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BILATERAL MATCHING DECISION-MAKING IN PROPERTY TRADING PLATFORM: A METHOD CONSIDERING INTERMEDIARY MORAL HAZARD

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Abstract. Effective method of bilateral matching decision-making could drive the property transaction market more dynamic and healthier. In the property trade process, once intermediaries are conscientious, the portrait of matching parties are clearly described, a reasonable and satisfactory result can be got. However, the intermediary moral hazard and the loss of the description about the characteristics of matching parties can affect the matching result. By developing a method for a property transaction platform, this paper proposes a novel approach that considering intermediary moral hazard to improve matching efficiency. A mathematical model of intermediary moral hazard is performed, and then the price and other evaluation indicators of sellers and buyers are described by five different types of value forms. A multi-objective bilateral matching decision-making model that "minimizes the intermediary moral hazard in the case of the maximum benefits of the matching parties" is constructed and solved by the dictionary order method. 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 sellers and buyers under the intermediary moral hazard and has substantial practical application.

Keywords: moral hazard, intermediary, multi-type heterogeneous information, bilateral matching decision-making, property intermediary platform.

Introduction

With the rapid development of the domestic economy, the property trade has become an important part of the market transaction (Hui & Yam, 2014). Effective and professional property trading services are able to create value-added activities and customized solutions to satisfy the requirements of both the property sellers and buyers (Wang & Li, 2017; Zolnik, 2020). In the property trading market, there are three players: the property sellers (suppliers) who provide the property to be selected, buyers (demanders) who seek the new property, and the intermediaries who match the sellers and the buyers (Zeithaml et al., 1993; Sladić et al., 2021). With the popularity of e-commerce, online and offline platforms of property transaction intermediaries have become an important media for bilateral matching of property. Since the individuation of property demand and the diversity of property supply appear significantly, a proper match between the property sellers and buyers has become increasingly important. As information and resources are often restricted or proprietary, it has become necessary for property sellers or buyers to use the expert knowledge services of intermediaries as a bridge to find suitable partners. Consequently, bilateral matching problems among property sellers, intermediaries, and buyers have emerged and have been studied by many colleges (Benassi & Minin, 2009; Belleflamme & Peitz, 2019; Italo & Oswaldo, 2020; Zolnik, 2020; Cullen & Farronato, 2021; Yash & Daniela, 2021; Zuo et al., 2020, 2023). Meanwhile, in the search process, only the intermediaries themselves know their own work attitude and effort, while the sellers and the buyers have no way to know. Especially, online platform is more difficult to observe and monitor the intermediaries' work (Sim & Chan, 2000; Allon et al., 2012; Halevy et al., 2020; Yash & Daniela, 2021; Cullen & Farronato, 2021; Bojd & Yoganarasimhan, 2022). The higher the number and efficiency of matching, the greater the income

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of intermediary. However, if the income obtained by matching is lower than that obtained by crowding the interests of both matching parties, the intermediary may take risks for its own benefit (Liu et al., 2022; Suzuki & Shibata, 2022; Sladić et al., 2021). At the same time, customer portraits and product descriptions have become an important part of the bilateral matching of property transaction. Among them, customer portraits include the demand information of buyers and sellers and the evaluation information of the property, and product descriptions include the complex and diverse attribute information of property itself. The more accurate the customer portrait and product description, the more efficient the bilateral matching.

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; Irving et al., 2008; Echenique & Oviedo, 2004; Pais, 2008; Hatfield & Kojima, 2010; Jiang et al., 2011; Azevedo, 2014; Yu et al., 2018b; Halaburda et al., 2018; Hu & Zhou, 2018; Zhang et al., 2018; Liang et al., 2020; Greinecker & Kah, 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. In the context of professional intermediaries and trading platforms have replaced self-matching, the received attention of intermediaries platforms is insufficient which cannot match with the value of the problem (Zeithaml et al., 1993; Sim & Chan, 2000; Hoppe & Ozdenoren, 2005; Benassi & Minin, 2009; Jiang et al., 2011; Lee & Niederle, 2015; Halaburda et al., 2018). Due to the key role of intermediaries in the whole process of property transactions, the intermediaries' moral hazard is an important issue in bilateral matching. The research on intermediaries' moral hazard and its theoretical model can further promote the in-depth study of broker ethics, so as to better implement the relevant requirements of property transaction ethics in management practice.

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, 2022; Liu et al., 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 property transaction matching more accurate, in which the intermediary's moral hazard 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 property matching process, the income levels of property 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. Therefore, an intermediary moral hazard model is established to describe the profit-seeking impulse of intermediaries in bilateral matching, which provides a method for studying the impact of intermediary behavior on matching results. Meanwhile, a bilateral matching decision-making approach for property transaction is proposed by considering more behavior and psychology details of the three parties.

This paper contributes to the following aspects: firstly, a hybrid of decision-making methods extends the application of both bilateral matching and game theory to property transaction field. This interdisciplinary study covers both transaction research and property management, aiming to be a useful tool for knowledge and experience transfer. Secondly, the study avoids underestimation of the intermediaries' characteristics, as well as considers both psychological problems (e.g., maximization of benefit) and behavioral issues (e.g., minimization of efforts and risks). Therefore, the approach is superior to the traditional research that not fully considered these important details. Thirdly, it provides insights for property trading platforms 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), and more accurate matching algorithm by using a more practical model solving method (e.g., dictionary order method). The department of market supervision may benefit from the moral hazard construction integrating with bilateral matching results to deliver further guidance to practitioners on developing moral hazard avoidance. Lastly, it also enriches property 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 intermediary moral hazard is introduced and the intermediary moral hazard model is innovatively established. In Section 3, the dominance regarding the price and other evaluation indicators of the seller and buyer are constructed and calculated respectively. A multi-objective decision model considering the moral hazard of intermediaries is developed. In Section 4, the proposed model and method is specifically applied to the case of property intermediary platform. A comparison analyses are conducted. In the last section, this paper concludes.

1. 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; Irving et al., 2008; Echenique & Oviedo, 2004; Pais, 2008; Hatfield & Kojima, 2010; Jiang et al., 2011; Azevedo, 2014; Yu et al., 2021, 2022). Among them, some researchers studied the optimal cheating strategy and the truncation strategy in bilateral matching (Teo et al., 2001). 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., 2020; 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), 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 (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; Anton & Dam, 2020; Meng et al., 2021; Sladić et al., 2021; Fudge Kamal et al., 2021; Francis, 2022) recently.

