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Bilateral Matching Decision Method for Two-Stage House Leasing Based on FBWM

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Abstract: ***Based on the situation of the long-term rental market, this method aims to improve the existing bilateral matching decision method, and presents an efficient decision method for matching the renters and tenants. Considering the influence of market thickness and demand, we takes Bilateral Matching Decision Method for Two-stage Housing Lease Based on FBWM after dividing the city into several parts. This decision method can reduce the cost of renters and tenants for providing information and inspecting listings, providing an efficient means of matching. First, considering the uncompromising conditions in the rental, we add a hard indicators filter. Pairs that do not meet the rigorous conditions will be filtered out. Subsequently, the satisfaction is calculated based on the weights of both parties. When calculating satisfaction, the weight is taken instead of the indicator as a variable, and the FBWM is used to calculate the weights to reduce the cost of renters and tenants and deal with the dilemma of fuzzy language. Finally, a multi-objective optimization model is established and transformed into a single-objective optimization model for solving.***

Keywords: Decision making, Bilateral matching, FBWM, Multi-objective optimization model

1. Introduction

At present, the matching between supply and demand of long-term rental housing is inefficient in Chinese large and medium-sized cities. Especially in intensive demand situation, inefficiency brings a lot of economic costs to tenants. Landlords are willing to cooperate with real estate agencies, while tenants like acquaintances to find housing [1]. In limited budgets between the supply and demand parties, there is no intermediary means to improve matching efficiency and reduce the time and economic cost to select and inspect houses. Existing bilateral matching research mostly focuses on the transaction of physical or digital property, and its algorithm focuses on innovation in a specific context. There are few researches on long-term rental matching [2]. And the long-term rent issue has some differences from other areas. Both parties of long-term rentals need to consider more issues, such as living habits, rent payment, and surrounding environment. The research on the decision-making method of matching supply and demand for long-term renting can make up for the weak research in this situation.

In recent years, bilateral matching research has focused on the application of algorithms, such as online transaction matching between buyers and sellers, human resources matching, etc., while house leasing issues have not received high attention. At the same time, in bilateral matching research, the bilateral matching method of preference ordinal number has been the research focus of scholars for many years [2].

2. Literature Survey

Jung J J and Jo G S [3] consider the satisfactory binding relationship between buyers and sellers based on electronic intermediaries. They proposed a matching process including the competitive layer and the constraint satisfaction layer. Zhang Z H and Wang D W [4] gave a method based on bilateral satisfaction for the matching of second-hand houses and second-hand cars. Fan Z P [5] proposed an analysis method based on theorem for the product matching problem of multi-attribute evaluation information of electronic intermediaries. Chen X [6] combined the two-tuple linguistic information processing method to study the matching of buyers and sellers of electronic intermediary language evaluation information. Xu W J and Dong P C[7] studied online leasing strategies considering preferential contract conditions. Kong D C and Jiang Y P [8] combined the multi-objective discrete differential evolution algorithm to discuss a bilateral matching decision method for personnel and positions that considers collaborative information. Gao Y X and Du Y P [9] considered the individual needs of patients in medical treatment, and constructed a satisfactory and stable goal-oriented matching decision model.

Regarding housing leasing, existing research focuses on the fair distribution of affordable housing. Liu X and Ma H M [10] proposed a public housing allocation method based on multi-attribute bilateral matching, and established a multi-level index system to ensure the matching degree between family and public housing. Ge H Z and Zhang J L [11] referred to the idea of bilateral matching and gave a public housing matching and distribution method based on axiomatic design and excess functions.

The above-mentioned research focuses on the transaction matching problem in a certain field, and discusses various situations. Existing research mostly considers the measurement index of the exchanged object, and mainly focuses on how to optimize the index setting. In long-term rental transactions, there are still some special factors to consider. For this reason, this research proposes a two-stage matching decision-making method to optimize the traditional bilateral matching under the long-term lease.

3. Problem Definition

Combined with the actual situation of house leasing, this method is based on the classic bilateral matching model , and proposes an optimized bilateral matching model considering hard constraints.

3.1 Background

Since long-term rental matching is closely related to the location of the housing, location factors must be considered when designing. In addition, Jun Li and Serguei Netessine [12] proposed that as the thickness of the market increases, the matching rate of online platforms will decrease. This means that more objects are involved in matching, resulting in a decrease in matching success rate and efficiency. Therefore, this method first divides into cells according to geographic location, and then analyzes the situation of both supply and demand in this area.

