Two-way Referral Research Based on Simulation Optimization with Both Patient and Medical Resource Transfer Considered

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Abstract. Due to the unreasonable allocation of medical and health resources in urban and rural areas, many high-quality medical resources are concentrated in cities, resulting in the widespread overcrowding of large city hospitals and inadequate utilization of resources at the primary hospitals. In order to solve this problem, a sound two-way referral mechanism has been built. However, only transferring patients between medical services does not fundamentally solve the problem, there are still a large number of patients with normal disease go to the city hospitals to get their first treatment. Therefore, by using the quantitative method, this paper mainly focuses on how to stimulate the city hospital to transfer resources into primary hospitals thus patients would like to get first treatment in the primary hospital, and at the same time to promote the primary hospitals to transfer patients with serious disease to city hospital for treatment on time. This paper models and analyzes the cooperation between hospitals, explores the profit of the hospital under different combinations of referral strategies, and uses Arena to simulate the treatment process in hospitals. Finally we use the method of simulation optimization and try to find out the best referral decisions that could minimize patient's waiting time and maximize the profit of hospitals.

Introduction

“Letting the primary hospitals deal with small illnesses, and city hospitals deal with serious illnesses, then still letting the primary hospitals deal with rehabilitation” is the main direction of China’s health care reform[1]. For a long time, the allocation of medical and health resources in urban and rural areas in China has been irrational. The high-quality medical resources have been concentrated in cities, resulting in widespread overcrowding in city hospitals, and the average medical treatment of primary hospitals is only ten people per day[2]. In city hospitals, over 94% of common and frequently-occurring diseases can be resolved in primary hospitals[3]. Also a large number of patients with common disease entering city hospitals not only result in wasted medical resources, but also increase waiting time for treatment[4].

In order to effectively transferring the patients with common disease from city hospitals to primary hospitals, and efficiently using medical resources in primary hospitals, The Opinions on Deepening the Reform of the Medical and Health System was issued by the Central Committee of the Communist Party in 2009. The Option encourages cooperation between city hospitals and primary hospitals. Through reallocation and reorganization of medical resources, especially to transfer the high-quality medical resources into primary hospitals, so that the treatment capacity of primary hospitals can be strengthen and more patients with common disease are willing to get their first treatment in primary hospitals[5]. When receiving patients with serious disease, the primary health care institution will decide whether to transfer those patients to the city hospital after considering the trade-off between the benefits obtained from treating patients and the cost generating from misdiagnose. Based on the two-way referral decision made by city hospitals and primary hospitals, this paper studies the best referral rate hospitals could choose to maximize their own returns while using their resources in the most efficient ways.

Since a relatively perfect hierarchical diagnosis and treatment system has been built in foreign countries, many foreign researches use queuing theory to model and analyze the optimal capacity of
medical resources\textsuperscript{[6-7]}. Some are studying the referral number of patients between hospitals with the goal of maximizing hospital revenue and minimizing patient waiting time\textsuperscript{[8]}. There are also some scholars in China have started to study the hierarchical diagnosis and treatment system by considering one-way referral\textsuperscript{[9]} and two-way referral of patients between hospitals\textsuperscript{[10]}. However, most of the literature focuses on how hospitals referral patients, ignoring the fact that patients are free to choose the hospital to get first treatment, and people’s willingness of choosing hospital can be changed when hospitals reallocate their medical resources. Therefore, considering the actual situation, we study the influence of patients’ choice by reallocating medical resources and referral patients between hospitals. Our goal is to optimize the total profit of both hospitals by using the queuing theory, while setting the referral rates between hospitals as decision variables. Finally, the simulation optimization method was used to find the optimal referral decision between hospitals and to provide theoretical support of the two-way referral decisions for hospitals.

Mathematical Modeling

Our paper mainly focuses on the Pediatric department in a two-tiered medical consortium consisted of a city hospital and a primary hospital. The city hospital with specialists is designated as HH (High-Level Hospital); the primary hospital with general practitioners is designated as LH (Low-Level Hospital). All patients can freely choose either hospital for their first treatment. The city hospital have the ability to cure all patients, while the primary hospital can only cure patients with common disease because of limited medical resources, if the primary hospital choose to treat patients with serious disease then there is a high possibility of misdiagnosis. Patients who are misdiagnosed will be transferred to the city hospitals for follow-up treatment.