However, there are only a few studies on the moral hazard of intermediaries in the bilateral matching decision-making field. For example, Hoppe and Ozdenoren (2005) analyzed the functions of an invention service broker and constructed a balanced model for two-sided demand and supply matching. Benassi and 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 and Jinag (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., 2011; Yu et al., 2018a; Yu & Li, 2022), 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.

2. Preliminary

2.1. 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 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: $S_i\bigcup B_j \to S\bigcup B$, where $\forall S_i\in S$, $\forall B_j\in B$, which satisfies the following three conditions: (1) $\mu(S_i)\in B$; (2) $\mu(B_j)\in S\bigcup\{B_j\}$; (3) if and only if $\mu(B_j)=S_i$, where $\mu(S_i)=B_j$ 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.

2.2. Expression of heterogeneity indicators

Let S_i $(i=1,2,\cdots,m)$ represent the ith 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 kth 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 $\Omega=\{\Omega_1,\Omega_2,\cdots,\Omega_5\}$ as 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 jth 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 number is $|H|$; all σ under the hth 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

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

2.3. Construction of intermediary moral hazard model

In order to eliminate all kinds of asymmetric information in the matching process as much as possible, both sides of the match party leave the search and matching work to intermediaries. In the specific work, only the intermediaries are aware of the work attitude and effort of the intermediaries, especially online platform is more difficult to observe and monitor their work. The moral risk of intermediaries is mainly manifested in two aspects. On the one hand, they do not strictly and accurately review the basic information of both sides. Because a rigorous review will cause some matching parties to abandon the commission, which will substantially reduce the expected revenue of the intermediary, and this requires more costs in terms of manpower, time and effort from the intermediary. On the other hand, intermediaries may conspire with one party and profit from it. The explicit incentive contract has been proven to overcome the moral hazard of intermediaries, but it is not applicable to some transaction situations.

In a single bilateral match, the effort of the intermediary to find suitable matching objects for S_i and B_j is denoted as η_{ij} $(i=1,2,\cdots,m; j=1,2,\cdots,n)$, and the value that the intermediary can create for S_i and B_j is denoted as ν_{ij} $(i=1,2,\cdots,m; j=1,2,\cdots,n)$, then:

$$v_{ij}=\beta_{ij}\eta_{ij}+a \quad (i=1,2,\cdots,m; j=1,2,\cdots,n), \tag{1}$$

where: $\beta_{ij}\in[0,1]$ is the coefficient of the effort of the intermediary; η_{ij} is the private information; a is a constant, $a\in(0,1)$.

If the transaction price between S_i and B_j is p_{ij}, the benefits obtained by both parties are:

$$V_{ij}^{SB}=p_{ij}v_{ij} \quad (i=1,2,\cdots,m; j=1,2,\cdots,n). \tag{2}$$

The intermediary charges a commission according to the α ratio of the transaction price, it can be described as:

$$\Phi_{ij}^{M}=\varpi p_{ij} \quad (i=1,2,\cdots,m; j=1,2,\cdots,n). \tag{3}$$

Assuming that the cost function is a strictly increasing convex function about $c(\eta)$, and satisfies $c'(\eta)>0$, $c'''(\eta)>0$, $c(0)=c'(0)=0$. Further, let $c(\eta_{ij})=(b\eta_{ij}^2)/2$, then the benefit of the intermediary can be obtained by successfully matching S_i and B_j is:

$$V_{ij}^{M}=\Phi_{ij}^{M}-(b\eta_{ij}^2)/2=\varpi p_{ij}-(b\eta_{ij}^2)/2$$
$$(i=1,2,\cdots,m; j=1,2,\cdots,n), \tag{4}$$

where b is a constant, $b\in[0,1]$.

According to Eq. (2) and Eq. (4), the total benefit of bilateral matching based on the degree of intermediary effort is:

$$\overline{V}_{ij}=V_{ij}^{SB}+V_{ij}^{M}=p_{ij}v_{ij}+\varpi p_{ij}-(b\eta_{ij}^2)/2$$
$$(i=1,2,\cdots,m; j=1,2,\cdots,n). \tag{5}$$

In order to investigate the relationship between the effort level of the intermediary and the total income obtained by the S_i and B_j, Eq. (5) is derived. That is, let $\partial\overline{V}_{ij}/\partial\eta_{ij}=0$, the optimal effort level of the intermediary to search for suitable matching objects for S_i and B_j can be obtained. It is expressed as:

$$\eta_{ij}^{*}=\beta_{ij}p_{ij}/b \quad (i=1,2,\cdots,m; j=1,2,\cdots,n). \tag{6}$$

At this time, the optimal effort level η_{ij}^{*} of the intermediary is proportional to the transaction price p_{ij} and its coefficient. Once the effort of the intermediary is positively correlated with the transaction price, the moral hazard of the intermediary appears, and η_{ij}^{*} is expressed as:

$$\Gamma_{ij}=1-\eta_{ij}^{*}=1-\beta_{ij}p_{ij}/b \quad (i=1,2,\cdots,m; j=1,2,\cdots,n). \tag{7}$$

Moral hazard arises because, on the one hand, the matching parties have incomplete information on whether the intermediary is doing their best; on the other hand, many realistic bilateral matching problems are often one-off and the matching group is relatively loose. In the process of the match, both parties cannot formulate explicit delegation contracts to supervise the behavior of the intermediary. At the same time, due to lax market supervision and low opportunity cost, intermediaries often have obvious moral hazard impulses.

3. Construction and solution of bilateral matching model considering intermediary moral hazard

Based on the classic TODIM method, and according to the concept of dominance degree proposed by Jiang et al. (2011), the degree of dominance is used to indicate the degree of recognition of the evaluation index of the matching object by both parties. Specifically, if S_i and B_j have a greater dominance over the matching object, it means that they have obtained the most perceptual benefit. In the matching process, the greater the dominance of the matching parties, the more likely they are to match. Therefore, the dominance of S_i and B_j is the aggregation of all the evaluation indexes of the matching object.

At the same time, other decision variables involved in this paper are as follow: p_i^S represents the lowest price acceptable to the S_i, p_i^B represents the B_j's acceptable price, p_i^M represents the evaluation price given by the intermediary, and p_{ij} represents the price that the intermediary successfully matched. Among which p_i^S, p_i^B are only known to the intermediary.