First, identify the areas of customer needs before receiving new customers. Subsequently, the landlord (or tenant) is issued the landlord information statistics table (or tenant information statistics table) respectively according to the needs of the customers. After the information statistics table is retrieved, a preliminary screening is performed to filter some objects with incomplete data and unsatisfactory basic conditions. And the rest enter the bilateral matching algorithm for pairing. Match with the goal of maximizing total satisfaction, and then arrange for the successfully matched landlord and tenant to visit the house. Customers who are not matched and who are dissatisfied with the inspection will enter the next round of matching until the lease intention is reached or the customer voluntarily withdraws.

3.2 Concept Definition

In this method, the landlord and the tenant perform one-to-one matching, that is, one (group) landlord matches at most one (group) tenant, and one (group) tenant matches at most one (group) landlord. Here, the situation of multiple people living together (family or friends living together) and multiple heads of households are regarded as the same decision-making object.

Now, we consider the problem of one-to-one bilateral matching of landlords and tenants. Set $A=\{A_1,A_2,...,A_m\}$ as a collection of m landlords, A_i representing the i-th landlord. Set $B=\{B_1,B_2,...,B_n\}$ as a collection of n tenants, representing the j-th tenant.

Definition 1 Housing rental service matching μ is defined as mapping μ: $A\cup B\rightarrow A\cup B$. For $\forall A_i\in A$, $\forall B_j\in B$, there are:

(1) $\mu(A_i)\subseteq B\cup\{A_i\}$, if $\mu(A_i)=A_i$, that the landlord A_i did not match the tenant B_j, $j=1,...,n$;

(2) $\mu(B_j)\subseteq A\cup\{B_j\}$, if $\mu(B_j)=B_j$, that the tenant B_j did not match the landlord A_i, $i=1,...,m$;

(3)If $\mu(A_i)=B_j$, $\mu(B_j)=A_i$, (A_i,B_j) is called a pairing determined by mapping μ;

(4) For $A_i\in A$, if $\mu(A_i)=B_j$, that $\mu(A_i)\neq B_k$, $k=1,...,n$ and $k\neq j$;

(5) For $B_j\in B$, if $\mu(B_j)=A_i$, that $\mu(B_j)\neq A_k$, $k=1,...,m$ and $k\neq j$;

The set of all the matching determined by the housing rental service matching μ is called the matching plan.

Suppose α_{ij} and β_{ij} respectively represent the A_i's satisfaction with B_j and the B_j's satisfaction with A_i. In order to facilitate decision-making, set $c_{ij}=\eta\alpha_{ij}+(1-\eta)\beta_{ij}$ and weight η and $1-\eta$ to indicate the importance of landlord and tenant's satisfaction in reality, which is defined as follows.

Definition 2 For housing rental service matching μ: the matching scheme determined by $A\cup B\rightarrow A\cup B$, if $\exists A_i,A_l\in A$, $\forall B_k,B_j\in B$, $i\neq l$ and $k\neq j$ where $\mu(A_i)=B_j$ and , $\mu(A_l)=B_k$ such that (A_i,B_j) and (A_l,B_k) satisfies $\alpha_{ij}+\alpha_{lk}\le\alpha_{ik}+\alpha_{lj}$ and $\beta_{ij}+\beta_{lk}\le\beta_{ik}+\beta_{lj}$ (or $c_{ij}+c_{lk}\le c_{ik}+c_{lj}$), then the matching scheme is called an unsatisfactory matching scheme.

Definition 3 For housing rental matching μ: the matching plan determined by $A\cup B\rightarrow A\cup B$, if the following conditions are met:

(1)For $\forall A_i\in A$, if $\mu(A_i)=A_i$, set $\alpha_{ij}<0$, $j=1,...,n$;

(2)For $\forall B_j\in B$, if $\mu(B_j)=B_j$, set $\beta_{ij}<0$, $i=1,...,m$;

For $\forall A_i,A_l\in A$, $\forall B_k,B_j\in B$ ($i\neq l$, $k\neq j$, $\beta_{ij}<0$), if $\mu(A_i)=B_j$ and $\mu(A_l)=B_k$, that $\alpha_{ij}+\alpha_{lk}>\alpha_{ik}+\alpha_{lj}$ and $\beta_{ij}+\beta_{lk}>\beta_{ik}+\beta_{lj}$ (or $c_{ij}+c_{lk}>c_{ik}+c_{lj}$), then we called μ satisfactory matching scheme.

Definition 4 For housing rental matching μ : the matching scheme determined by $A\cup B\rightarrow A\cup B$, if $\forall A_i\in A$ ($i=1,...,m$) and $\forall B_j\in B$ ($j=1,...,n$), $\mu(A_i)=B_j$ and $\mu(B_j)=A_i$, then form a matching pair (A_i,B_j). If all $\alpha_{ij}>0$ and $\beta_{ij}>0$ are true, then the matching scheme μ is called an individual rational matching scheme.

