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MULTI-SCENARIOS DYNAMIC MATCHING ALGORITHM FOR HIERARCHICAL TREATMENT SYSTEM

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ABSTRACT

To deal with Two-Sided Matching (TSM) problem in hierarchical medical system, a matching decision making approach based on multiple scenarios was proposed. This paper describes the medical resource matching problem in hierarchical medical system, and determines unilateral satisfaction and composite influence weight. According to the reality, four scenarios were identified: superior-hospital strength, lower-hospital strength, unstable cooperation, stable and balanced cooperation. By comparing the four kinds of scenarios, it analyzes multi-context matching satisfaction degree of these cooperation situations in different forms of environment respectively and specifically. The simulation results provide stable and optimal solution is obtained by solving the model. By comparing the examples, the multi - scenario dynamic matching method is superior to the random matching algorithm and the "F-Y" algorithm (improved G - S algorithm), and it is effective to obtain the stable and feasible solution.

KEYWORDS: hierarchical medical system; bilateral matching; multiple scenarios; medical resources;

1. INTRODUCTION

Medical administration departments around the world are facing increasing pressure to improve the quantity and quality of healthcare services. "Availability" of medical resources is an important aspect of social medical treatment goals, especially in rapidly urbanized countries or regions. The contradiction between supply and demand of medical resources is mainly reflected in quantity shortage and improper allocation. In response to the increasingly severe supply and demand situation of medical resources, some developed countries adopt the "three-level medical service network (UK)" and "family doctor (Japan)" and other forms of Hierarchical Treatment System (HTS) to improve the efficiency of medical resources utilization. In 2015, the Chinese government promulgated the Guiding Opinions on Promoting the Construction of the Classification and Treatment System. It aims to deepen the reform of the medical and health system, effectively allocate medical resources and promote the equalization of basic medical and health services.

Since its introduction around 2007, much has been written on the requirements and implications of HTS. The results show that the medical service resource market is a complex bilateral market with multiple attributes and non-affiliated platforms. The validity of the bilateral matching decision among the participating subjects is the prerequisite for the optimal allocation of medical resources. However, one subject appears to have drawn less attention and that is the optimal allocation of medical resources under different scenarios. Exactly, previous studies take little account about the different priorities and influences of medical service resources subjects when they were participating in the cooperative game.

According to the collected data from China Government, the Chinese government has invested a lot of money (more than 3 trillion RMB, from 2009 to 2015) on health care in recent years, and it has significantly increased the supply of hospitals, doctors and other medical resources. For example, at November 2016, the total number of registered hospitals in China came up to 28751 from 19822 in 2008. The results show that the Chinese government has done most of the measures it can do, and the number of per capita medical resources is growing rapidly, the data close to moderately developed countries such as Italy, Spain, Japan and South Korea (Department of Health Statistics, 2016). However, increasing numbers of patients visiting hospitals every year (total attendance has risen at 7.8 billion in 2016 according to Chinese Health and Family Planning Development Statistical Bulletin(2017)), and evidences of some hospitals taking special actions to avoid overcrowding while other hospital's medical resources are often idle , suggests that optimal allocation of medical resources is still a high priority.

Utilization rate of all medical resources exhibit number-dependent behavior; that is, the patient arrival rate changes. The volume of patients is also likely to vary in different hospitals, but the number of medical resources supply cannot change flexibly in a short time. Under the condition that patients never made any reservations and the influence power of decision-making is variable, the patient quantity volume will becomes very large without any signs and the medical resources service capacity is insufficient, the service level of hospitals will be obviously weakened and other hospitals without the patient will become idle. Our purpose is to determine the optimal match between Superior hospitals, Subordinate hospitals, and patients so as to meet the largest resource utilization and highest total system satisfaction in different scenes.

2. RELATED WORKS

To establish a service system with time-varying requirements is a major challenge, the traditional matching theory cannot be directly applied to this type of system as the main parameters (mainly the satisfaction matrix) are often change in dynamic and random way, so the matching system cannot get stable matching results. It has attracted a significant researches over the last two decades, and many approaches have been developed.

The aim of the matching decision-making method is to focus on matching pricing decision and matching stability, improving the willingness and management effect of the bilateral market matching. Rochet and Tirole (2008) [4] proposed a bilateral market matching price equilibrium condition: when fixed costs and benefits do not exist, the price structure must be satisfied: $-\frac{p^i-(c-p^j)}{p^i}=\frac{1}{\eta^i}$; when the royalty does not exist, the price structure must satisfy: $-\frac{p^i-(-b^j)}{p^i}=\frac{1}{\eta^i}$. Helder (2015) [5] analyzed the four factors of bilateral market matching pricing decision: bilateral market price elasticity, network externality intensity, single attribution and multi-attribution and product differentiation. James and Vicki (2014) [6] proposed a vertical bilateral market matching price strategy, József (2014) [7] obtained the pricing model of the bilateral market matching when the participants were unequal. In the specific application areas, bilateral market matching pricing decision research has also become a hot topic, as the e-commerce platform pricing (Sülzle, 2009) [8], renewable energy power system pricing (Elisabeth and Alexandra, 2013) [9], self-media social platform Pricing (Helmut et al., 2013) [10], bilateral pricing model decision in media (Cheng Guishen, 2011) [11].

In the stable matching scheme, the matching relationship between the matching subjects can be maintained and the efficiency of the bilateral market is improved. Many studies are designed to find the it, Fleiner (2011) [12] used a fixed point theory to obtain a stable match, and pointed out that the bilateral match is Knaster-Tarski fixed point problem, rather the bilateral matching is Kakutani fixed point problem. Sarne and Kraus (2008) [13] found a way to improve the efficiency of the stable matching algorithm. Mcmermid (2012) [14] proved that even if the matching subject's score and preference order are consistent with stable marriage matching problems, it is still a strong NP-hard problem.

The matching algorithms are covering a wide range, such as the linear programming model in the marriage match; Gale-Shapley algorithm to solve the problem of student enrollment matching (Gale and Shapley, 1962) [15]. The stable matching algorithm is solved by using the graph theory (Tilman, K., 2009) [16], exactly by setting the stable distribution of the irreversible utility and the transferable utility in the stable matching structure. Using the Hospital-Resident algorithm to solve the optimal stability of 1-n bilateral matching (Roth, 1985) [17], (Coles and Shorrer, 2014) [18]. More stable matching results can be obtained based on the recursive algorithm of the Break-marring operator (Archishman and Alessandro, 2010) [19]. The improved matching decision algorithm includes the cumulative foreground theory decision algorithm (Le Qi et al., 2015) [20], multi-objective optimization based on perceptual utility (Li Mingyang and Fan Zhiping, 2014) [21], Path-Relinking process of greedy random adaptation Algorithm (Kong Defu and Jiang Yanping, 2016) [22], stakeholder preference fusion algorithm (Chen Shengqun et al., 2016) [23].

Participants of the medical resources bilateral-market, the abilities and preferences are dynamically adjusted, so the system matching is instable and to find a stable matching is very difficult. Traditional static matching models and algorithms cannot adapt to dynamic changes and meet the optimization goals. It is noteworthy that the rapid growth of medical demands and increasingly inadequate medical resources are the main reasons which leading to excessive load in hospitals. However, based on our survey data in Chinese hospitals, the matching efficiency between patients and hospitals is the main reason leading to unbalanced utilization of medical resources, then it led to excessive load of some hospitals. Optimization of medical resource matching model will significantly improve the efficiency of medical resources utilization. In comparison to the unrestricted increase in therapeutic resources, this is likely to be a much more cost-effective solution.

The paper is organized as follows. A generic patient-hospital (P-H) model is discussed in Section 3. The comprehensive satisfaction matrix calculation is explained in Section 4, especially included the multi-context of comprehensive satisfaction; and is designed the model solution and decision-making steps in Section 5. This is followed by the case study and discussions, conclusions in section 6 - 7.