3.1. Establishment of dominance of price of matching parties

(1) Establishment of S_i's price dominance

In the case of $p_i^B \geq p_i^S$, if $p_{ij} < p_i^B$, the dominance of S_i is 0, then S_i is unwilling to match B_j. If $p_{ij} \geq p_i^M$, S_i's dominance is 1, then S_i is extremely willing to match B_j. As p_{ij} increases, S_i's dominance increases. When the transaction price is p_{ij}, the dominance of S_i is:

$$g_{ij}^S = \begin{cases} 1 & (p_{ij} \geq p_i^M) \\ \dfrac{p_{ij} - p_i^B}{p_i^M - p_i^B} & (p_i^B \leq p_{ij} < p_i^M) \\ 0 & (p_{ij} < p_i^B) \end{cases}$$

$$(i = 1,2,\cdots,m; j = 1,2,\cdots,n). \quad (8)$$

In the case of $p_i^B < p_i^S$, if $p_{ij} < p_i^S$, the dominance of S_i is 0, then S_i is unwilling to match B_j. If $p_{ij} > p_i^M$, S_i's dominance is 1, then S_i is extremely willing to match B_j. As p_{ij} increases, S_i's dominance increases. When the transaction price is p_{ij}, the dominance of S_i is:

$$g_{ij}^S = \begin{cases} 1 & (p_{ij} \geq p_i^M) \\ \dfrac{p_{ij} - p_i^S}{p_i^M - p_i^S} & (p_i^S \leq p_{ij} < p_i^M) \\ 0 & (p_{ij} < p_i^S) \end{cases}$$

$$(i = 1,2,\cdots,m; j = 1,2,\cdots,n). \quad (9)$$

(2) Establishment of B_j's price dominance

In the case of $p_i^B \geq p_i^S$, if $p_{ij} \geq p_i^M$, the dominance of B_j is 0, then B_j is unwilling to match S_i. If $p_{ij} < p_i^B$, B_j's dominance is 1, then B_j is extremely willing to match S_i. As p_{ij} increases, B_j's dominance increases. When the transaction price is p_{ij}, the dominance of B_j is:

$$g_{ji}^B = \begin{cases} 0 & (p_{ij} \geq p_i^M) \\ \dfrac{p_i^M - p_{ij}}{p_i^M - p_i^B} & (p_i^B \leq p_{ij} < p_i^M) \\ 1 & (p_{ij} < p_i^B) \end{cases}$$

$$(i = 1,2,\cdots,m; j = 1,2,\cdots,n). \quad (10)$$

In the case of $p_i^B < p_i^S$, if $p_{ij} \geq p_i^M$, the dominance of B_j is 0, then S_i is not in the selection of B_j. If $p_{ij} < p_i^S$, B_j's dominance is 1, then B_j is extremely willing to match S_i. As p_{ij} increases, B_j's dominance increases. When the transaction price is p_{ij}, the dominance of B_j is:

$$g_{ji}^B = \begin{cases} 0 & (p_{ij} \geq p_i^M) \\ \dfrac{p_i^M - p_{ij}}{p_i^M - p_i^S} & (p_i^S \leq p_{ij} < p_i^M) \\ 1 & (p_{ij} < p_i^S) \end{cases}$$

$$(i = 1,2,\cdots,m; j = 1,2,\cdots,n). \quad (11)$$

When the dominance of S_i and B_j is close, the two parties are most likely to successfully match. Based on this, the transaction price of the two sides' can be determined according to $g_{ij}^S = g_{ji}^B$, that is:

$$p_{ij} = \begin{cases} \dfrac{p_i^B + p_i^M}{2} & (p_i^B \geq p_i^S) \\ \dfrac{p_i^S + p_i^M}{2} & (p_i^B < p_i^S) \end{cases}$$

$$(i = 1,2,\cdots,m; j = 1,2,\cdots,n). \quad (12)$$

When the intermediary has moral hazard, regardless of the quotations of both parties, the final transaction price will be higher than the price that should be transaction. In this case, the intermediary is likely to become a collaborator with S_i or B_j, making the other party become the loser.

3.2. Establishment of dominance of other indicators' of matching parties

There are many matching problems in reality, and both sides of the match not only pay attention to the price, but also attach great importance to other indicators. Taking the ideal value as the reference point, the actual value of the matching object is compared with it to define the dominance of other evaluation indicators, it can be expressed as:

$$g_{ijk\theta}^S = \begin{cases} 0 & (\bar{\tilde{r}}_{jk\theta}^B \leq c_{ijk\theta} \bar{\tilde{r}}_{ik\theta}^{*S}) \\ \bar{\tilde{r}}_{jk\theta}^B / \bar{\tilde{r}}_{ik\theta}^{*S} & (c_{ijk\theta} \bar{\tilde{r}}_{ik\theta}^{*S} \leq \bar{\tilde{r}}_{jk\theta}^B \leq (1 + c_{ijk\theta}) \bar{\tilde{r}}_{ik\theta}^{*S}) \\ 1 & ((1 + c_{ijk\theta}) \bar{\tilde{r}}_{ik\theta}^{*S} \leq \bar{\tilde{r}}_{jk\theta}^B) \end{cases}, \quad (13)$$

where $c_{ijk\theta} \in (0,1)$ represents the multiple of the difference between the actual value of the secondary evaluation index $k\theta$ of B_j and the ideal value of S_i. When $\bar{\tilde{r}}_{jk\theta}^B \leq c_{ijk\theta} \bar{\tilde{r}}_{ik\theta}^{*S}$, it means that the actual value of the secondary evaluation index of B_j is $c_{ijk\theta}$ times lower than the ideal value of S_i. At this time, the dominance of S_i over the evaluation index is 0. When $c_{ijk\theta} \bar{\tilde{r}}_{ik\theta}^{*S} \leq \bar{\tilde{r}}_{jk\theta}^B \leq (1 + c_{ijk\theta}) \bar{\tilde{r}}_{ik\theta}^{*S}$, it means that the actual value of the secondary evaluation index $k\theta$ of B_j is within the range of the ideal value of S_i. At this time, the ratio of the two is used to describe the dominance of the evaluation index $k\theta$ of S_i. When $(1 + c_{ijk\theta}) \bar{\tilde{r}}_{ik\theta}^{*S} \leq \bar{\tilde{r}}_{jk\theta}^B$ means that the actual value of the secondary evaluation index $k\theta$ exceeds $(1 + c_{ijk\theta})$ times of the ideal value of S_i. In this case, S_i's dominance of the evaluation index is 1.