Definition 5 For housing rental matching μ : the matching plan determined by $A\cup B\rightarrow A\cup B$, $\exists A_i,A_l\in A$, $\forall B_k,B_j\in B$, $i\neq l$, $k\neq j$, where $\mu(A_i)=B_j$ and

$\mu(A_i)=B_k$, if (A_i,B_j) and (A_i,B_k) meet one of the following three conditions: (1) $\alpha_{ij}\le\alpha_{ik}$ and $\beta_{lk}>\beta_{ik}$; (2) $\alpha_{ij}>\alpha_{ik}$ and $\beta_{lk}\le\beta_{ik}$; (3) $\alpha_{ij}>\alpha_{ik}$ and $\beta_{lk}>\beta_{ik}$, then the plan is called It is a stable matching scheme, otherwise it is called an unstable matching scheme.

Definition 6 For housing rental matching μ: the matching plan determined by $A\cup B\rightarrow A\cup B$, if μ is a satisfactory and stable matching plan, μ is called the optimal housing rental matching plan.

4. Methodology

This section will describe the construction process of the bilateral matching model. First define the various symbols and variables mentioned, then introduce the steps of the algorithm, and finally introduce the complete model structure.

This method mainly solves the problem of housing lease matching in the determined area. Its purpose is to maximize the overall satisfaction under the premise of improving efficiency and shorten the time from demand to transaction for landlords and tenants.

The evaluation index of the landlord is divided into two parts: the hard constraint index and the satisfaction index. The hard constraint index vector is set as $\boldsymbol{Z}=(Z_1,Z_2,\ldots,Z_k)$, which Z_h represents the h-th hard constraint index. When the condition Z_h is satisfied ($1\le h\le k$), $Z_h=1$, otherwise $Z_h=0$; the hard constraint index vector of the landlord i is recorded as Z_{A_i}. Let the vector $\boldsymbol{X}=(\boldsymbol{X}_1,\boldsymbol{X}_2,\ldots,\boldsymbol{X}_p)$ be the vector of p satisfaction indicators of the landlord. The satisfaction index vector of the landlord A to the tenant B_j is $\boldsymbol{X}_j=(X_{j1},X_{j2},\ldots,X_{jp})$. For these p satisfaction indicators, let the weight vector $\boldsymbol{W}_i=(w_{i1},w_{i2},\ldots,w_{ip})^{\mathrm{T}}$ of the landlord i be the weight vector corresponding to the satisfaction index vector $\boldsymbol{X}$, which w_{is} represents the weight of the landlord i on the index $\boldsymbol{X}_s$ ($0\le w_{is}\le 1$, $\sum_{s=1}^{p}w_{is}=1$). α_{ij} indicates A_i's satisfaction with B_j.

Tenants' evaluation indicators for landlords are divided into two parts: hard constraint indicators and satisfaction indicators. The hard constraint index vector is set as $\boldsymbol{Z}=(Z_1,Z_2,\ldots,Z_k)$, which Z_h represents the h-th hard constraint index, when the condition Z_h is satisfied ($1\le h\le k$), $Z_h=1$, otherwise $Z_h=0$; the hard constraint index of tenant j is marked as Z_{B_j}. Let the vector $\boldsymbol{Y}=(\boldsymbol{Y}_1,\boldsymbol{Y}_2,\ldots,\boldsymbol{Y}_q)$ be the vector of q satisfaction indicators for each tenant, and the satisfaction index vector of each tenant for the landlord i is $\boldsymbol{Y}_i=(Y_{i1},Y_{i2},\ldots,Y_{iq})$. For these q satisfaction indexes, let the weight vector $\boldsymbol{V}_j=(v_{j1},v_{j2},\ldots,v_{jq})^{\mathrm{T}}$ of tenant j be the weight vector corresponding to the satisfaction index vector $\boldsymbol{Y}$, which v_{jr} represents the weight of the tenant B_j for the index Y_r ($0\le v_{jr}\le 1$, $\sum_{r=1}^{q}v_{jr}=1$). β_{ij} indicates B_j's satisfaction with A_i.

Set x_{ij} as a 0-1 variable, which represents the match between the i-th landlord and the j-th tenant. If $x_{ij}=1$, it means that the i-th landlord and the j-th tenant match successfully. Otherwise $x_{ij}=0$, it means the match fails.

First gather the required information from the landlords and tenants. Subsequently, the data is processed and the hard-constrained index filtering is started. Then calculate the satisfaction of both parties separately. Finally, a multi-objective optimization model is established, which is transformed into single-objective optimization and solved.

(1)Filter combinations that do not match the hard constraints
Compare the hard constraint vectors $\boldsymbol{Z}$ of m landlords and n tenants. If the vector (Z_{A_i}) of the i-th landlord and the vector (Z_{B_j}) of the j-th tenant are not equal, it is recorded as $x_{ij}=0$.