3. A GENERIC PATIENT-HOSPITAL (P-H) MODEL

In the hierarchical treatment system, medical resources can be divided into two categories: Superior hospital collection A, Subordinate hospital collection B. When the patient is ill, he first went to Subordinate Hospital B for initial treatment. If the condition cannot be healed in the Subordinate hospital B, he will go to Superior hospital A to find the appropriate referral recipient by matching the platform. Superior hospital A will determine whether to accept a referral request based on its own medical capacity and service resource constraints. If it is not acceptable, subordinate hospital B will need to select another Superior hospital A again as a referral hospital until a satisfactory match is obtained. Our goal is to meet the overall satisfaction of the decision-making of the bilateral market, and obtain the global optimal stable matching scheme.

Superior hospital collection$\mathrm{A} = \{\mathrm{A}_1, \mathrm{A}_2, \cdots, \mathrm{A}_\mathrm{m}\}$, A_i is a subject in A, $\mathrm{I} = \{1,2, \cdots, \mathrm{m}\}, \mathrm{i} \in \mathrm{I}$. Subordinate hospital collection$\mathrm{B} = \{\mathrm{B}_1, \mathrm{B}_2, \cdots, \mathrm{B}_\mathrm{n}\}$, B_j is a subject in B, J= $\{1,2, \cdots, \mathrm{n}\}, \mathrm{j} \in \mathrm{J}$. The number of B subjects can be accepted by A_i is s_i, and $\sum_{\mathrm{i}=1}^{\mathrm{m}} \mathrm{s}_\mathrm{i} = \mathrm{s}$, every B_j can match only 1 A_i. Without loss of general, let $2 \leq \mathrm{s} \leq \mathrm{n}$, and then build a typical 1-n matching problem, displayed in Fig. 1.

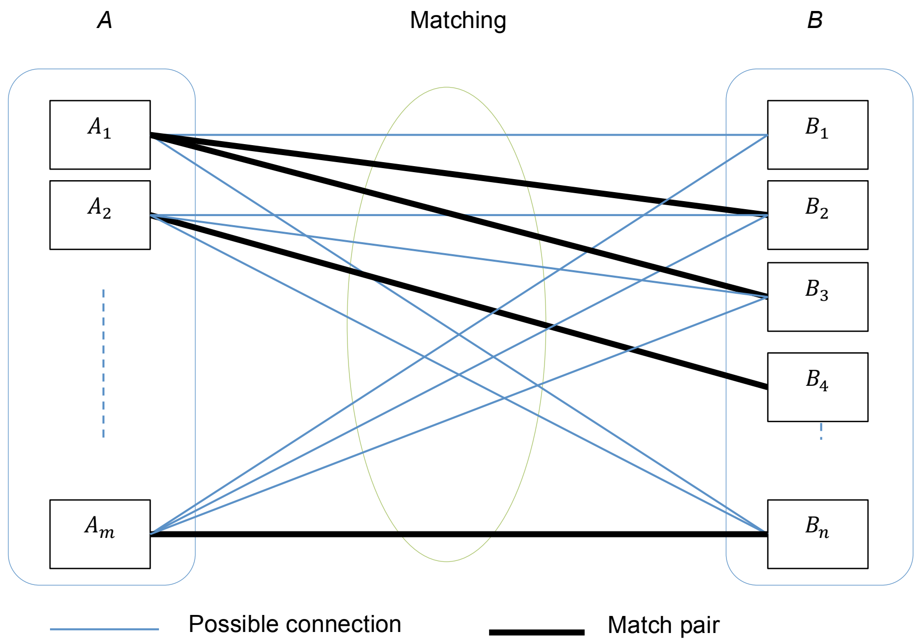


Fig. 1. 1-n Bilateral Matching

R is the preference order matrix given by the set A for the main set B, $R = [r_{ij}]_{m \times n}$, r_{ij} is the preference order given by A_i for B_j, that is, in the order of precedence, B_j is ranked the r_{ij} in preference sequence of A_i, $r_{ij} \in I$. Similarly, T is the preference order matrix given by the set B for the main set A, $T = [t_{ij}]_{m \times n}$, t_{ij} is the preference order given byB_j for A_i, $t_{ij} \in J$. In order to achieve the stable matching, Roth A E(1985) given the definition as follows:

Definition 1. 1-n bilateral matching

Mapping μ: $\mu: A \cup B \rightarrow B \cup A, \forall A_i \in A, B_j \in B$, the following conditions are satisfied, the mapping is 1-n bilateral matching.

1) $\mu(A_i) \in B \cup \{A_i\}$;

2) $\mu(B_j) \in A \cup \{B_j\}$;

3) If$\mu(A_i) = \{B_{j1}, \cdots, B_{js_i}\}$, and$\{j1, \cdots, js_i\} \in J$, then$\mu(B_{j1}) = A_i, \cdots \mu(B_{js_i}) = A_i$;

4) If $\mu(B_j) = A_i$, then $B_j \in \mu(A_i)$;

5) $\forall i, l \in I, i \neq l$, $\mu(A_i) \cap \mu(A_l) = \emptyset$

Definition 2. Matching scheme

If $\mu(A_i) = B_j$, then $A_i \in \mu(B_j)$, call $\mu_1(A_i, B_j)$ as μ-matched subject pair; if $\mu(B_j) \notin A$, then $\mu(B_j) = B_j$, B_j did not find the appropriate A to match, call $\mu_2(B_j, B_j)$ as the μ-unmatched subject. All μ-matched subject pairs and μ-unmatched subjects constitute matching scheme θ, $\theta = \mu_1 \cup \mu_2$, $\mu_1 = \{A_i, B_{f(i)} | i \in I\}$,

$$\mu_2 = \{B_j, B_j | j \in J \setminus \{f(1), f(2), \dots f(m)\}\}, f(i) \in J, \forall k, l \in I, k \neq l, f(k) \neq f(l).$$

Definition 3. Hinder matching pair

For 1-n bilateral matching, if the μ-matched subject pair satisfies any of the following conditions, and then it is a hinder matching pair:

1) $\exists A_i, A_l \in A, B_j, B_k \in B, \mu(A_i) = B_k, \mu(A_l) = B_j, r_{ij} < r_{ik}$ and $t_{ij} < t_{lj}$;

2) $\exists A_i \in A, B_j, B_k \in B, \mu(A_i) = B_k, \mu(B_j) = B_j$,and $r_{ij} < r_{ik}$;

3) $\exists A_i, A_l \in A, B_j \in B, \mu(A_l) = B_j, \mu(A_i) = A_i$,and $t_{ij} < t_{lj}$;

4) $\exists A_i \in A, B_j \in B, \mu(A_i) = A_i, \mu(B_j) = B_j$.

Definition 4: Stable matching scheme

For 1-n bilateral matching, if hinder matching pair does not exist, then it is a stable matching scheme.

There are many differences among hospitals in facilities, service level, management mechanism, profit distribution and other aspects, and these differences are low-standardization, so evaluation value cannot be determined by quantitative methods directly. Taking into account the competition - cooperation relationship between different medical resources providers, it is a general and feasible measure to use satisfaction method to get satisfaction. In the relevant studies, the satisfaction is a mathematical transformation based on the strict preference order, provided that the preference order is strict and invariant. In the relevant studies, the strict preference order is the basis for mathematical transformation, and the preference order is strict and invariant. In addition, the difference sizes between preference values did not get attention. The method of weight determining is mainly based on qualitative analysis. There is little equilibrium analysis of the preference values in different contexts. For all of these reasons, most of the matching results are quite different from the realities. The first problem we want to solve in this paper is to obtain variable comprehensive satisfaction matrix and weight matrix in multiple contexts.