In the same way, the dominance of B_j about other secondary evaluation indexes is:

$$g_{jih\sigma}^B = \begin{cases} 0 & (\bar{\tilde{r}}_{ih\sigma}^S \leq c_{jih\sigma} \bar{\tilde{r}}_{jh\sigma}^{*B}) \\ \bar{\tilde{r}}_{ih\sigma}^S / \bar{\tilde{r}}_{jh\sigma}^{*B} & (c_{jih\sigma} \bar{\tilde{r}}_{jh\sigma}^{*B} \leq \bar{\tilde{r}}_{ih\sigma}^S \leq (1 + c_{jih\sigma}) \bar{\tilde{r}}_{jh\sigma}^{*B}) \\ 1 & ((1 + c_{jih\sigma}) \bar{\tilde{r}}_{jh\sigma}^{*B} \leq \bar{\tilde{r}}_{ih\sigma}^S) \end{cases}. \quad (14)$$

Because the evaluation indexes involve a variety of data types, there may be three situations in the process in comparing the actual value and the ideal value:

(1) If the evaluation index is a benefit-type index, the actual value and the ideal value are easy to compare, it can be used $\tilde{\bar{r}}^{S}_{ih\sigma} / \tilde{\bar{r}}^{*B}_{jh\sigma}$ to describe.

(2) If the actual value is not within the ideal value range, and the index is not a benefit-type or cost-type indicator. At this time, it indicates that this index is not within the scope of consideration.

(3) If some evaluation index is cost-based index and the ideal value is within an interval, the actual value should be measured in combination with the upper and lower limits of the ideal value. In addition, when the actual value and ideal value are real numbers, interval numbers, triangular fuzzy numbers, intuitionistic fuzzy numbers and multi-granularity language evaluation values respectively. The processing method of heterogeneous data is normalized according to Wang and Li (2017).

According to Eq. (13) and Eq. (14), the dominance of other secondary evaluation indexes of S_i and B_j are:

$$\bar{g}^{S}_{ij} = \sum_{k=1}^{|K|} \left(\sum_{\theta=1}^{|\Theta^k|} w^{S}_{k\theta} g^{S}_{ijk\theta}\right); \tag{15}$$

$$\bar{g}^{B}_{ji} = \sum_{h=1}^{|H|} \left(\sum_{\sigma=1}^{|\Upsilon^h|} w^{B}_{h\sigma} g^{B}_{jih\sigma}\right), \tag{16}$$

where $w^{S}_{k\theta}$ and $w^{B}_{h\sigma}$ represent the preference of S_i and B_j for the secondary index $k\theta$ and $h\sigma$ respectively. The values obtained through interviews with the intermediary and matching parties.

The overall dominance is the aggregate dominance of price and other secondary evaluation indexes. Therefore, the overall dominance of S_i and B_j can be expressed as:

$$G^{S}_{ij} = \omega^{S} g^{S}_{ij} + (1-\omega^{S})\bar{g}^{S}_{ij}; \tag{17}$$

$$G^{B}_{ji} = \omega^{B} g^{B}_{ji} + (1-\omega^{B})\bar{g}^{B}_{ji}, \tag{18}$$

where $\omega^{S} \in [0,1]$, $\omega^{B} \in [0,1]$ represent the proportion of price dominance and other evaluation index dominance in the overall dominance of S_i and B_j respectively. The larger the overall dominance, the higher the recognition degree.

3.3. Bilateral matching model considering intermediary moral hazard

A bilateral matching decision model is built from the perspective of "under the premise that the overall dominance of both parties is the largest, the intermediary moral hazard is as small as possible". If the multi-objective optimization model is converted into a single-objective optimization model by the simple weighting method, the determination of the weight of each objective is difficult to determine. Therefore, the lexicographical method is used to solve the multi-objective decision-making model of bilateral matching.

$$\max\{\sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{S} g^{S}_{ij} + (1-\omega^{S})\bar{g}^{S}_{ij}]x_{ij}\}; \tag{19}$$

$$\max\{\sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{B} g^{B}_{ji} + (1-\omega^{B})\bar{g}^{B}_{ji}]x_{ij}\}; \tag{20}$$

$$s.t.\begin{cases} \sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{S} g^{S}_{ij} + (1-\omega^{S})\bar{g}^{S}_{ij}]x_{ij} = \sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{B} g^{B}_{ji} + (1-\omega^{B})\bar{g}^{B}_{ji}]x_{ij} \\ \sum_{j=1}^{n} x_{ij} \le \kappa_i \quad (i=1,2,\cdots,m) \\ \sum_{i=1}^{m} x_{ij} \le \zeta_j \quad (j=1,2,\cdots,n) \\ x_{ij} \in \{0,1\} \quad (i=1,2,\cdots,m; j=1,2,\cdots,n) \end{cases}. \tag{21}$$

First of all, the optimal solution should be solved under ensuring the maximum dominance of both sellers and buyers. Then, a bilateral matching multi-objective decision-making model that "minimizes the intermediary moral hazard in the case of the maximum benefits of the matching parties" is constructed as follows:

$$\min\{\sum_{i=1}^{m}\sum_{j=1}^{n}(1-\beta_{ij} p_{ij} / b)x_{ij}\}; \tag{22}$$

$$s.t.\begin{cases} \sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{S} g^{S}_{ij} + (1-\omega^{S})\bar{g}^{S}_{ij}]x_{ij} = \sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{B} g^{B}_{ji} + (1-\omega^{B})\bar{g}^{B}_{ji}]x_{ij} \\ \sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{B} g^{B}_{ji} + (1-\omega^{B})\bar{g}^{B}_{ji}]x_{ij} \ge \varepsilon \sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{S} g^{S}_{ij} + (1-\omega^{S})\bar{g}^{S}_{ij}]x^{*}_{ij} \\ \sum_{i=1}^{m} x_{ij} \le \kappa_i \quad (j=1,2,\cdots,n) \\ \sum_{j=1}^{n} x_{ij} \le \zeta_j \quad (i=1,2,\cdots,m) \\ x_{ij} \in \{0,1\} \quad (i=1,2,\cdots,m; j=1,2,\cdots,n) \end{cases}, \tag{23}$$

where

$\sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{S} g^{S}_{ij} + (1-\omega^{S})\bar{g}^{S}_{ij}]x_{ij} = \sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{B} g^{B}_{ji} + (1-\omega^{B})\bar{g}^{B}_{ji}]x_{ij}$ indicates that the overall dominance of both the two matching parties are equal.