(2)Satisfaction calculation
The landlord A_i' s weight vector $\boldsymbol{W}_i=(w_{i1},w_{i2},\ldots,w_{ip})^{\mathrm{T}}$ is multiplied with the B_j' s satisfaction index vector $\boldsymbol{X}_j=(X_{j1},X_{j2},\ldots,X_{jp})$ to get A_i's satisfaction with B_j.

In the same way, the tenant B_j' s weight vector $\boldsymbol{V}_j=(v_{j1},v_{j2},\ldots,v_{jq})^{\mathrm{T}}$ is multiplied by the A_i's satisfaction index vector $\boldsymbol{Y}_i=(Y_{i1},Y_{i2},\ldots,Y_{iq})$ to get B_j's satisfaction with A_i.

(3)Build a multi-objective optimization model
x_{ij} represents a 0-1 variable, which $x_{ij}=1$ means that the match is successful and $x_{ij}=0$ means that the match fails. A landlord can only match up to one tenant, and a tenant can only match up to one landlord.

(4) Converted to single-objective optimization model solution

Use linear weighting to convert the multi-objective model into a single-objective model, and use LINGO to solve it.

According to the above ideas, an optimized bilateral matching model is established.

(1)Hard constraint filtering

The hard constraints that need to be considered in the long-term rent problem are shown in formula (1), and the conforming index value is 1, otherwise it is 0.

$$Z_h = \begin{cases} 1, & \text{Condition h is met} \\ 0, & \text{Condition h is not met} \end{cases} \quad (1)$$

The hard constraint vector of landlord i is shown in formula (2), and the hard constraint vector of tenant j is shown in formula (3)

$$\boldsymbol{Z}_{A_i} = (Z_1, Z_2, ..., Z_k) \quad (2)$$

$$\boldsymbol{Z}_{B_j} = (Z_1, Z_2, ..., Z_k) \quad (3)$$

The hard constraint vector of each landlord is shown in Table 1; the hard constraint vector of each tenant is shown in Table 2.

Table 1: Landlords' hard constraint value

Landlord	A_1	A_2	……	A_m
Hard constraint vector	$\boldsymbol{Z}_{A_1}$	$\boldsymbol{Z}_{A_2}$		$\boldsymbol{Z}_{A_m}$

Table 2: Tenants' hard constraint value

Tenant	B_1	B_2	……	B_n
Hard constraint vector	$\boldsymbol{Z}_{B_1}$	$\boldsymbol{Z}_{B_2}$		$\boldsymbol{Z}_{B_n}$

Next, perform a pairwise comparison of the landlords' and tenants' hard constraint vectors according to the conditions of formula (4). As shown in Table 3, the unequal pairing is recorded as 0, and the set of this part is 0, and the equal pairing is not restricted.

$$x_{ij} = \begin{cases} \text{null} & , \boldsymbol{Z}_{A_i} = \boldsymbol{Z}_{B_j} \\ 0 & , \boldsymbol{Z}_{A_i} \neq \boldsymbol{Z}_{B_j} \end{cases} \quad (4)$$

Table 3: Hard constraint comparison

x_{ij}	$\boldsymbol{Z}_{B_1}$	$\boldsymbol{Z}_{B_2}$	……	$\boldsymbol{Z}_{B_n}$
$\boldsymbol{Z}_{A_1}$	0/null	0/null	……	0/null
$\boldsymbol{Z}_{A_2}$	0/null	0/null	……	0/null
.	.	.	……	.
$\boldsymbol{Z}_{A_m}$	0/null	0/null	……	0/null

(2)Calculation of satisfaction of both parties

First, transform the information of both parties into satisfaction indicators.

In order to calculate the satisfaction index value of each landlord (tenant), information about the landlord (tenant) is collected. One is the degree of importance the landlord (tenant) attaches to the tenant (landlord) indicators, which is used to calculate the weight. The second is the evaluation of the landlord (tenant) on its own situation, according to the indicators given in the questionnaire, and the level according to the actual situation, which is used to calculate the satisfaction index value.

In order to calculate the weight of each landlord (tenant), the fuzzy best-worst method (FBWM) is introduced. BWM is a method for solving multi-criteria decision-making problems, which makes optimal decisions for existing schemes according to several criteria [13]. On the basis of BWM, FBWM introduces fuzzy numbers to collect and calculate fuzzy information, which reduces the influence of subjective factors of information providers [14]. Combined with FBWM, various bilateral matching decision-making problems can be studied.