4 COMPREHENSIVE SATISFACTION MATRIXES

4.1 Split process

In 1-n matching, the number of B subjects can be accepted by the subject A_i is s_i. So A_i can be split into s_i virtual entities {A_i^1,A_i^2,⋯,A_i^(s_i) }, and they have the same preference. For any virtual subjectA_i^(δ_i), the number of objects can be matched is 1(1≤δ_i≤s_i). After transformation, A is written as A˜, as follows:

$$\tilde{A} = \begin{cases} \left[A_1^1, A_1^2, \cdots, A_1^{s_1}\right]^T & s_1 \\ \vdots & \\ \vdots & \\ \left[A_i^1, A_i^2, \cdots, A_i^{s_i}\right]^T & s_i \\ \vdots & \\ \vdots & \\ \left[A_m^1, A_m^2, \cdots, A_m^{s_m}\right]^T & s_m \end{cases}$$

R˜ is preference order matrix of $\tilde{A}$, $\tilde{R} = \left[{r_i^{\delta_i}}_j\right]_{s\times n}$, ${r_i^{\delta_i}}_j$ is the preference order given by $A_i^{\delta_i}$ for $\mathrm{B_j}$, $1 \le \delta_i \le s_i$.

$$\tilde{A} = \begin{cases} \left[A_1^1, A_1^2, \cdots, A_1^{s_1}\right]^T & s_1\text{个} \\ \vdots & \\ \vdots & \\ \left[A_i^1, A_i^2, \cdots, A_i^{s_i}\right]^T & s_i\text{个} \\ \vdots & \\ \vdots & \\ \left[A_m^1, A_m^2, \cdots, A_m^{s_m}\right]^T & s_m\text{个} \end{cases}$$

4.2 Unilateral satisfaction matrix

Unilateral satisfaction formula as follows:

α _ij=(1/r_ij)^(ε_A),i∈I; j∈J

β _ij=(1/t_ij)^(ε_B),i∈I; j∈J

In order to prevent the occurrence of 0 elements, the modified unilateral satisfaction formula is as follows:

α _ij=(1/r_ij +1/2m)^(ε_A),i∈I; j∈J

β _ij=(1/t_ij +1/2n)^(ε_B),i∈I; j∈J

According to the split process of A_i described above:

〖〖r_ij=r〗_i^1〗_j=〖r_i^2〗_j=,⋯,=〖r_i^(δ_i)〗_j=,⋯,=〖r_i^(s_i)〗_j i∈I; 1≤δ_i≤s_i; j∈J

〖〖t_ij=t〗_i^1〗_j=〖t_i^2〗_j=,⋯,=〖t_i^(δ_i)〗_j=,⋯,=〖t_i^(s_i)〗_j i∈I; 1≤δ_i≤s_i; j∈J

Based on the unilateral satisfaction formula, ∀ i∈I,1≤δ_i≤s_i,j∈J, 0<ε≤1,

〖α _i^1〗_j=〖α _i^2〗_j=,⋯,=〖α _i^(δ_i)〗_j=,⋯,=〖α _i^(s_i)〗_j 〖=(1/r_ij +1/2s)〗^(ε_A)

〖β _i^1〗_j=〖β _i^2〗_j=,⋯,=〖β _i^(δ_i)〗_j=,⋯,=〖β _i^(s_i)〗_j 〖=(1/t_ij +1/2n)〗^(ε_B)

The 〖α _i^(δ_i)〗_jand〖〖 β〗_i^(δ_i)〗_j satisfies the following equations:

1) 0<〖α _i^(δ_i)〗_j≤1,0<〖β _i^(δ_i)〗_j≤1;

2) ∀ j,k∈J, if 〖r_i^(δ_i)〗_j<〖r_i^(δ_i)〗_k, then 〖α _i^(δ_i)〗_j>〖α _i^(δ_i)〗_k;∀ i∈I; 1≤δ_i≤s_i,if 〖t_i^(δ_i)〗_j<t_lj, then 〖β _i^(δ_i)〗_j>β_lj.

3) Descent speed of subject satisfaction will be faster when ε becomes larger.

After got the unilateral satisfaction matrix, two questions need to be considered:

First, the differences of preference value in other subject's view. When it is a very large, indicates the subject is controversial and should pay attention on it.

Second, the difference between unilateral satisfactions within each other, such as 〖α _i^(δ_i)〗_j and 〖β _i^(δ_i)〗_j. If |〖α _i^(δ_i)〗_j- 〖β _i^(δ_i)〗_j | is very large, that will indicate the difference between mutual recognition is great. If these two subjects compose a matching pairs, it will easy have a "unilateral psychological gap" and weaken the stability of matching. In this article, we used weights to solve these two problems.

4.3 Influence weight

According to the definition of the average information "entropy" by Shannon's Theorem, the satisfaction coefficient of the same subject (such as$A_i^{\delta_i}$) in other subjects (such asB_j) can determine Influence weight.

Step 1. **Calculate the satisfaction of entropy.**

Calculate the specific gravity ${p_i^{\delta_i}}_{j\beta}$, $\forall\, i \in I;\ 1 \le \delta_i \le s_i$,

$$ {p_i^{\delta_i}}_{j\beta} = \frac{{\beta_i^{\delta_i}}_j}{\sum_{j=1}^{n} {\beta_i^{\delta_i}}_j} \text{ , } {\beta_i^{\delta_i}}_j > 0, \sum_{j=1}^{n} {\beta_i^{\delta_i}}_j > 0 \text{ ;} $$

Get the entropy of preference sequence ${e_i^{\delta_i}}_\beta$.

$$ {e_i^{\delta_i}}_\beta = -k \sum_{j=1}^{n} {p_i^{\delta_i}}_{j\beta} ln\left({p_i^{\delta_i}}_{j\beta}\right) $$

If $\forall\, j \in \Box$, ${p_i^{\delta_i}}_{j\beta} = {}^1/_n$, then it's information will be minimum, and the "entropy" will reach the maximum 1. It can be seen, $k = \frac{1}{ln\, n}$, and get the following equals:

$$ {e_i^{\delta_i}}_\beta = -\frac{1}{ln\, n} \sum_{j=1}^{n} {p_i^{\delta_i}}_{j\beta} ln\left({p_\Box^{\delta_i}}_{j\beta}\right) \quad (1) $$

As the same way, can get $e_{j\alpha}$.

$$ e_{j\alpha} = -\frac{1}{ln\, s} \sum_{i=1}^{m} \sum_{\delta_i=1}^{s_i} {p_i^{\delta_i}}_{j\alpha} ln\left({p_i^{\delta_i}}_{j\alpha}\right) \quad (2) $$

Step 2. **Calculate the difference coefficient**

$\forall\, \mathrm{i} \in \mathrm{I}, 1 \le \delta_\mathrm{i} \le \mathrm{s_i}, \mathrm{j} \in \mathrm{J}$, ${\mathrm{e}_\mathrm{i}^{\delta_\mathrm{i}}}_\beta$ can represent its rarity and information content. So, we can use difference coefficient to express this.

$\mathrm{g}_{\mathrm{j}\alpha} = 1 - \mathrm{e}_{\mathrm{j}\alpha}$, ${\mathrm{g}_\mathrm{i}^{\delta_\mathrm{i}}}_\beta = 1 - {\mathrm{e}_\mathrm{i}^{\delta_\mathrm{i}}}_\beta$, $\mathrm{i} \in \mathrm{I};\ 1 \le \delta_\mathrm{i} \le \mathrm{s_i};\ \mathrm{j} \in \mathrm{J}$;

Step 3. **Calculate the influence weight**

Normalization of the difference coefficient, then get the influence weight.

$$ w_i^{\delta_i} = \frac{{g_i^{\delta_i}}_\beta}{\sum_{i=1}^{m} \sum_{\delta_i=1}^{s_i} {g_i^{\delta_i}}_\beta} \quad (3) $$

$$ \mathrm{w_j} = \frac{\mathrm{g}_{\mathrm{j}\alpha}}{\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{g}_{\mathrm{j}\alpha}} \quad (4) $$

4.4 Comprehensive satisfaction in multiple situations

We used comprehensive satisfaction integration function$\tau(\cdot)$ and difference adjustment function $\varphi(\cdot)$ to react the difference between unilateral satisfactions within each other in this part. The sum of $\tau(\cdot)$ and $\varphi(\cdot)$ is comprehensive satisfaction of $\mu\left(A_i^{\delta_i}, B_j\right)$, write as ${\sigma_i^{\delta_i}}_j$, then get the comprehensive satisfaction matrix Θ. $\tau(\cdot)$ is a strictly increasing function, which increases with two sides' unilateral matching satisfaction. $\varphi(\cdot)$ is a decreasing function, and it change with the absolute difference of unilateral satisfaction between two sides.