$\sum_{i=1}^{m}\sum_{j=1}^{n}[\omega^{B} g^{B}_{ji} + (1-\omega^{B})\bar{g}^{B}_{ji}]x_{ij} \ge \varepsilon \sum_{i=1}^{m}\sum_{j=1}^{n} g^{S}_{ij} x^{*}_{ij}$ aims to ensure that the dominance of S_i and B_j is not small, and that the moral hazard of the intermediary is minimized. ε is a coefficient, $\varepsilon \in [0,1]$, $1 - \varepsilon$ means the two matching parties give up their $1 - \varepsilon$ proportion of dominance space to the intermediary in order to reach the deal. The value of ε is determined according to the specific transaction situation. One B_j is at most equal to κ S_i matches, and one S_i is at most equal to ζ_j B_j matches. $x_{ij} = 1$ indicates that S_i and B_j parties reach a match, and $x_{ij} = 0$ indicates that they are not matched.

In summary, the specific steps of the bilateral matching decision method considering intermediary moral hazard under multi-type heterogeneous information are as follows:

Step 1: Normalize the multi-type heterogeneous evaluation indexes of both parties based on the normalization methods of interval number, triangular fuzzy number, intuitionistic fuzzy number and multi-grain linguistic evaluation value.

Step 2: Calculate the price dominance of matching parties under different quotation situations based on Eqs (8)–(12).

Step 3: Calculate the dominance of other evaluation indexes of matching parties based on Eqs (13)–(16).

Step 4: Construct a multi-objective decision model for bilateral matching considering intermediary moral hazard under multi-type heterogeneous information according to Eqs (17)–(18).

Step 5: Compute the Eqs (19)–(23) by applying the dictionary order method to obtain the overall dominance of two parties and intermediaries, and the final bilateral matching results.

4. Application of the model in property intermediary platform and comparative analysis

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 real estate 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. Further, the performance of our proposed model and algorithm is compared with existing research by Liang and Jinag (2013), Liu et al. (2017) and Zhang et al. (2018). In this part, we first give performance measures for comparative analyses, and then calculate the matching results under different circumstances, and make sensitivity analysis on some assumptions.

4.1. Calculation of bilateral matching cases in property intermediary platform

With typical bilateral matching characteristics, a property intermediary platform is selected as an example. Enter the homepage of a famous property intermediary platform's official website and type the key conditions, the system will select a number of property list which meet the search conditions. 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 property sellers and buyers are shown in Tables 1–4, the minimum acceptable price of the property sellers is shown in Table 5, the offer price of the property buyers is shown in Table 6, and the evaluation price by intermediary is shown in Table 7.

After compiling the data from the field research, the coefficients of the intermediary's effort are shown in Table 8. Meanwhile, the b coefficient is taken as 0.5.

According to Eq. (12), if the property buyer and seller are matched successfully, the transaction price is shown in Table 9.

Step 1: Based on the normalization methods of interval number, triangular fuzzy number, intuitionistic fuzzy number and multi-granularity linguistic evaluation value, the multi-type heterogeneous information in Tables 1–4 is normalized. In view of the layout restrictions, the normalization process is not reflected in the text.

Step 2: Based on Eqs (8)–(12), the price's dominance of the property's sellers and buyers are calculated, and the results are shown in Tables 10–11.

Table 1. Actual values of secondary evaluation indexes of the property 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 property 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 property 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 property 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 property seller (unit: 10,000 yuan)

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

Table 6. Offer price of the property buyers

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	310	300	310	280	310	280
B_2	295	320	305	285	320	270
B_3	300	310	318	275	320	295
B_4	290	290	300	305	300	300
B_5	300	305	290	290	345	290
B_6	290	300	300	285	310	310

Table 7. Evaluation price of the property by intermediary (unit: 10,000 yuan)

	S_1	S_2	S_3	S_4	S_5	S_6
Appraisal price	315	317	315	300	340	308

Table 8. Effort factor of intermediaries

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	0.45	0.5	0.55	0.6	0.7	0.65
B_2	0.65	0.55	0.65	0.5	0.6	0.7
B_3	0.5	0.45	0.5	0.45	0.55	0.45
B_4	0.35	0.4	0.3	0.4	0.45	0.45
B_5	0.6	0.55	0.65	0.55	0.6	0.7
B_6	0.3	0.4	0.35	0.4	0.45	0.4

Table 9. Transaction price of the property (unit: 10,000 yuan)

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	310	320	315	297.5	340	307.5
B_2	307.5	322.5	312.5	297.5	340	309
B_3	307.5	321.5	316.5	300	340	310
B_4	307.5	320	312.5	305	340	307.5
B_5	308	320	312.5	297.5	342.5	307.5
B_6	309	315.5	312.5	301.5	340	310

Table 10. The price's dominance of the property sellers

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	0	1	1	0.75	1	0.833
B_2	0.25	1	0.5	0.75	1	1
B_3	0.25	1	1	1	1	1
B_4	0.25	1	0.5	1	1	0.833
B_5	0.3	1	0.5	0.75	1	0.833
B_6	0.4	0.25	0.5	1	1	1

Table 11. The price's dominance of the property buyers

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	1	1	0	0.25	1	0.167
B_2	0.75	0	0.5	0.25	1	1
B_3	0.75	1	0	0	1	1
B_4	0.75	1	0.5	0	1	0.167
B_5	0.7	1	0.5	0.25	0	0.167
B_6	0.6	0.75	0.5	1	1	0

Table 12. Overall dominance of other evaluation indexes of the property sellers

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	0.799	0.735	0.478	0.569	0.679	0.499
B_2	0.660	0.680	0.300	0.500	0.610	0.450
B_3	0.839	0.755	0.478	0.569	0.719	0.499
B_4	0.879	0.755	0.498	0.535	0.719	0.379
B_5	0.760	0.680	0.400	0.500	0.410	0.300
B_6	0.739	0.755	0.378	0.769	0.719	0.499

Table 13. Overall dominance of other evaluation indexes of the property buyers

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	0.800	0.576	0.615	0.601	0.686	0.667
B_2	0.777	0.747	0.674	0.664	0.689	0.728
B_3	0.672	0.552	0.693	0.622	0.629	0.644
B_4	0.666	0.546	0.633	0.711	0.605	0.688
B_5	0.733	0.593	0.628	0.618	0.743	0.659
B_6	0.783	0.514	0.604	0.597	0.583	0.727

Step 3: Based on Eqs (13)–(16), the overall dominance of other evaluation indexes about the property's sellers and buyers are calculated respectively, and the results are shown in Tables 12–13.