Next, calculate the satisfaction index. Calculate scores for each satisfaction index of each landlord (tenant) according to the algorithm in formula (5). Here, take the first satisfaction index score of each landlord for tenant j as an example.

$$X_{j1} = \frac{Q_{j1} - Q_{W1}}{Q_{B1} - Q_{W1}} \quad (5)$$

Among them, Q represents the original value in the questionnaire, and Q_{B1} and Q_{W1} are the maximum and minimum value of the first index of all tenants respectively. Q_{j1} is the score scored by the tenant j for the first satisfaction index in the questionnaire.

The landlord A_i's weight vector $\boldsymbol{W}_i = (w_{i1}, w_{i2}, ..., w_{ip})^{\mathrm{T}}$ is multiplied by the B_j's satisfaction index vector $\boldsymbol{X}_j = (X_{j1}, X_{j2}, ..., X_{jp})$ to get A_i's satisfaction with B_j:

$$\alpha_{ij} = \boldsymbol{X}_j \cdot \boldsymbol{W}_i \quad (6)$$

In the same way, the tenant B_j's weight vector $\boldsymbol{V}_j = (v_{j1}, v_{j2} ..., v_{jq})^{\mathrm{T}}$ is multiplied by A_i's satisfaction index vector $\boldsymbol{Y}_i = (Y_{i1}, Y_{i2}, ..., Y_{iq})$ to get B_j's satisfaction with A_i:

$$\beta_{ij} = \boldsymbol{Y}_i \cdot \boldsymbol{V}_j \quad (7)$$

For the pairs filtered out in the hard-constrained matching, the satisfaction is recorded as $-\infty$, so that it cannot be matched when the model is solved.

(3)Build a multi-objective optimization model

x_{ij} represents the 0-1 variable, which $x_{ij} = 1$ means the match is successful, and $x_{ij} = 0$ means the match fails. A landlord can only rent to one tenant, and a tenant can only choose one landlord.

$$\max S_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} \alpha_{ij} x_{ij} \quad (8a)$$

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$$\max S_2 = \sum_{i=1}^{m}\sum_{j=1}^{n}\beta_{ij}x_{ij} \quad (8b)$$

s.t.

$$\sum_{j=1}^{n} x_{ij} \le 1,\ i=1,2,\ldots,m \quad (8c)$$

$$\sum_{i=1}^{m} x_{ij} \le 1,\ j=1,2,\ldots,n \quad (8d)$$

$$x_{ij} + \sum_{k:\alpha_{ik}\ge\alpha_{ij}} x_{ik} + \sum_{l:\beta_{lk}\ge\beta_{ij}} x_{lk} \ge 1,\ i=1,2,\ldots,m;\ j=1,2,\ldots,n \quad (8e)$$

$$x_{ij} = 0,\ x_{ij}\in X' \quad (8f)$$

$$x_{ij} = 0 \text{ or } 1,\ i=1,2,\ldots,m,\ j=1,2,\ldots,n \text{ and } x_{ij}\notin X' \quad (8g)$$

Among them, formula (8a) is the objective function, set the highest total satisfaction of all landlords as the goal; formula (8b) is the objective function, set the highest total satisfaction of all tenants as the goal; formula (8c) indicates that landlord A_i can rent a house for 1 A tenant; formula (8d) means that tenant B_j can rent a house from a landlord; formula (8e) is a stability constraint to ensure that the matching result obtained by model (8) is stable; formula (8f) represents a hard constraint vector the elements in the paired set X' that failed to match cannot be matched; formula (8g) is expressed x_{ij} as a 0-1 variable.

Theorem Satisfying $x_{ij} + \sum_{k:\alpha_{ik}\ge\alpha_{ij}} x_{ik} + \sum_{l:\beta_{lk}\ge\beta_{ij}} x_{lk} \ge 1$ ($i=1,2,\ldots,m$, $j=1,2,\ldots,n$) is a sufficient condition for the obtained matching scheme to be a stable matching scheme.

Proof: It can be obtained from the constraint condition (8d), $x_{ij} + \sum_{k:\alpha_{ik}\ge\alpha_{ij}} x_{ik} \le 1$, since x_{ij} is a 0-1 variable, the situations is discussed as follows:

(1)When $x_{ij} + \sum_{k:\alpha_{ik}\ge\alpha_{ij}} x_{ik} = 0$ is true, from the constraints (8d) and (8e), $\sum_{l:\beta_{lk}\ge\beta_{ij}} x_{lk} = 1$. It is obvious that the tenant B_j's satisfaction with any currently matched landlord A_l is greater than that of the landlord A_i, so matching (A_i, B_j) will not hinder the stable matching scheme.