In the hierarchical treatment system, there are four possible scenarios:

***Scenario 1*. Superior hospitals have an overwhelming influence on matching**

The comprehensive satisfaction mainly decided by superior hospitals.

$$\tau(\cdot)^{(a)} = {\alpha^{\delta_i}_{i\ j}}^{w_i^{\delta_i}}, \varphi(\cdot)^{(a)} = |\alpha^{\delta_i}_{i\ j} - \beta^{\delta_i}_{i\ j}|^{-\left(w_i^{\delta_i}\right)}$$

$$\sigma^{\delta_i\ (a)}_{i\ j} = {\alpha^{\delta_i}_{i\ j}}^{w_i^{\delta_i}} + |\alpha^{\delta_i}_{i\ j} - \beta^{\delta_i}_{i\ j}|^{-\left(w_i^{\delta_i}\right)} \quad (5a)$$

***Scenario 2*. Subordinate hospitals have an overwhelming influence on matching**

The comprehensive satisfaction mainly decided by subordinate hospitals.

$$\tau(\cdot)^{(b)} = {\beta^{\delta_i}_{i\ j}}^{w_j}, \varphi(\cdot)^{(b)} = |\alpha^{\delta_i}_{i\ j} - \beta^{\delta_i}_{i\ j}|^{-(w_j)}$$

$$\sigma^{\delta_i\ (b)}_{i\ j} = {\beta^{\delta_i}_{i\ j}}^{w_j} + |\alpha^{\delta_i}_{i\ j} - \beta^{\delta_i}_{i\ j}|^{-(w_j)} \quad (5b)$$

***Scenario 3*. Initiate a partnership**

The comprehensive satisfaction is synthesized by bilateral market.

$$\tau(\cdot)^{(c)} = {\alpha^{\delta_i}_{i\ j}}^{w_i^{\delta_i}} + {\beta^{\delta_i}_{i\ j}}^{w_j}, \varphi(\cdot)^{(c)} = |\alpha^{\delta_i}_{i\ j} - \beta^{\delta_i}_{i\ j}|^{-\left(\max\left(w_i^{\delta_i}, w_j\right)\right)}$$

$$\sigma^{\delta_i\ (c)}_{i\ j} = {\alpha^{\delta_i}_{i\ j}}^{w_i^{\delta_i}} + {\beta^{\delta_i}_{i\ j}}^{w_j} + |\alpha^{\delta_i}_{i\ j} - \beta^{\delta_i}_{i\ j}|^{-\left(\max\left(w_i^{\delta_i}, w_j\right)\right)} \quad (5c)$$

***Scenario 4*. Relationship is stable and balanced**

The comprehensive satisfaction is obtained by means of balanced coordination.

$$\tau(\cdot)^{(d)} = {\alpha^{\delta_i}_{i\ j}}^{w_j} + {\beta^{\delta_i}_{i\ j}}^{w_i^{\delta_i}}, \varphi(\cdot)^{(d)} = |\alpha^{\delta_i}_{i\ j} - \beta^{\delta_i}_{i\ j}|^{-\left(\max\left(w_i^{\delta_i}, w_j\right)\right)}$$

$$\sigma^{\delta_i\ (d)}_{i\ j} = {\alpha^{\delta_i}_{i\ j}}^{w_j} + {\beta^{\delta_i}_{i\ j}}^{w_i^{\delta_i}} + |\alpha^{\delta_i}_{i\ j} - \beta^{\delta_i}_{i\ j}|^{-\left(\max\left(w_i^{\delta_i}, w_j\right)\right)} \quad (5d)$$

In the above four scenarios, we can normalize the comprehensive satisfaction matrix Θ to obtain the weight matrix W, and $w^{\delta_i}_{i\ j}$ is the weight of $A_i^{\delta_i}$ and B_j matching pair in the bipartite graph, the formula is:

$$w^{\delta_i}_{i\ j} = \sigma^{\delta_i}_{i\ j} \Big/ \max_{i,\delta_i,j} \sigma^{\delta_i}_{i\ j} \quad i \in I;\ 1 \le \delta_i \le s_i;\ j \in J \quad (6)$$

5 MODEL SOLVING AND DECISION MAKING STEPS

5.1 Solving methods

Based on definition 1-4, we get the stable matching constraint, optimize target, and the optimization target is the maximum total number of matching bimodal, the optimization model is as follows:

$$\max \quad Z = \sum_{i=1}^{m} \sum_{\delta_i=1}^{s_i} \sum_{j=1}^{n} \sigma^{\delta_i}_{i\ j} x^{\delta_i}_{i\ j} \quad (7)$$

s.t.

$$\sum_{j=1}^{n} x^{\delta_i}_{i\ j} = 1 \quad i \in I, 1 \le \delta_i \le s_i; \quad (7a)$$

$$\sum_{i=1}^{m} \sum_{\delta_i=1}^{s_i} x^{\delta_i}_{i\ j} \le 1 \quad j \in J; \quad (7b)$$

$$x^{\delta_i}_{i\ j} + \sum_{k:\ r^{\delta_i}_{i\ k} \le r^{\delta_i}_{i\ j}} x^{\delta_i}_{i\ k} + \sum_{l:\ t_{lj} \le t^{\delta_i}_{i\ j}} x_{lj} \ge 1\ ;\ i \in I, 1 \le \delta_i \le s_i;\ j \in J \quad (7c)$$

$$x^{\delta_i}_{i\ j} = 0,1 \quad i \in I;\ 1 \le \delta_i \le s_i;\ j \in J \quad (7d)$$

And $x^{\delta_i}_{i\ j}$ is a 0-1 variable, $x^{\delta_i}_{i\ j} = \begin{cases} 1, & A_i^{\delta_i} = \mu(B_j) \\ 0, & A_i^{\delta_i} \ne \mu(B_j) \end{cases}$.

In the model, the optimization result is the maximum matching of bipartite graph. The constraint (7a) shows that any subject $A_i^{s_i}$ only can match with 1 subject in set B, constraint (7b) shows that any subject $\mathrm{B_j}$ can only match with 1 subject in set $\tilde{\mathrm{A}}$. In Fig. 1, all vertices of set A is fully-saturated matching point, and only part of set B's are fully-saturated matching points. Eq. (7c) is stable matching constraints, all columns and rows including $x_{i\ j}^{\delta_i}$, matching pair $\mu\left(A_i^{\delta_i}, B_j\right)$. In all the preference value of $A_i^{\delta_i}$ is better than $r_{i\ j}^{\delta_i}$ and all the preference value of B_j is better than $t_{i\ j}^{\delta_i}$, there must be at least one set of matching pair, so as to eliminate hinder matching pairs. The constraint (7d) indicates whether any subject $A_i^{s_i}$ is connected to vertex of subject B_j, connected is 1, not is 0. The above is an integer programming model, which can be solved by LINGO software. If the problem is large, it can be solved by genetic algorithm.

5.2 Decision making steps

Step 1. Get the preference order matrix based on preference value.

Step 2. Adding the virtual subject element to built $\tilde{A}$, and then converting the 1-n matching problem into the 1-1 matching problem.

Step 3. Get the unilateral satisfaction matrix, the entropy value, the difference coefficient and the influence weight according to the formulas 1 to 4.

Step 4. Use the formula 5a-d to calculate the comprehensive satisfaction, and get the ownership matrix.