LH’s treatment ability can be strengthened by receiving the specialists from HH, thus many patients with common disease will choose LH for first treatment, reducing the waiting time in the HH. However the cooperation between hospitals is still not going well. On the one hand, it is unclear whether the referral strategy can increase both hospitals’ profits, HH is often unwilling to transfer specialists to LH, because the decrease in the number of doctors available in the HH may increase the waiting time for patients in HH. On the other hand, more patients entering the LH for their first treatment can increase the profit of LH, but at the same time patients’ waiting time in LH will increase. Thus HH will decide the proportion of specialists to be transferred, at the mean time after comprehensively considering tread-off between the benefits of curing patients and the costs of misdiagnosis, LH will decide the proportion of referral patients with serious illness to HH. Our goal is to maximize hospitals profits respectively.

We conduct a model to analysis of the decision of two-way referral between HH and LH. Suppose a simulation period is T, the arrival rate of patients is $\lambda$, and this arrival rate follows a Poisson distribution\textsuperscript{[9]}. The number of the patient with common disease is $\alpha\lambda$ and the patient with serious disease is $(1-\alpha)\lambda$ $(0<\alpha<1)$. In the two hospitals, the patients formed an M/M/1 queuing system respectively. The service time follows the exponential distribution, and the service rule is first come first service (FCFS). The patient does not know his or her own condition of illness, but the hospital can determine the condition of the patient after diagnose. Suppose that there are two types of patients, and $\beta_i\lambda$ represents the number of patients enter the primary hospital, while $(1-\beta_i)\lambda$ represents the number of patients enter the city hospital ($i$ represents the patient type, $i=1$ means the patient with common disease, $i=2$ means the patient with serious disease). Assuming that the number of resources in HH and LH (which can be understood as the number of doctors) is $n_1$ and $n_2$ respectively, the ratio of referral resources is $x$. Initially due to the lack of trust in the treatment capacity of primary hospitals, only a small number of both types of patients entered the primary hospital for their first treatment. With more doctors are transferred into primary hospitals, more patient are willing to get their first treatment in the primary hospital. The primary hospital decides whether to transfer the patient with serious illness after diagnosis. If the decision is to transfer, then the transfer rate is $y$; if the treatment is determined, the rate of misdiagnosed is $g$, and the rate of misdiagnosis will decrease as the ratio of referral resources increase.

The revenue of city hospital ($R_S$) can be represented as Eq. 1, and the $P_{i2}$ represents the fees
charges from two types of patients, $C_{i2}$ is the cost of patient waiting for getting treatment, $W_{i2}$ is the waiting time in the city hospital, $C_{r2}$ is the wage of doctors in city hospital.

$$\text{Max } R_S = T\lambda(1-\beta_1)P_{12} + T\lambda(1-\alpha)(1-\beta_2)P_{22} + T\lambda(1-\alpha)\beta_2yP_{22} + T\lambda(1-\alpha)\beta_2(1-y)gP_{22} - C_{i2}W_{i2}$$
$$T\lambda(1-\beta_1) - C_{r2}W_{i2} T\lambda(1-\alpha)(1-\beta_2) - C_{r2}W_{i2} T\lambda(1-\alpha)\beta_2[y + g(1-y)] - C_{r2} W_{i2} - C_{r2}W_{r2}$$

The revenue of primary hospitals ($R_B$) can be represented as Eq. 2, and $P_{i1}$ represents the fees charges from two types of patients, $C_{i1}$ is the cost of patient waiting for getting treatment, $W_{i1}$ is the waiting time in the primary hospital, $C_{r1}$ is the wage of doctors in primary hospitals, $C_a$ is the subsidy giving to the doctors transferred from city hospital, $C_g$ is misdiagnose cost.

$$\text{Max } R_B = T\lambda\beta_1P_{11} + T\lambda(1-\alpha)\beta_2P_{21} - C_{i1}W_{i1} T\lambda\beta_1 - C_{i1}W_{i1} T\lambda(1-\alpha)\beta_2 - C_g T\lambda(1-\alpha\beta_2)(1-y) - C_{r1}n_1 - (C_{r2} + C_a)xn_2$$

**Simulation Modeling**

Because the model involves changes in the amount of resources in medical institutions, it is not easy to be deduced through using the traditional queuing theory model. Therefore, we use Arena software to establish a simulation model for further research. Arena is a simulation software developed by Rockwell Software Corporation of the United States. It can be used to intuitively simulate actual processes and is able to do simple model verification. Through using Arena simulation technology, we can simulate the process of treatment in the hospitals (see Figure 1).