(2)When $x_{ij} + \sum_{k:\alpha_{ik}\ge\alpha_{ij}} x_{ik} = 1$ is true, consider the existence of two situations $x_{ij}=1$ or $\sum_{k:\alpha_{ik}\ge\alpha_{ij}} x_{ik} = 1$: when $x_{ij}=1$, the tenant B_j will not give up the current matching object A_i and choose A_l; when $\sum_{k:\alpha_{ik}\ge\alpha_{ij}} x_{ik} = 1$, $x_{ij}=0$, the landlord A_i is more satisfied with the currently matched tenant B_k than the tenant B_j, so A_i will not give up B_k and choose B_j.

(4) Converted to single-objective optimization model solution. Let η and $1-\eta$ denote the weights of the objective function S_1 and S_2 respectively, $0\le\eta\le1$,and transform into the following single-objective optimization model:

$$\max S = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} \quad (9a)$$

s.t.

$$\sum_{j=1}^{n} x_{ij} \le 1, i=1,2,\ldots,m \quad (9b)$$

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

$$x_{ij} + \sum_{k:\alpha_{ik}\ge\alpha_{ij}} x_{ik} + \sum_{l:\beta_{lk}\ge\beta_{ij}} x_{lk} \ge 1,\ i=1,2,\ldots,m; j=1,2,\ldots,n \quad (9d)$$

$$x_{ij} = 0,\ x_{ij}\in X' \quad (9e)$$

$$x_{ij} = 0 \text{ or } 1,\ i=1,2,\ldots,m,\ j=1,2,\ldots,n \text{ and } x_{ij}\notin X' \quad (9f)$$

Among them, $c_{ij} = \eta\alpha_{ij} + (1-\eta)\beta_{ij}$, weight η and $1-\eta$ indicate the importance of the satisfaction of landlords and tenants in reality.

According to expectations, the calculation result of the model will yield a stable and satisfactory result, that is, the optimal housing lease matching scheme. The landlord A_i will match no more than 1 tenant, and the tenant B_j will match no more than 1 landlord. This is the result of the highest total satisfaction of all landlords and tenants under the weighted case.

5. Results & Discussion

From the rental module of 58.com (https://xa.58.com/), 7 pieces of housing information and 7 pieces of rental information were collected.

Organize and analyze the collected information, and classify hard constraints and satisfaction indicators.

5.1 Hard constraint filtering

Choose three hard constraint indicators, as shown in Table 4:

Table 4: Introduction to Hard Constraint Index

Symbol	Hard constraint indicator name	Explanation
Z_1	Can pets be kept	1-yes；0-no
Z_2	Is it restricted to women	1-yes；0-no
Z_3	Whether to share	1-yes；0-no

Next, the comparison of the landlord's and tenant's hard-constrained index vectors is performed. The results are shown in Table 5, and x_{ij} of unequal pairs are recorded as 0. Suppose this part x_{ij} is 0 as set X', and there is no restriction on equal pairs.

5.2 Calculation of satisfaction

Next, calculate the satisfaction of the landlord and tenant respectively.

(1)Information from both parties is transformed into satisfaction indicators

A. Landlord information is transformed into satisfaction index for tenants' reference

Tenants consider a total of 7 satisfaction indicators $\{Y_1, Y_2, \ldots, Y_7\}$, as shown in Table 6. Table 7 shows the scores of each landlord calculated.

B. The tenant information is transformed into the satisfaction index that the landlord can refer to

It is assumed here that the landlord considers a total of 7 satisfaction indicators $\{X_1, X_2, \ldots, X_7\}$, as shown in Table 8. Table 9 shows the scores of each landlord calculated.

(2)Calculate the weight of both parties

A. Landlord weight calculation

Calculate the weight of each landlord, and the results are shown in Table 10.

B. Tenant weight calculation

In the same way, the weight calculation results of each tenant are shown in Table 11.

(3)Satisfaction index calculation

A. Landlord’s satisfaction matrix for tenants

According to formula (6), the landlord’s satisfaction with the tenant can be calculated according to the weight vector of each landlord and the satisfaction index vector of each tenant. The results are shown in Table 12.

B. Tenant's satisfaction matrix with landlord

In the same way, the tenant’s satisfaction table with the landlord is calculated according to formula (7). The results are shown in Table 13.

Table 5: Hard constraint index comparison results

landlord \ tenant		B_1	B_2	B_3	B_4	B_5	B_6	B_7
		(0,0,1)	(1,0,1)	(1,0,1)	(0,0,1)	(1,0,1)	(1,0,1)	(0,0,1)
A_1	(1,0,1)	0			0			0
A_2	(1,0,1)	0			0			0
A_3	(0,0,1)		0	0		0	0	
A_4	(1,0,1)	0			0			0
A_5	(1,0,1)	0			0			0
A_6	(0,0,1)		0	0		0	0	
A_7	(0,0,1)		0	0		0	0	