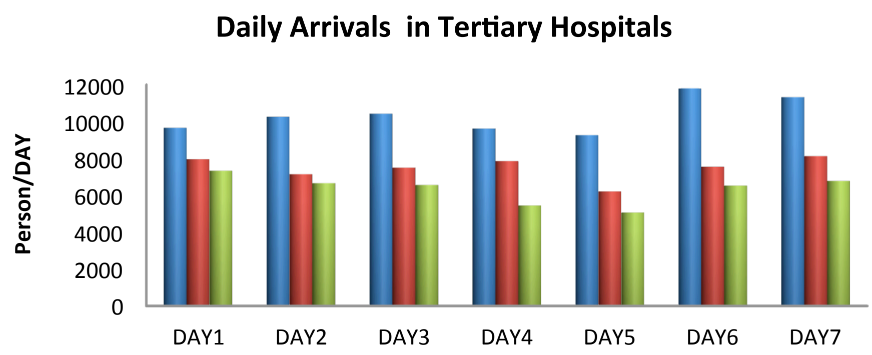
Step 5. Establish model (7), solve and get the optimal matching scheme.

Step 6. Discuss the matching satisfaction in different modes.

6. CASE STUDY AND DISCUSSIONS

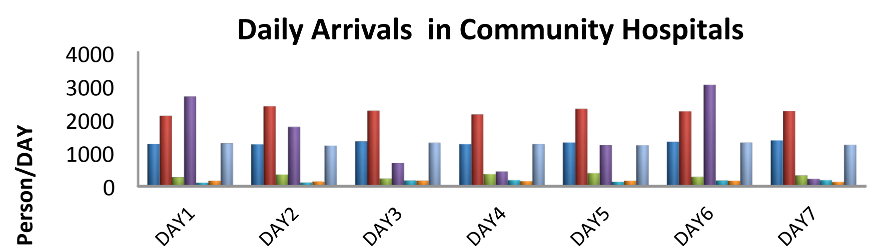
6.1 Case study

To test our approach, we obtained the information provided in the 7-day questionnaire conducted by 3 Tertiary Hospitals and 7 community hospitals in Changsha city, P.R. China. Tertiary Hospital is superior hospital, and a community hospital is subordinate hospital. Based on the survey data, daily arrivals in Tertiary Hospitals (average) are as high as 8043 persons; however, the daily arrivals in Community Hospitals are only 976 persons, as shown in Figures 2 and 3. In contrast to the above data, we can see that the average daily arrivals are quite different in terms of Tertiary Hospitals and Community Hospitals. Daily transfers from Community Hospital are illustrated in Fig. 4, and daily accept transfers by Tertiary Hospital are showed in Fig. 5. As there did not establish a strict and exclusive referral system within the 10 hospitals, the daily total turnover quantity is not equal to the number of transfer.



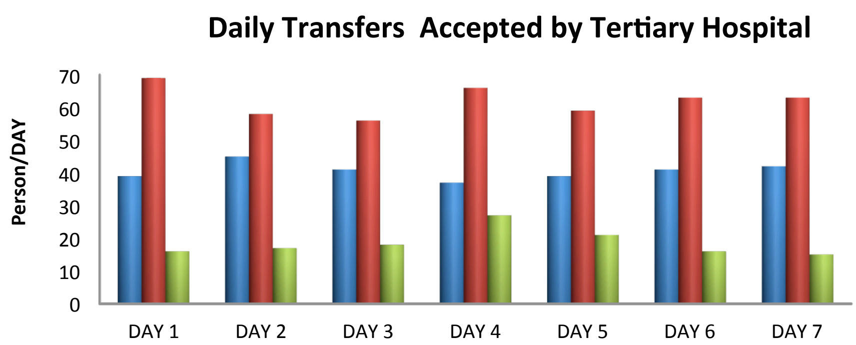
	DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7
Tertiary Hospital 1	9653	10260	10418	9615	9261	11791	11314
Tertiary Hospital 2	7951	7135	7495	7847	6206	7542	8120
Tertiary Hospital 3	7323	6645	6551	5443	5056	6517	6770

Fig. 2. Daily Arrivals in Tertiary Hospitals



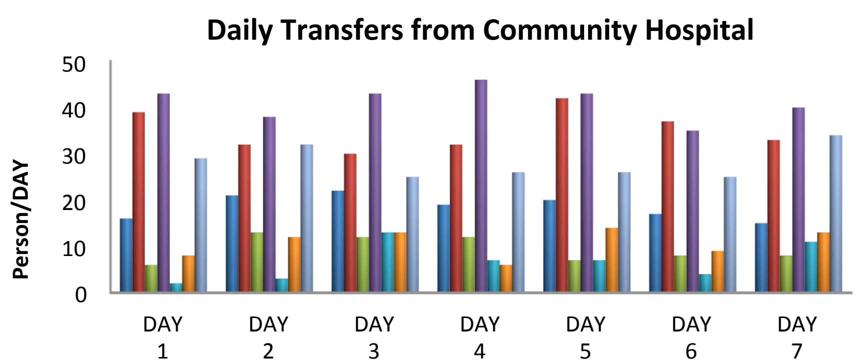
	DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7
Community Hospital 1	1261	1251	1340	1257	1304	1323	1368
Community Hospital 2	2105	2387	2254	2143	2308	2234	2236
Community Hospital 3	264	348	225	356	389	277	317
Community Hospital 4	2677	1770	688	433	1221	3029	214
Community Hospital 5	98	103	164	182	130	163	180
Community Hospital 6	156	139	159	147	154	156	126
Community Hospital 7	1279	1208	1297	1259	1220	1300	1228

Fig. 3. Daily Arrivals in Community Hospitals



	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
Tertiary Hospital 1	39	45	41	37	39	41	42
Tertiary Hospital 2	69	58	56	66	59	63	63
Tertiary Hospital 3	16	17	18	27	21	16	15

Fig. 4. Daily Transfers Accepted by Tertiary Hospitals



	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
Community Hospital 1	16	21	22	19	20	17	15
Community Hospital 2	39	32	30	32	42	37	33
Community Hospital 3	6	13	12	12	7	8	8
Community Hospital 4	43	38	43	46	43	35	40
Community Hospital 5	2	3	13	7	7	4	11
Community Hospital 6	8	12	13	6	14	9	13
Community Hospital 7	29	32	25	26	26	25	34

Fig. 5. Daily Transfers from Community Hospitals

To improve the using efficient of medical resources, the regional government has carry out hierarchical diagnosis and treatment cooperation. The hospitals are numbered as follows: tertiary hospitals (A_1, A_2, A_3) and community hospitals $(B_1, B_2, B_3, B_4, B_5, B_6, B_7)$. The number of B_j subjects can be accepted by A_i is estimated by hospitals management experts and the numbers are assumed to be 2, 3, 1.

To test and verify the advantage of stabilizing performance using our algorithm, we compare the simulation calculation with the stochastic matching algorithm, the strict matching method based on the partial preference information (abbreviated as "F-Y" algorithm) and the multi - scenario dynamic matching method proposed in this paper are adopted. Superior hospitals determine the order of subordinate hospitals in strict order as follows: medical data integrity, delivery timeliness, physical distance, medical data accuracy and other indicators, we set strict order of subordinate hospitals as in Table 1. On the other hand, subordinate hospitals determine the strict order of superior hospitals in according to the following aspects: technical training, benefit distribution, physical distance, information system and other indicators, we set it in Table 2.

Table 1

Strict order of subordinate hospitals.

Superior hospitals	Strict order
A_1	$B_7 \succ B_5 \succ B_3 \succ B_6 \succ B_2 \succ B_4 \succ B_1$
A_2	$B_1 \succ B_3 \succ B_6 \succ B_5 \succ B_4 \succ B_2 \succ B_7$
A_3	$B_5 \succ B_6 \succ B_4 \succ B_1 \succ B_3 \succ B_7 \succ B_2$

Table 2

Strict order of superior hospitals.