Step 4: In the process of property transaction, the seller attaches most importance to price, and does not focus on other indexes. Meanwhile, the buyer not only considers the price, but also attaches more importance to many other indicators. Based on this, we set the coefficient of the seller's emphasis on price to 0.8 and the coefficient of other indexes to 0.2. Similarly, the two coefficients of the buyer are 0.4 and 0.6 respectively. Based on Eqs (17)–(18), we construct the multi-objective decision model (19)–(21) and calculate the optimal solution by LINGO. The optimal solution can be obtained as follows: $x_{12} = x_{35} = x_{41} = x_{54} = 1$, other $x^*_{ij} = 0$ $(i = 1,2,\cdots,6; j = 1,2,\cdots,6)$, the overall dominance of the seller and buyer are 2.981, 2.981 respectively, and optimal solution is 2.981.

Step 5: Based on models (22)–(23), the dictionary order method is applied to calculate the bilateral matching decision model, where ε is taken as 0.8 by transaction situation. The optimal matching results are as follows: $x^*_{12} = x^*_{35} = x^*_{41} = x^*_{54} = 1$, other $x^*_{ij} = 0$ $(i = 1,2,\cdots,6; j = 1,2,\cdots,6)$. The results show that seller S_1 matches with buyer B_2, seller S_3 matches with buyer B_5, seller S_4 matches with buyer B_1, and seller S_5 matches with buyer B_4. The overall dominance of the seller, buyer and intermediary are 2.527, 2.567, and 2.841 respectively.

4.2. Analysis and comparison

In this section, we first give performance measures for comparative analyses by the existing research (Liang & Jinag, 2013; Liu et al., 2017; Zhang et al., 2018), and then make sensitivity analysis on some assumptions.

(1) Disregarding the intermediary moral hazard issues

On the basis of the above property intermediary platform data, the bilateral matching results without considering the moral hazard of intermediaries are as following: $x_{12} = x_{35} = x_{41} = x_{54} = 1$, other $x_{ij} = 0$ $(i = 1,2,\cdots,6; j = 1,2,\cdots,6)$. The results show that seller S_1 matches with buyer B_2, seller S_3 matches with buyer B_5, seller S_4 matches with buyer B_1, and seller S_5 matches with buyer B_4. The overall dominance of the seller, buyer and intermediary are 2.981, 2.981 and 3.13 respectively.

When minimizing the moral hazard of intermediary, the number of successful matched decreases, the dominance of the property seller and buyer decrease, and the intermediary also decreases. It is worth noting that dominance of intermediaries decreases more than buyers and sellers. This indicates that the suppression of intermediary moral hazard can only be achieved by paying more process costs or reducing their own satisfaction. The dominance of intermediaries inevitably decreases significantly with the buyers and sellers' restraint.

(2) Change in efforts of intermediary

We conduct sensitivity analysis with respect to the effort coefficient of intermediaries β_{ij} in our established model. In response to β_{ij}, their values adopted in this study are designed in three cases: ① $\beta_{ij} \in [0.01, 0.15]$ indicates that the intermediary has made little effort to find suitable matching objects for both parties. ② $\beta_{ij} \in [0.45, 0.65]$ indicates that the intermediary has made moderate efforts. ③ $\beta_{ij} \in [0.85, 0.99]$ indicates that the intermediary has made as much effort as possible to find suitable matching objects for both parties. The values of three types of β_{ij} are showed in Tables 14–16 respectively, and b remains unchanged and still takes 0.5.

The results are used to examine the impact of the change of intermediary effort on the final matching results and the dominance of three parties including property sellers, buyers and the intermediary. The results are presented in Table 17.

From Table 14 to Table 17, it can be seen that the efforts of intermediaries to search and match buyers and sellers have gradually increased, and the matching results have also changed. From basically no effort [0.01, 0.15] to a lot of effort [0.45, 0.65], the matching pairs remained stable, the dominance of the seller and the buyer decreased slightly, but the dominance of the intermediary decreased sharply. This shows that the intermediary wants to retain customers as much as possible in the fierce competition, and should pay more efforts to satisfy both buyers and sellers in the process of searching and matching. At this time, the dominance of the intermediary must be reduced. The dominance of the matching parties has declined slightly, indicating that the intermediary will communicate and coordinate with both parties many times when trying to search and match, and the matching parties may pay more communication costs, while the matching objects that really meet their own requirements

Table 14. The effort coefficient of intermediary ($\beta_{ij} \in [0.01, 0.15]$)

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	0.05	0.01	0.15	0.05	0.15	0.01
B_2	0.1	0.01	0.05	0.05	0.5	0.01
B_3	0.05	0.1	0.05	0.1	0.1	0.15
B_4	0.05	0.15	0.05	0.1	0.05	0.15
B_5	0.1	0.05	0.05	0.1	0.1	0.15
B_6	0.15	0.15	0.01	0.1	0.15	0.01

Table 15. The effort coefficient of intermediary ($\beta_{ij} \in [0.45, 0.65]$)

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	0.50	0.55	0.50	0.45	0.50	0.45
B_2	0.45	0.45	0.55	0.50	0.50	0.55
B_3	0.50	0.50	0.45	0.50	0.45	0.50
B_4	0.45	0.50	0.45	0.45	0.45	0.45
B_5	0.55	0.45	0.55	0.50	0.50	0.50
B_6	0.50	0.45	0.50	0.55	0.45	0.45

Table 16. The effort coefficient of intermediary ($\beta_{ij} \in [0.85, 0.99]$)

	S_1	S_2	S_3	S_4	S_5	S_6
B_1	0.95	0.99	0.85	0.95	0.85	0.9
B_2	0.85	0.95	0.95	0.95	0.85	0.99
B_3	0.9	0.85	0.9	0.95	0.85	0.95
B_4	0.95	0.85	0.95	0.9	0.95	0.95
B_5	0.99	0.95	0.9	0.99	0.9	0.9
B_6	0.85	0.99	0.95	0.99	0.95	0.9