Table 6: Introduction to the satisfaction index of the landlord

	Satisfaction index name	Explanation
Y_1	Lighting situation	Room orientation and lighting conditions
Y_2	Toilet conditions	Personal/independent/public restrooms
Y_3	Fully furnished	Check in with bags/Basic furniture/Bring your own furniture
Y_4	Convenient transportation	Subway station/bus station/traffic arteries
Y_5	Affordable rent	The higher the rent, the lower the score
Y_6	Good greening	Residential greening level / nearby parks
Y_7	Living area	Tenant's personal actual usable area

Table 7: Score table of satisfaction index for landlord

	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7
A_1	5	3	3	6	4	4	1
A_2	7	3	6	7	7	8	7
A_3	6	2	9	4	2	7	9
A_4	5	6	2	6	5	3	6
A_5	9	5	3	6	6	5	2
A_6	9	1	7	6	9	4	5
A_7	7	4	2	6	6	8	9

Table 8: Introduction to the satisfaction index of tenants

	Satisfaction index name	Explanation
X_1	Working condition	Engage in formal and stable work
X_2	Schedule	The degree of living time in line with the public
X_3	Healthy life	Health of living habits
X_4	Pay attention to hygiene	Personal hygiene status and frequency in life
X_5	Child visit	The lower the frequency of children's visits, the higher the score
X_6	Education level	The higher the degree, the higher the score
X_7	Available time	Tenant's estimated length of renting

Table 9: Score Table of Tenant’s Satisfaction Index

	X_1	X_2	X_3	X_4	X_5	X_6	X_7
B_1	4	1	2	5	9	1	4
B_2	2	8	6	8	7	5	2
B_3	5	4	6	9	9	9	5
B_4	7	2	2	3	8	2	7
B_5	3	8	4	7	8	4	3
B_6	2	8	7	2	6	2	2
B_7	7	3	1	1	4	6	1

Table 10: Calculation results of each landlord's weight

landlord A_i	w_{i1}	w_{i2}	w_{i3}	w_{i4}	w_{i5}	w_{i6}	w_{i7}
A_1	0.2006	0.2262	0.1996	0.1109	0.0764	0.1109	0.0754
A_2	0.1861	0.1503	0.1503	0.1503	0.1734	0.0965	0.0932
A_3	0.1861	0.0965	0.1503	0.1734	0.1503	0.1503	0.0932
A_4	0.1846	0.1690	0.1690	0.1696	0.1696	0.0923	0.0461
A_5	0.2181	0.1069	0.1069	0.1937	0.0737	0.1069	0.1937
A_6	0.1999	0.0980	0.0980	0.1780	0.0676	0.1805	0.1780
A_7	0.1212	0.1212	0.2424	0.1212	0.1212	0.0606	0.2122

Table 11: Calculation results of the weight of each tenant

tenant B_j	v_{j1}	v_{j2}	v_{j3}	v_{j4}	v_{j5}	v_{j6}	v_{j7}
B_1	0.2149	0.0787	0.1180	0.2149	0.2360	0.0787	0.0590
B_2	0.1053	0.0789	0.0789	0.1579	0.1053	0.3158	0.1579
B_3	0.1429	0.1770	0.1665	0.0918	0.1665	0.0886	0.1665
B_4	0.2003	0.1098	0.2197	0.1098	0.1955	0.1098	0.0549
B_5	0.2191	0.1204	0.0803	0.0602	0.0602	0.2408	0.2191
B_6	0.2108	0.1157	0.0578	0.2314	0.1157	0.0578	0.2108
B_7	0.0714	0.0714	0.1429	0.2857	0.1429	0.1429	0.1429

Table 12: Landlord's satisfaction table with tenants

tenants / landlord	B_1	B_2	B_3	B_4	B_5	B_6	B_7
A_1	$-\infty$	0.6034	0.7321	$-\infty$	0.5771	0.4967	$-\infty$
A_2	$-\infty$	0.5748	0.7836	$-\infty$	0.5813	0.4163	$-\infty$
A_3	0.3830	$-\infty$	$-\infty$	0.5005	$-\infty$	$-\infty$	0.3076
A_4	$-\infty$	0.6137	0.7861	$-\infty$	0.6031	0.4462	$-\infty$
A_5	$-\infty$	0.4955	0.7693	$-\infty$	0.5129	0.3132	$-\infty$
A_6	0.3419	$-\infty$	$-\infty$	0.5294	$-\infty$	$-\infty$	0.3407
A_7	0.3768	$-\infty$	$-\infty$	0.5259	$-\infty$	$-\infty$	0.1937