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**Figure 1. Process of patient treatment.**

As for the data inputting into Arena software, the number of daily arrivals and the number of doctors in hospitals the actual survey data obtained from a pediatrics department and a subordinate primary hospitals in a city hospital. The treatment costs and fees are estimated data based on actual conditions. The module definition and data settings are as follows: First a Create module is defined to simulate the arrival of the patient. According to the actual patient arrivals observed in a hospital, assume that there are 300 patients per day and the arrival follows Poisson distribution; Then a Decision module is defined, dividing the patient into two types according to their conditions, 20% of them are patients with serious disease, and the remaining 80% are patients with normal disease; Next two Decision modules are describes the choices of patients for hospitals. When the city hospital decides not to transfer the doctors into primary hospitals, the ratios of with common disease and those with serious disease go to primary hospitals for their first treatment were $\beta_1 = 0.1, \beta_2 = 0.05$; With more doctors are transferring to primary hospitals, more patients are entered the primary hospital for their first treatment. At this time, the ratio of the two types of patients entering the primary hospital was $\beta_1 = 1.8x + 0.1, \beta_2 = 0.5x + 0.05$.

When the patient chooses the city hospital for first treatment, a Process module is defined to simulate the patient's treatment process; when treatment is completed, patients will be released through the Depose module. When the patient chooses the primary hospital for first treatment, a
Decision module is defined, in this model primary hospitals will decide whether to transfer patients with serious disease to the city hospital; next a Process module is defined to simulate the process of patients receiving treatment in primary hospitals; and because there are certain misdiagnosis rates when primary hospitals treating patients with serious disease, a Decision module is defined to describe the process. When there are no doctors been transferring to primary hospitals, the misdiagnoses rate is $g = 0.7$. With more doctors been transferring into primary hospitals, the rate of misdiagnosis in primary hospitals gradually decreases $g = -x + 0.7$. The treatment time of patients in all levels of medical institutions obeys the exponential distribution.

According to observations, the number of specialists in the city hospital is $n_2 = 8$ (people/per day), and the number of general practitioners in the primary hospital is $n_1 = 5$ (people/per day). Assuming that $C_{i2}$ is daily doctor's salary in city hospital, $C_{i1}$ is daily doctor's salary in primary hospitals, $C_{i2} = 700$ (yuan/per person), $C_{i1} = 200$ (yuan/per person). The subsidy given to the transferred doctors by community hospitil is $C_a$, $C_a = 100$ (yuan/per person). The gains from two types of patients in the city hospital are $P_{12} = 500$ (yuan/per person), $P_{22} = 5000$ (yuan/per person); The gains from two types of patients in the primary hospital are $P_{11} = 300$ (yuan/per person), $P_{21} = 300$ (yuan/per person). The waiting costs of two types of patients in the city hospital are $C_{12} = 30$ (yuan/per minut), $C_{22} = 90$ (yuan/per minut); The waiting costs of two types of patients in the primary hospital are $C_{11} = 2$ (yuan/per minut), $C_{21} = 15$ (yuan/per minut). The misdiagnose cost in the primary hospital is $C_g = 2000$ (yuan/per person).

Simulation Experiments and Analysis

According to the simulation model we built, the OptQuest tool was used to find the optimal referral decision between hospitals. OptQuest is a tool that developed by U.S. Technology Systems Corporation in 1992. And OptQuest is used to find the optimal solution for complex systems and to display possible solutions in an intuitive manner.

Two different scenarios are considered in our model. In the first scenario, we set the benchmark while both hospitals don’t make referral decisions. Then in the second scenario, the objective function is to maximize the sum of both hospitals’ profit, under this scenario we use the simulation optimization method to find out the best decision-making combination of the two hospitals.

In scenario 1, both hospitals don’t make referral decisions. So the resources transfer rate $x = 0$, and the patients with serious disease transfer rate $y = 0$.