Table 17. Matching results obtained by different intermediary effort coefficient

β_{ij}	Matching results	Dominance
$\beta_{ij} \in [0.01, 0.15]$	$x_1 \to x_4; x_2 \to x_1; x_5 \to x_6; x_6 \to x_3$	$G^S = 2.981, G^B = 2.981, G^M = 3.283$
$\beta_{ij} \in [0.45, 0.65]$	$x_1 \to x_4; x_2 \to x_1; x_5 \to x_6; x_6 \to x_3$	$G^S = 2.533, G^B = 2.589, G^M = 0.123$
$\beta_{ij} \in [0.85, 0.99]$	–	No optimal solution

have not increased due to the increase of communication costs. Although the efforts of the intermediary have been significantly improved, the matching results have not changed, which means that the matching results have a certain degree of objectivity, that is, the matching parties will not change their expectations or needs at will because of more recommendation and lobbying of the intermediary. Further, when the intermediary makes great efforts from [0.45, 0.65] to [0.85, 0.99], the calculation result of the model is unbounded and has no optimal solution. This shows that the efforts of intermediary have a certain boundary. When the dominance of the intermediary is close to 0 or below 0, it have no motivation to continue to make efforts. Although this suppresses the moral hazard of the intermediary, it also reduces the motivation of the intermediary's efforts. Therefore, it can not only inhibit the moral hazard of the intermediary, but also make the intermediary maintain the motivation of effort. What is the optimal threshold of the intermediary's effort of β_{ij} is the question we need to further explore in the future.

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 (Liang & Jinag, 2013; Liu et al., 2017; Zhang et al., 2018) is given. Compared with the existing literature, the differences and advantages of this paper are as follows.

(1) In the matching model, Liang and Jinag (2013) and Liu et al. (2017) assume that the intermediary benefits are maximized, which is actually an ideal state. In real transactions, the realization of the maximization of intermediary interests often needs the transfer from the interests of both matching parties, and an obvious impulse to pursue profits will make many customers flow to other competitors. In order to retain customers, intermediaries often maximize their own interests when both matching parties are satisfied. Therefore, this paper overcomes this shortcoming in the matching model and solution method, which is mainly reflected in the following two aspects: ① In the model, we ensure the maximum dominance of the buyer and the seller, and then minimize the moral hazard of the intermediary. ② In the solution method, the dictionary order method is used to solve the maximum dominance of both matching parties firstly, and then solve the bilateral matching results under suppressing of intermediary moral hazard. The model displaying in this paper cannot be achieved by changing the multi-objective function into a single-objective function.

(2) It should be emphasized that the bilateral matching method proposed in this paper considers the intermediary's moral hazard. However, the methods proposed in Liang and Jinag (2013), it only considered the intermediary's three trading attitude of the intermediary, such as profit-oriented, service-oriented and compromise-oriented. In the paper, the authors have not deeply explored the trade attitude formation of each type and its impact on the bilateral matching results, nor have it established a mathematical model related to intermediary moral hazard. Meanwhile, the intermediary's role was not considered in Liu et al. (2017) and Zhang et al. (2018), which is very important variable in the matching process.

(3) In the papers of Liang and Jinag (2013) and Liu et al. (2017), the attributes other than price are not considered. It is noted that the matching parties not only pay attention to the price, but also pay attention to other attributes. Therefore, the two proposed bilateral matching model in Liang and Jinag (2013) and Liu et al. (2017) that contains other attributes except the price, and the final matching result may have some defects. In addition, the other attribute dominance model built in our paper is a piecewise function, which reflects the real transaction situation to the greatest extent, and has good operability.

(4) In the papers of Zhang et al. (2018), although it realized that the previous research on the preference information was relatively simple and could not fully reflect the needs of matching parties, it only used two forms of evaluation score and language phrase to express the diversity of information. However, according to the different types of demand information of matching parties, this paper uses five data types to express. 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.

Conclusions

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 moral hazard of intermediary institutions. In this model, we can fully understand the important factors that affect the intermediary moral hazard can be demonstrated clearly. Then, the dominance of price and other evaluation indicators to each matching party is built respectively, and different dominance is built according to the different transaction situations. Further, by the intermediary's moral hazard model and the dominance of matching parties, the method of bilateral matching decision-making considering intermediary's moral hazard is built and the final matching result is determined by the dictionary order method. The major contributions of this paper are discussed as follows.

First, this paper focuses on bilateral matching decision-making considering intermediary's moral hazard, which is a new research topic with a lot of practical backgrounds. In the problem, based on the role of intermediary in property matching, its behavioral characteristics and psychological demands are fully considered, and the various factors which effect intermediary's behavior in the matching process are also demonstrated clearly. Furthermore, the intermediary's impulse of pursue profits is first depicted by a moral hazard model in the bilateral matching decision-making area.

Second, this paper presents a method for solving the bilateral matching decision-making considering intermediary's moral hazard and the application in the property transaction platform. This method is superior to the existing methods in the following aspects: ① It considers the intermediary's moral hazard and builds a model, which is an important foundation for the following research. ② 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. ③ It develops a method of establishing the dominance of the matching parties' and properties by game theory. The dominance is divided into price and other attributes. Among them, the dominance of the price in different situations are took into accounted, and the dominance of other attributes is expressed by a piecewise function. The method is clear to understand and easy to operate. ④ Based on "minimizing the moral hazard of the intermediary under the maximum satisfaction of the matching parties", it uses the dictionary order method to solve the model. 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 platform 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.

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Author contributions

Rui Wang was the corresponding author and responsible for the research design, model development and the conclusion. Wenjin Zuo developed the data collection and data analysis.

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References

Allon, G., Bassamboo, A., & Cil, E. B. (2012). Large-scale service marketplaces: the role of the moderating firm. *Management Science*, *58*(10), 1854–1872. https://doi.org/10.1287/mnsc.1120.1533

Anton, A., & Dam, K. (2020). A two-sided matching model of monitored Finance. *Economica*, *87*(345), 132–157. https://doi.org/10.1111/ecca.12298

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

Balafoutas, L., Kerschbamer, R., & Sutter, M. (2017). Second-degree moral hazard in a real-world credence goods market. *The Economic Journal*, *127*(599), 1–18. https://doi.org/10.1111/ecoj.12260

Bell, D. E. (1985). Disappointment in decision making under uncertainty. *Operations Research*, *33*(1), 1–27. https://doi.org/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. https://doi.org/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. https://doi.org/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. https://doi.org/10.1007/BF01584237

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

Bojd, B., & Yoganarasimhan, H. (2022). Star-cursed lovers: role of popularity information in online dating. *Marketing Science*, *41*(1), 73–92. https://doi.org/10.1287/mksc.2021.1301

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. https://doi.org/10.1016/j.ins.2016.01.096