Table 13: Tenant's satisfaction with landlord

landlord / tenants	A_1	A_2	A_3	A_4	A_5	A_6	A_7
B_1	$-\infty$	$-\infty$	0.3094	$-\infty$	$-\infty$	0.7236	0.5704
B_2	0.2414	0.7966	$-\infty$	0.3280	0.4912	$-\infty$	$-\infty$
B_3	0.2211	0.6617	$-\infty$	0.4137	0.5210	$-\infty$	$-\infty$
B_4	$-\infty$	$-\infty$	0.4345	$-\infty$	$-\infty$	0.6754	0.5158
B_5	0.1651	0.7119	$-\infty$	0.3232	0.5251	$-\infty$	$-\infty$
B_6	0.2534	0.7147	$-\infty$	0.4513	0.5814	$-\infty$	$-\infty$
B_7	$-\infty$	$-\infty$	0.4321	$-\infty$	$-\infty$	0.6068	0.6364

5.3 Calculation results

Respectively set $\eta = 0.1, 0.2, ..., 0.9$, substitute the data into the single-objective optimization model for calculation, and use the LINGO software to obtain the corresponding results. At $\eta = 0.7$, the results are shown in Table 14.

Table 14: Calculation results ($\eta = 0.7$)

	B_1	B_2	B_3	B_4	B_5	B_6	B_7
A_1	0	0	0	0	0	1	0
A_2	0	1	0	0	0	0	0
A_3	0	0	0	0	0	0	1
A_4	0	0	0	0	1	0	0
A_5	0	0	1	0	0	0	0
A_6	0	0	0	1	0	0	0
A_7	1	0	0	0	0	0	0

Table 14 shows the matching results at $\eta = 0.7$, which are respectively (A_1,B_6), (A_2,B_2), (A_3,B_7), (A_4,B_5), (A_5,B_3), (A_6,B_4), (A_7,B_1).

Taking the data of this calculation example, it is actually a process of matching within the two sets $\{A_1, A_2, A_4, A_5; B_2, B_3, B_5, B_6\}$ and $\{A_3, A_6, A_7; B_1, B_4, B_7\}$.

Next, we analy S ze the changes in overall satisfaction based on the matching results. With the increase of η, the overall satisfaction of the landlord S_1 has shown an upward trend, while the overall satisfaction of the tenant S_2 has shown a downward trend. As η increased, overall satisfaction showed a slow downward trend. On the left side of the intersection of S_1 and S_2, the leading role is S_2, S trend of change changes with S_2; on the right of the intersection of S_1 and S_2, the leading role is S_1, S trend of change changes with S_1. Therefore, in reality, we should pay attention to the selection of η to ensure the greatest overall satisfaction.

6. Conclusion

This research first analyzes the actual situation of the long-term rental market and reviews the existing research on bilateral matching. Subsequently, a method for efficiently matching landlords and tenants is proposed: first, filter the hard constraint indicators to filter out the pairs with unequal hard constraint vectors; then calculate the satisfaction degree by calculating the respective weight vectors and satisfaction vectors of both parties Matrix, in which the weight vector is calculated in conjunction with FBWM; then a multi-objective optimization model is established and converted to a single-objective optimization model for solution. After that, a calculation example was analyzed in combination with actual data, and the matching results were obtained and analyzed.

This method adds a hard constraint filtering link to make the decision-making method more suitable for real needs. In addition, weights rather than indicators are used as bilateral matching variables. This reduces the requirements for the amount of data and the depth of data collection, and greatly saves the time cost of landlords and tenants.

This decision-making method can also provide efficient matching methods for similar situations, such as vehicle rental, government public rental housing, and low-cost housing. It can improve matching efficiency, reduce information requirements, and simplify the calculation process.

7. Future Scope

The method proposed in this paper only focuses on the matching process, and does not study the regional division and matching charging mode before matching. Subsequent research can carry out reasonable regional divisions. After each city is divided into regions, this method is used to match each area separately.

The profit model of the operator can choose to charge a single customer, charge a transaction contract amount, or a charge model in which the two are in parallel. The specific choice is awaiting in-depth study.

When there are many objects participating in the matching, the minimum satisfaction condition can be introduced to set the lower limit for the satisfaction of the matching, and there may be a result closer to the actual application [19].

Study the method of determining the market thickness threshold in the case of zoning. Exceeding this threshold means that the matching rate will decrease; below this threshold, it may lead to low overall matching satisfaction, thereby affecting customer satisfaction with the service.

Considering the actual situation, this method still has some shortcomings:

1) Hard constraints cannot be achieved vary from person to person
   Different landlords and tenants may have different hard constraint requirements, which cannot be met in this method. In actual use, we can collect the main hard constraint indicators through the questionnaire survey method, extract the most important indicators, and make the sum of the votes of these indicators reach the lowest coverage (such as 80%) to meet the needs of most users .
2) There is room for improvement in the method of determining weights

Considering the actual situation, the expert scoring method can be used to determine the η value in combination with the actual income demand.

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