Subordinate hospitals	Strict order
B_1	$A_2 \succ A_3 \succ A_1$
B_2	$A_2 \succ A_1 \succ A_3$
B_3	$A_3 \succ A_2 \succ A_1$
B_4	$A_3 \succ A_1 \succ A_2$
B_5	$A_2 \succ A_3 \succ A_1$
B_6	$A_2 \succ A_1 \succ A_3$
B_7	$A_1 \succ A_3 \succ A_2$

Step 1. Get the preference order matrix based on preference value.

$$
R = \begin{bmatrix} & B_1 & B_2 & B_3 & B_4 & B_5 & B_6 & B_7 \\ A_1 & 7 & 5 & 3 & 6 & 2 & 4 & 1 \\ A_2 & 1 & 6 & 2 & 5 & 4 & 3 & 7 \\ A_3 & 4 & 7 & 5 & 3 & 1 & 2 & 6 \end{bmatrix}
$$

$$
T = \begin{bmatrix} & B_1 & B_2 & B_3 & B_4 & B_5 & B_6 & B_7 \\ A_1 & 3 & 2 & 3 & 2 & 3 & 2 & 1 \\ A_2 & 1 & 1 & 2 & 3 & 1 & 1 & 3 \\ A_3 & 2 & 3 & 1 & 1 & 2 & 3 & 2 \end{bmatrix}
$$

Step 2. Adding the virtual subject element to built $\tilde{A}$, and then converting the 1-n matching problem into the 1-1 matching problem. Considering the degree of preference change in superior hospitals and subordinate hospitals, let $\varepsilon_A = 0.6, \varepsilon_B = 0.5$, and obtain the unilateral satisfaction matrix A and B.

$$
\tilde{A} = [A_1^1, A_1^2, A_2^1, A_2^2, A_2^3, A_3^1]
$$

$$
A = \left[\alpha_{i\ j}^{\delta_i}\right]_{6\times 7} = \begin{bmatrix} 0.41 & 0.47 & 0.59 & 0.44 & 0.72 & 0.52 & 1.05 \\ 0.41 & 0.47 & 0.59 & 0.44 & 0.72 & 0.52 & 1.05 \\ 1.05 & 0.44 & 0.72 & 0.47 & 0.52 & 0.59 & 0.41 \\ 1.05 & 0.44 & 0.72 & 0.47 & 0.52 & 0.59 & 0.41 \\ 1.05 & 0.44 & 0.72 & 0.47 & 0.52 & 0.59 & 0.41 \\ 0.52 & 0.41 & 0.47 & 0.59 & 1.05 & 0.72 & 0.44 \end{bmatrix}
$$

$$B = \left[\beta_{i\ \ j}^{\delta_i}\right]_{6\times7} = \begin{bmatrix} 0.64 & 0.76 & 0.64 & 0.76 & 0.64 & 0.76 & 1.04 \\ 0.64 & 0.76 & 0.64 & 0.76 & 0.64 & 0.76 & 1.04 \\ 1.04 & 1.04 & 0.76 & 0.64 & 1.04 & 1.04 & 0.64 \\ 1.04 & 1.04 & 0.76 & 0.64 & 1.04 & 1.04 & 0.64 \\ 1.04 & 1.04 & 0.76 & 0.64 & 1.04 & 1.04 & 0.64 \\ 0.76 & 0.64 & 1.04 & 1.04 & 0.76 & 0.64 & 0.76 \end{bmatrix}$$

Step 3. Get the unilateral satisfaction matrix, the entropy value, the difference coefficient and the influence weight according to the formulas 1 to 4.

$e_{1\beta}^{1} = e_{1\beta}^{2} = 0.9925$, $e_{2\beta}^{1} = e_{2\beta}^{2} = e_{2\beta}^{3} = 0.9887$, $e_{3\beta}^{1} = 0.9906$;

$g_{1\beta}^{1} = g_{1\beta}^{2} = 0.0075$, $g_{2\beta}^{1} = g_{2\beta}^{2} = g_{2\beta}^{3} = 0.0113$, $g_{3\beta}^{1} = 0.0094$;

$w_{1\beta}^{1} = w_{1\beta}^{2} = 0.1280$, $w_{2\beta}^{1} = w_{2\beta}^{2} = w_{2\beta}^{3} = 0.1940$, $w_{3\beta}^{1} = 0.1619$;

$e_{1\alpha} = 0.9780, e_{2\alpha} = 0.7938, e_{3\alpha} = 0.9525, e_{4\alpha} = 0.8267,$

$e_{5\alpha} = 0.9636, e_{6\alpha} = 0.9196, e_{7\alpha} = 0.8985,$

$g_{1\alpha} = 0.0220, g_{2\alpha} = 0.2062, g_{3\alpha} = 0.0475, g_{4\alpha} = 0.1733,$

$g_{5\alpha} = 0.0361, g_{6\alpha} = 0.0804, g_{7\alpha} = 0.1015,$

$w_{1\alpha} = 0.0330, w_{2\alpha} = 0.3091, w_{3\alpha} = 0.0712, w_{4\alpha} = 0.2598,$

$w_{5\alpha} = 0.0542, w_{6\alpha} = 0.1205, w_{7\alpha} = 0.1522,$

Step 4. Use the formula 5a-d to calculate the comprehensive satisfaction, and get the ownership matrix.

Scenario (a): Comprehensive satisfaction $\Theta^{(a)} = \left[\sigma_{i\ \ j}^{\delta_i\ (a)}\right]_{6\times7}$

$\Theta^{(a)} = \left[\sigma_{i\ \ j}^{\delta_i\ (a)}\right]_{6\times7} =$

2.1008	2.0805	2.4198	2.0553	2.3231	2.1195	2.7259
2.1008	2.0805	2.4198	2.0553	2.3231	2.1195	2.7259
3.3071	1.9550	2.8939	2.2809	2.0164	2.0744	2.1767
3.3071	1.9550	2.8939	2.2809	2.0164	2.0744	2.1767
3.3071	1.9550	2.8939	2.2809	2.0164	2.0744	2.1767
2.1575	2.1353	1.9814	2.0582	2.2245	2.4261	2.0749

Similarly, the comprehensive satisfaction matrix for scenario (b, c, d) can be obtained:

$\Theta^{(b)}$=

2.0423	2.3653	2.1580	2.3225	2.2956	2.0280	3.0570
2.0423	2.3653	2.1580	2.3225	2.2956	2.0280	3.0570
2.1828	2.1725	2.1883	2.5766	2.0886	2.0203	2.2113
2.1828	2.1725	2.1883	2.5766	2.0886	2.0203	2.2113

2.1828	2.1725	2.1883	2.5766	2.0886	2.0203	2.2113
2.0468	2.4239	2.0330	2.2835	2.1291	2.0489	2.1653

$\Theta^{(c)}$=

3.0833	3.2736	3.3958	3.2220	3.2689	3.1129	4.0632
3.0833	3.2736	3.3958	3.2220	3.2689	3.1129	4.0632
4.3084	3.0227	3.8789	3.4393	3.0206	3.0753	3.1033
4.3084	3.0227	3.8789	3.4393	3.0206	3.0753	3.1033
4.3084	3.0227	3.8789	3.4393	3.0206	3.0753	3.1033
3.1466	3.2910	2.9832	3.2029	3.1906	3.4154	3.0407

$\Theta^{(d)}$=

3.1179	3.2098	3.4007	3.1482	3.2685	3.1495	4.0637
3.1179	3.2098	3.4007	3.1482	3.2685	3.1495	4.0637
4.3063	2.9519	3.8846	3.4165	3.0659	3.1662	3.1124
4.3063	2.9519	3.8846	3.4165	3.0659	3.1662	3.1124
4.3063	2.9519	3.8846	3.4165	3.0659	3.1662	3.1124
3.1883	3.2479	3.0609	3.1342	3.1789	3.3990	3.0368

Step 5. Establish model (7), solve and get the optimal matching scheme.

Step 6. Discuss the matching satisfaction in different modes.