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

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. https://doi.org/10.1007/s10115-019-01390-x

Echenique, F., & Bumin, Y. M. (2007). A solution to matching with preferences over colleagues. *Games and Economic Behavior*, *59*(1), 46–71. https://doi.org/10.1016/j.geb.2006.07.003

Echenique, F., & Oviedo, J. (2004). Core many-to-one matchings by fixed-point methods. *Journal of Economic Theory*, *115*(2), 358–376. https://doi.org/10.1016/S0022-0531(03)00184-4

Fudge Kamal, 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. https://doi.org/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. https://doi.org/10.4169/amer.math.monthly.120.05.386

Greinecker, M., & Kah, C. (2021). Pairwise stable matching in large economies. *Econometrica*, *89*(6), 2929–2974. https://doi.org/10.3982/ECTA16228

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

Halevy, N., Halali, E., & Cohen, T. R. (2020). Brokering orientations and social capital: influencing others' relationships shapes status and trust. *Journal of Personality and Social Psychology*, *119*(2), 293–316. https://doi.org/10.1037/pspi0000213

Hatfield, J. W., & Kojima, F. (2010). Substitutes and stability for matching with contracts. *Journal of Economic Theory*, *145*(5), 1704–1723. https://doi.org/10.1016/j.jet.2010.01.007

Hoppe, H. C., & Ozdenoren, E. (2005). Intermediation in innovation. *International Journal of Industrial Organization*, *23*(5), 483–503. https://doi.org/10.1016/j.ijindorg.2005.03.003

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

Hui, E. C. M., & Yam, S. C. P. (2014). Can we beat the "buy-and-hold" strategy? Analysis on European and American securitized real estate indices. *International Journal of Strategic Property Management*, *18*(1), 28–37. https://doi.org/10.3846/1648715X.2013.862190

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

Italo, A. G., & Oswaldo, M. (2020). Reverting to informality: unregistered property transactions and the erosion of the titling reform in Peru. *Economic Development and Cultural Change*, *69*(1), 317–334. https://doi.org/10.1086/703064

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. https://doi.org/10.1016/j.eswa.2010.09.079

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*, 103155. https://doi.org/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. https://doi.org/10.1016/j.ins.2020.11.032

Lee, S., & Niederle, M. (2015). Propose with a rose? Signaling in internet dating markets. *Experimental Economics*, *18*(4), 731–755. https://doi.org/10.1007/s10683-014-9425-9

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. https://doi.org/10.1016/j.asoc.2020.106427

Liang, H. M., & Jinag, Y. P. (2013). A method for buy-sell two-sided matching decision-making method considering the trade attitude of the broker. *Operations Research and Management Science*, *22*(5), 129–133. http://www.jorms.net/EN/Y2013/V22/I5/128

Liu, L. J., Zuo, W. J., Hu, Q., & Zeng, L. T. (2022). Research on property service mode innovation in the context of transformation and upgrading. *International Journal of Strategic Property Management*, *26*(5), 332–344. https://doi.org/10.3846/ijspm.2022.17588

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.

Meng, L., Erik, B., & Jason, D. (2021). Do digital platforms reduce moral hazard? The case of Uber and Taxis. *Management Science*, *67*(8), 4665–4685. https://doi.org/10.1287/mnsc.2020.3721

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

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

Pierce, L., Snow, D. C., & McAfee, A. (2015). Cleaning house: the impact of information technology monitoring on employee theft and productivity. *Management Science*, *61*(10), 2299–2319. https://doi.org/10.1287/mnsc.2014.2103

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

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. https://doi.org/10.1287/moor.10.3.379

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. https://doi.org/10.1287/moor.18.4.803

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

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

Sim, K. M., & Chan, R. A. (2000). A brokering protocol for agent-based ecommerce. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, *30*(4), 474–484. https://doi.org/10.1109/5326.897074

Sladić, G., Milosavljević, B., Nikolić, S., Sladić, D., & Radulović, A. (2021). A blockchain solution for securing real property transactions: a case study for Serbia. *ISPRS International Journal of Geo-Information*, *10*(1), 35. https://doi.org/10.3390/ijgi10010035

Suzuki, M., & Shibata, A. (2022). The economic premium of housing certificates aimed at promoting long-life property and transaction of existing housing in Japan. *Journal of Cleaner Production*, *366*, 132935. https://doi.org/10.1016/j.jclepro.2022.132935

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

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. https://doi.org/10.1016/S0377-2217(02)00729-4

Wang, R., & Li, D. F. (2017). Bargain game models of the second-hand housing commence. *Journal of Systems Engineering*, *32*(5), 588–595. https://doi.org/10.13383/j.cnki.jse.2017.05.002

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. https://doi.org/10.3233/JIFS-191495

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. https://doi.org/10.1287/mnsc.2020.3794

Yu, D. J., Kou, K., Xu, Z. S., & Shi, S. S. (2021). Analysis of collaboration evolution in AHP research: 1982–2018. *International Journal of Information Technology & Decision Making*, *20*(1), 7–36. https://doi.org/10.1142/S0219622020500406

Yu, D. J., Sheng, L. B., & Xu, Z. S. (2022). Analysis of evolutionary process in intuitionistic fuzzy set theory: a dynamic perspective. *Information Sciences*, *601*, 175–188. https://doi.org/10.1016/j.ins.2022.04.019

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

Yu, D. J., Xu, Z. S., & Wang, W. R. (2018b). Bibliometric analysis of fuzzy theory research in China: a 30-year perspective. *Knowledge-Based Systems*, *141*, 188–199. https://doi.org/10.1016/j.knosys.2017.11.018

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. https://doi.org/10.1016/j.cie.2022.108796

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. https://doi.org/10.1177/0092070393211001

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. *Computer Integrated Manufacturing Systems*, *24*(12), 3136–3143.

Zhang, Z., Gao, J., Gao, Y., & Yu, W. (2021). Two-sided matching decision making with multigranular hesitant fuzzy linguistic term sets and incomplete criteria weight information. *Expert Systems with Applications*, *168*, 114311. https://doi.org/10.1016/j.eswa.2020.114311

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

Zuo, W. J., Li, D. F., & Yu, G. F. (2020). A general multi-attribute multi-scale decision making method based on dynamic LINMAP for property perceived service quality evaluation. *Technological and Economic Development of Economy*, *26*(5), 1052–1073. https://doi.org/10.3846/tede.2020.12726

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. https://doi.org/10.1016/j.engappai.2023.106070