<table>
<thead>
<tr>
<th></th>
<th>profits in city hospital ($R_S$)</th>
<th>profits in primary hospitals ($R_B$)</th>
<th>Total Revenue</th>
<th>Total Waiting Cost</th>
<th>Total Resource Usage Cost</th>
<th>Mistreatment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HH</strong></td>
<td>298,898.63</td>
<td>404,470.00</td>
<td>603,368.63</td>
<td>99,971.37</td>
<td>5,600.00</td>
<td>5,600.00</td>
</tr>
<tr>
<td><strong>LH</strong></td>
<td>10,863.64</td>
<td>15,904.50</td>
<td>26,768.14</td>
<td>0.8595</td>
<td>1,000.00</td>
<td>4,040.00</td>
</tr>
</tbody>
</table>

In the Scenario 1, the two hospitals did not referral doctors or patients. At this time, the total profit of the two hospitals was $309,762.27$ yuan which is combined by the profit of HH and the profit of LH. Since 90% of patients with normal disease and 95% of patients with serious disease choose the city hospital for first treatment, therefore, the waiting time in the city hospital is long and the waiting cost is high. At the same time, since only a small percentage of patients choose the primary hospital first treatment, waiting time in primary hospitals is shorter and the waiting time is lower. Because the city hospital did not transfer specialists to the primary hospital, the misdiagnosis rate at the primary hospital was 70%, the primary hospital assumed higher misdiagnosis costs.

Based on Scenario 1, we use the OptQuest tool to find out the best combination of referral decisions between hospitals, figure 2 shows the results.
In scenario 2, the objective function is to maximize the sum of both hospitals’ profits. So the resources transfer rate $x = 0.2$, and the patients with serious disease transfer rate $y = 0.72$.

Table 2. Results in scenario 2.

<table>
<thead>
<tr>
<th></th>
<th>Profits in city hospital ($R_S$)</th>
<th>Profits in primary hospitals ($R_B$)</th>
<th>Total Revenue</th>
<th>Total Waiting Cost</th>
<th>Total Resource Usage Cost</th>
<th>Mistreatment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH</td>
<td>341,619.39</td>
<td>14,715.11</td>
<td>361,927.50</td>
<td>5,593.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LH</td>
<td>34,175.21</td>
<td>1,454.79</td>
<td>35,629.98</td>
<td>1,008.00</td>
<td>1,780.00</td>
<td></td>
</tr>
</tbody>
</table>

In the Scenario 2, the city hospital transfer 20% of doctors to the primary hospital and the community referral 72% patients to the city hospital. At this time, the total profit of the two hospitals was 375,794.60 yuan, the profit of both hospital is going up. With more doctors go to primary hospitals, more patients are willing to go to primary hospitals for their first treatment, so community can get more revenue from successfully treating more patients. At the same time, there are less number of patients go to the city hospital, so the waiting time in city hospital is shorter and the waiting cost is less compare with scenario 1. Also the treatment capacity of primary hospitals has been improved, so the misdiagnosis rate has also declined, and the cost of misdiagnosis cost undertaken by primary hospitals has also been reduced.

Conclusion and Discussion

In conclusion, in the short term s, transferring the high-quality medical resources in city hospital to primary hospitals can strengthen the patients’ confidence of primary hospitals, guiding more patients with normal disease into the primary hospital for their first treatment. In the long run, the treatment capacity of primary hospitals can be strengthened, and the pattern of “Letting the primary hospital deal with small illnesses, and city hospitals deal with serious illnesses, then still letting the primary hospital deal with rehabilitation” will be built.

In the further study, we are going to take the patient’s priorities into consideration, in reality there exists a “green channel” for patients between hospitals, which means that the city hospital will first treat patients who are referred from primary hospitals. Thus we are going to study the impact of
priority on patients’ choice of hospitals to do get treatment and the waiting time for patients in different hospitals. Although the profits of the two hospitals have risen, the increase in the city hospitals is smaller than that of the primary hospital, so we will study how to reallocate profits between hospitals, making them more inclined to cooperate. Also in order to stimulate the hospitals to establish a long-term and stable two-way transition cooperation relationship, how should the government compensate the hospitals is another question we are going to study on.

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Reference