According to the comprehensive satisfaction matrix under different scenarios, establish model and solve it, and get the matching result of multi-scenarios dynamic matching algorithm. Similarly, according to the random matching algorithm and the "F-Y" algorithm can get the matching results. The above results are summarized, show in Table 3-6.

Table 3

Comparison the results of matching algorithms in Scenario (a)

Algorithms / Results	Random matching algorithm	"F-Y" algorithm $(w_A = 1, w_B = 0)$	multi-scenarios dynamic matching algorithm (without stability constraints)	multi-scenarios dynamic matching algorithm (with stability constraints)
Matching	(A_1^1, B_1); (A_1^2, B_7); (A_2^1, B_5); (A_2^2, B_3); (A_2^3, B_2); (A_3^1, B_6) (B_4, B_4)	(A_1^1, B_7); (A_1^2, B_2); (A_2^1, B_3); (A_2^2, B_1); (A_2^3, B_6); (A_3^1, B_5) (B_4, B_4)	(A_1^1, B_5); (A_1^2, B_7); (A_2^1, B_4); (A_2^2, B_1); (A_2^3, B_3); (A_3^1, B_6) (B_2, B_2)	(A_1^1, B_2); (A_1^2, B_7); (A_2^1, B_1); (A_2^2, B_3); (A_2^3, B_6); (A_3^1, B_5) (B_4, B_4)
Stable or not	No	Yes	No	Yes
Total satisfaction	14.1181	15.3063	15.9570	15.3063

Table 4

Comparison the results of matching algorithms in Scenario (b)

Algorithms / Results	Random matching algorithm	"F-Y" algorithm $(w_A = 1, w_B = 0)$	multi-scenarios dynamic matching algorithm (without stability constraints)	multi-scenarios dynamic matching algorithm (with stability constraints)
Matching	(A_1^1, B_6); (A_1^2, B_7); (A_2^1, B_1); (A_2^2, B_2); (A_2^3, B_3); (A_3^1, B_4) (B_5, B_5)	(A_1^1, B_7); (A_1^2, B_2); (A_2^1, B_1); (A_2^2, B_3); (A_2^3, B_6); (A_3^1, B_5) (B_4, B_4)	(A_1^1, B_7); (A_1^2, B_5); (A_2^1, B_4); (A_2^2, B_1); (A_2^3, B_3); (A_3^1, B_2); (B_6, B_6)	(A_1^1, B_2); (A_1^2, B_7); (A_2^1, B_3); (A_2^2, B_1); (A_2^3, B_6); (A_3^1, B_5); (B_4, B_4)
Stable or not	No	Yes	No	Yes
Total satisfaction	13.9122	13.9428	14.7242	13.9428

Table 5

Comparison the results of matching algorithms in Scenario (c)

Algorithms / Results	Random matching algorithm	"F-Y" algorithm ($w_A = 1, w_B = 0$)	multi-scenarios dynamic matching algorithm (without stability constraints)	multi-scenarios dynamic matching algorithm (with stability constraints)
Matching	(A_1^1, B_3); (A_1^2, B_2); (A_2^1, B_1); (A_2^2, B_6); (A_2^3, B_5); (A_3^1, B_4) (B_7, B_7)	(A_1^1, B_7); (A_1^2, B_3); (A_2^1, B_1); (A_2^2, B_2); (A_2^3, B_6); (A_3^1, B_5) (B_4, B_4)	(A_1^1, B_2); (A_1^2, B_7); (A_2^1, B_4); (A_2^2, B_1); (A_2^3, B_3); (A_3^1, B_6); (B_5, B_5)	(A_1^1, B_2); (A_1^2, B_7); (A_2^1, B_3); (A_2^2, B_1); (A_2^3, B_6); (A_3^1, B_5); (B_5, B_5)
Stable or not	No	No	Yes	Yes
Total satisfaction	20.2765	21.0559	22.3788	21.7900

Table 6

Comparison the results of matching algorithms in Scenario (d)

Algorithms / Results	Random matching algorithm	"F-Y" algorithm ($w_A = 1, w_B = 0$)	multi-scenarios dynamic matching algorithm (without stability constraints)	multi-scenarios dynamic matching algorithm (with stability constraints)
Matching	(A_1^1, B_5); (A_1^2, B_7); (A_2^1, B_1); (A_2^2, B_2); (A_2^3, B_3); (A_3^1, B_4) (B_6, B_6)	(A_1^1, B_7); (A_1^2, B_3); (A_2^1, B_1); (A_2^2, B_2); (A_2^3, B_6); (A_3^1, B_5) (B_4, B_4)	(A_1^1, B_5); (A_1^2, B_7); (A_2^1, B_4); (A_2^2, B_1); (A_2^3, B_3); (A_3^1, B_6); (B_2, B_2)	(A_1^1, B_2); (A_1^2, B_7); (A_2^1, B_3); (A_2^2, B_6); (A_2^3, B_1); (A_3^1, B_5); (B_4, B_4)
Stable or not	No	No	No	Yes
Total satisfaction	21.6092	21.0678	22.3386	21.8095

6.2 Discussions

In this section, we discuss the merits of the four algorithms firstly, and then discuss the possibility of applying multi-scenarios dynamic matching algorithm for regional medical resources matching management, and address some practical problems that may arise when implementing the results. The multi-scenarios dynamic matching algorithm is general and efficient, can be applied to a wide range of Hierarchical Treatment Systems. Comparison the results about total satisfaction and stability of matching algorithms are showed in Fig. 6 and Table 7.

Fig. 6. Comparison the results about total satisfaction

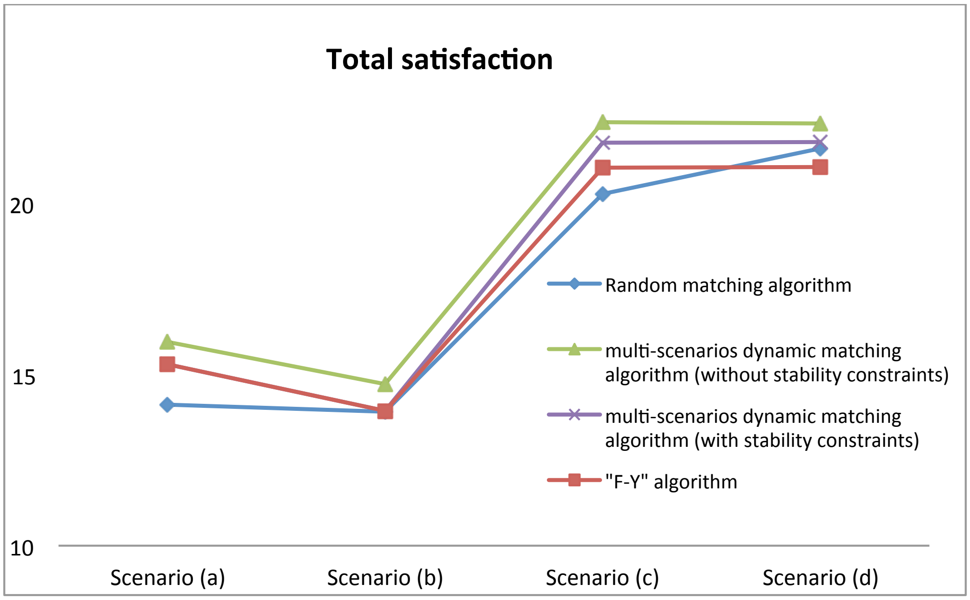


Table 7

Comparison the results about stability

Stable or not	Random matching algorithm	"F-Y" matching algorithm	multi-scenarios dynamic matching algorithm (without stability constraints)	multi-scenarios dynamic matching algorithm (with stability constraints)
Scenario (a)	No	Yes	No	Yes
Scenario (b)	No	Yes	No	Yes
Scenario (c)	No	No	Yes	Yes
Scenario (d)	No	No	No	Yes

To solve the problem of medical resource matching in Hierarchical Treatment Systems, the result of the random matching algorithm is the worst: total satisfaction is often the lowest (14.1181, 13.9122, 20.2765, and 21.6092), and there exists μ- hinder matching pair leading to unstable matching. Therefore, the solution to this problem must be optimized by scientific management methods, and this is why this problem is worth researching.

