–105.

Liu, S. Q., & Wang, B. W. (2020). Method for two-sided matching decision considering regret behavior in hesitant fuzzy environment. *Journal of Mathematics in Practice and Theory*, *50*(7), 97–105.

Liu, X., Liu, L., & Qi, E. S. (2017). A Buy-sell Two-sided Matching Decision-making Method for the E-Brokerage Based on Double Reference Points. *Operations Research and Management Science*, *26*(3), 72–77.

Loomes, G., & Sugden, R. (1982). Regret theory: An alternative theory of rational choice under uncertainty. *Economic Journal (London)*, *92*(368), 805–824. doi:10.2307/2232669

Michael, G., & Christopher, K. (2021). Pairwise stable matching in large economies. *Econometrica*, *89*(6), 2929–2974. doi:10.3982/ECTA16228

Munkres, J. (1957). Algorithms for the assignment and transportation problems. *Journal of the Society for Industrial and Applied Mathematics*, *5*(1), 32–38. doi:10.1137/0105003

Nan, J. X., Wei, L. X., Li, D. F., & Zhang, M. J. (2022). A preemptive goal programming for multi-objective cooperative games: An application to multi-objective linear production. *International Transactions in Operational Research*, itor.13233. Advance online publication. doi:10.1111/itor.13233

Pais, J. (2008). Random matching in the college admissions problem. *Economic Theory*, *35*(1), 99–116. doi:10.1007/s00199-006-0191-6

Ribeiro, E. P., & Golovanova, S. (2020). A unified presentation of competition analysis in two-sided markets. *Journal of Economic Surveys*, *34*(3), 548–571. doi:10.1111/joes.12362

Roth, A. E., Rothblum, U. G., & Vande, V. J. H. (1993). Stable matchings, optimal assignments and linear programming. *Mathematics of Operations Research*, *18*(4), 803–828. doi:10.1287/moor.18.4.803

Roth, A. E. E. (1985). Conflict and coincidence of interest in job matching: Some new results and open questions. *Mathematics of Operations Research*, *10*(3), 379–389. doi:10.1287/moor.10.3.379

Rothblum, U. G. (1992). Characterization of stable matchings as extreme points of a polytope. *Mathematical Programming*, *54*(1), 57–67. doi:10.1007/BF01586041

Sasaki, H., & Toda, M. (1996). Two-sided matching problems with externalities. *Journal of Economic Theory*, *70*(1), 93–110. doi:10.1006/jeth.1996.0077

Teo, C. P., Sethuraman, J., & Tan, W. P. (2001). Gale-sharpley stable marriage problem: Revisited strategic issues and applications. *Management Science*, *47*(9), 1252–1267. doi:10.1287/mnsc.47.9.1252.9784

Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty*, *5*(4), 297–323. doi:10.1007/BF00122574

Wakker, P. P. (2010). *Prospect Theory: For Risk and Ambiguity*. Cambridge University Press. doi:10.1017/CBO9780511779329

Wang, R., & Li, D. F. (2017). Bargain game models of the second-hand housing commence. *Communications in Computer and Information Science*, *32*(5), 588–595. doi:10.1007/978-981-10-6753-2_6

Wang, R., Li, D. F., & Yu, G. F. (2020). Research on bilateral matching decision method considering attribute association in heterogeneous information environment. *Journal of Intelligent & Fuzzy Systems*, *38*(4), 4779–4792. doi:10.3233/JIFS-191495

Wang, R. C., & Chuu, S. J. (2004). Group decision-making using a fuzzy linguistic approach for evaluating the flexibility in a manufacturing system. *European Journal of Operational Research*, *154*(3), 563–572. doi:10.1016/S0377-2217(02)00729-4

Wang, X. F., Zhou, L., Zhu, Y. F., & Jia, X. (2022). Two-sided matching decision making method with probabilistic hesitant fuzzy information based on regret theory. *Control and Decision*, *37*(9), 2380–2388.

Xu, H. L., Zhou, J., & Xu, W. (2011). A decision-making rule for modeling travelers' route choice behavior based on cumulative prospect theory. *Transportation Research Part C, Emerging Technologies*, *19*(2), 218–228. doi:10.1016/j.trc.2010.05.009

Yash, K., & Daniela, S. (2021). Facilitating the search for partners on matching platforms. *Journal of personality and social psychology*. *Management Science*, *67*(10), 5990–6029. doi:10.1287/mnsc.2020.3794

Yu, D. J., Wang, W. R., Zhang, W. Y., & Zhang, S. (2018). A bibliometric analysis of research on multiple criteria decision making. *Current Science*, *114*(4), 747–758. doi:10.18520/cs/v114/i04/747-758

Yu, G. F., & Li, D. F. (2022). A novel intuitionistic fuzzy goal programming method for heterogeneous MADM with application to regional green manufacturing level evaluation under multi-source information. *Computers & Industrial Engineering*, *174*: 108796. doi:10.1016/j.cie.2022.108796

Yu, G. F., Li, D. F., Liang, D. C., & Li, G. X. (2021). An intuitionistic fuzzy multi-objective goal programming approach to portfolio selection. *International Journal of Information Technology & Decision Making*, *20*(5), 1477–1497. doi:10.1142/S0219622021500395

Yue, Q. (2013). A decision method for the two-sided matching with uncertain preference ordinal information based on cumulative prospect theory. *Journal of Systems Science & Mathematical Sciences*, *33*(9), 1061–1070.

Zeithaml, V. A., Berry, L. L., & Parasuraman, A. (1993). The nature and determinants of customer expectations of service. *Journal of the Academy of Marketing Science*, *21*(1), 1–12. doi:10.1177/0092070393211001

Zhang, D., Dai, H. J., & Liu, X. R. (2020). Intuitionistic fuzzy two-sided matching method considering regret aversion and matching aspiration. *Operational Research and Management Science*, *29*(10), 132–139.

Zhang, D., Sun, T., Chen, Y., & Wan, L. Q. (2018). Two-sided matching method considering psychological behavior of agents based on multi-form preference information. *Jisuanji Jicheng Zhizao Xitong*, *24*(12), 3136–3143.

Zheng, X. X., Chang, C. T., Li, D. F., Liu, Z., & Lev, B. (2022). Designing an incentive scheme for producer responsibility organization of waste tires: A MCGP cooperative game approach. *Computers & Industrial Engineering*, *167*, 108009. doi:10.1016/j.cie.2022.108009

Zuo, W. J., Liu, L. J., Hu, Q., Zeng, S. Z., & Hu, Z. M. (2023). A property perceived service quality evaluation method for public buildings based on multisource heterogeneous information fusion. *Engineering Applications of Artificial Intelligence*, *122*, 106070. doi:10.1016/j.engappai.2023.106070