Scenario (A) and (b) all are easy scenarios, and the results of "F-Y" matching algorithm are the same as our algorithm in these two scenarios. However, in complex scenarios (c) and (d), linear weighting is used to transform the multi-objective problem into a single objective scheme in "F-Y" matching algorithm. The result is that it will be unsolvable if add a stable constraint, on the other way, there will exist μ-Hinder matching pair when it removes the stability constraint.

Multi-scenarios dynamic matching algorithm for hierarchical treatment system presented in this article is a possible idea of innovation. It takes the power-balance into consider between superior hospitals and subordinate hospitals in different scenarios, get a dynamic balance results, more in line with the reality, is feasible. In addition, this algorithm is analyzed from two situations: without stability constraints and with stability constraints. In all four scenarios, the results show that the total matching satisfaction value is higher when there without stability constraints. These results also prove that the stability constraint will sacrifice the unilateral satisfaction of some subjects. Stability is the result of multiple compromises.

The feasibility of different scenarios and dynamic balance resulting are the major practical considerations. In fact, to implement the results of our approach, we are required to determine the relative strength between superior hospitals and subordinate hospitals. This concerns the government regulation, hospital quantity in two types, benefits distribution and other factors in practice. In addition, the strict orders of each other are also necessary, and these can be obtained by a questionnaire survey. Hence, only is required to sort the preference data as the input, and use our algorithm to develop heuristic optimization program, hospitals can get a stable and optimal matching program. If a reasonable solution cannot be finding, then need to re-investigate the preference sequence data.

The actual problems that may emerge at this stage include changes in referral methods, dynamic changes of admission capacity in superior hospitals and subordinate hospitals, and other uncertainties. Each of these has to be determined according to local conditions. However, experience has shown that flexibility is usually present when the benefits of change are emphasized.

We note that our algorithm does not consider uncertainty and contingencies that is, uncertainty about acceptable capacity and other elements in the model. In addition, we set the admission number of superior hospitals based on projected load, rather than adaptively responding to the observed load.

7. CONCLUSIONS

This paper showed a Multi-scenarios dynamic matching algorithm for hierarchical treatment system by modifying comprehensive satisfaction integration function and differential adjustment function. We concentrated on the stability and total satisfaction goals of system matching.

The proposed multi-scenarios dynamic matching algorithm is suitable for referral matching in different situations. Based on the unilateral satisfaction, comprehensive satisfaction of both sides, and stability constraints, the 1-n matching model of multi-scenarios is constructed, and the matching scheme will be obtained after the model is solved. Compare with the random matching algorithm and "F-Y" matching algorithm (improved GS algorithm), this method is intuitive and adaptable, and can be used in Multi-scenarios, the total comprehensive satisfaction is scientifically, it is worth mentioning that the stability of multi-scenarios dynamic matching algorithm (with stability constraints) is the best one. The simulation results show that the algorithm proposed in this paper is more practical.

This method serves as a decision-making reference for the bilateral matching encountered in the problem of "hierarchical treatment system" around the world. However, most of the participants in a hierarchical treatment system are limited rational and incomplete information owner, their decision is not entirely rational but has a certain degree of randomness. In addition, the uncertainty of the system environment and individual capacity is also challenging the management mechanism. These are important directions for future research.

AUTHOR STATEMENTS

Ethical approval
Not required.

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COMPETING INTERESTS
None declared.

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8. REFERENCES

[1] National Health and Family Planning Commission of the People 's Republic of China.. Hierarchical treatment system is the only way to fine medical services [EB/OL]. 14 Sep 2015.< http://www.nhfpc.gov.cn/zhuzhan/zjd/201509/4a8c175a3d174b2c956b1163d33b8304.shtml>.

[2] Roth A E. Common and conflicting interests in two-sided matching markets [J] . European Economic Review, 1985, 27 (1): 75 - 96.

[3] Department of Health. Health Workforce Australia Annual Report, 2014, [EB/OL]. 19 May 2015 <http://www.health.gov.au/internet/main/publishing.nsf/Content/9A93834F675BE4F8CA257E4300236990/$File/HWA-Annual-Report-2013-14-2014-15.pdf>.

[4] Rochct, J.C., Tirole, J., 2008. Tying in two-sided markets and the honor all cards rule. International Journal of Industrial Organization, 26(3), 1333-1347.

[5] Helder, V., 2015. Is exclusionary pricing anticompetitive in two-sided markets? International Journal of Industrial Organization 40, 1-10.

[6] James, W. B., Vicki, K., 2014. What price stability? Social welfare in matching markets. Mathematical Social Sciences 67, 27-33.

[7] József, S., 2014. Price formation in a matching market with targeted offers. Games and Economic Behavior 87,161-177.

[8] Sülzle, K., 2009. Duopolistic competition between independent and collaborative B2B marketplaces. International Journal of Industrial Organization, 27(5), 615-624.

[9] Ewa, D.B., Zbigniew, S., 2013. A number of stable matching in models of the Gale–Shapley type. Discrete Applied Mathematics, 161(18), 2932-2936.

[10] Helmut, D., Markus, L., Lin, P., 2013. Advertising pricing models in media markets: Lump-sum versus per-consumer charges. Information Economics and Policy, 25(4), 257-271.

[11] Ewa, D.B., Zbigniew, S., 2013. A number of stable matching in models of the Gale–Shapley type. Discrete Applied Mathematics, 161(18), 2932-2936.

[12] Fleiner, T., Robert W. I., David F. M., 2011. An algorithm for a super-stable roommates problem. Theoretical Computer Science, 412(50), 7059-7065.

[13] Sarne D, Kraus S. Managing parallel inquiries in agents' two-sided search[J] .Artificial Intelligence,2008,172(4-5):541-569.

[14] Mcmermid, E., Irving, R.W., 2012. Sex-equal stable matching: complexity and exact algorithms. Algorithmica 3, 1-26.

[15] Gale, D., Shapley, L.S., 1962. College admissions and the stability of marriage, American Mathematical Monthly, (69) 9–15.

[16] Tilman, K., 2009. Two-sided matching with spatially differentiated agents. Journal of Mathematical Economics, 20(5-6), 376-390.

[17] Roth A E. The college admissions problem is not equivalent to the marriage problem [J] . Journal of economic theory, 1985,36(2): 277-288.

[18] Coles, P., Shorrer, R., 2014. Optimal truncation in matching markets. Games and Economic Behavior 87, 591-615.

[19] Archishman, C., Alessandro, C., 2010. Two-sided matching with interdependent values. Journal of Economic Theory, 145(1), 85-105.

[20] Navid Izady, Dave Worthington., 2011. Setting staffing requirements for time dependent queueing networks: The case of accident and emergency departments. European Journal of Operational Research.219 (11) ,531-540.

[21] Fletcher, A., Halsall, D., Huxham, S., Worthington, D., 2006. The DH accident and emergency department model: A national generic model used locally. Journal of the Operational Research Society 58 (12), 1554–1562.

[22] Munro, J., Mason, S., Nicholl, J., 2006. Effectiveness of measures to reduce emergency department waiting times: A natural

experiment. Emergency Medicine Journal 23 (1), 35–39.
[23] Sinreich, David., Jabali, Ola., 2007. Staggered work shifts: A way to downsize and restructure an emergency department workforce yet maintain current operational performance. Health Care Management Science 10 (3), 293–308.
[24] Ingolfsson, Armann, Campello, Fernanda, Wu, Xudong, Cabral, Edgar, 2010. Combining integer programming and the randomization method to schedule employees. European Journal of Operational Research 202 (1), 153-163.
[25] Feldman, Zohar., Mandelbaum, Avishai., Massey, William A., Whitt, Ward, 2008. Staffing of time-varying queues to achieve time-stable performance. Management Science 54 (2), 324–338.