Optimization of Beds Allocation Based on Queuing Model and the Particle Swarm Optimization Algorithm

Yumei Hou[1], Hui Zeng[1], Yimin Wang[2] , Xueqin Wang[1] and Qiuye Gao[2]

Abstract—Hospital bed is a critical resource. So it is very important for the beds allocation among the different departments. Based on queuing theory, the model of beds allocation among the departments is constructed, which has two constraints are the patient loss rate and the bed utilization rate. Then the particle swarm optimization algorithm with inertia weight is designed for the model of beds allocation among the departments. Accordingly M hospital's beds allocation among the departments is derived by the beds allocation optimization scheme and the particle swarm optimization algorithm. In the end the optimal beds allocation is compared with the current beds allocation planning which shows that the proposed scheme is able to allocate resources reasonably so that it can reduce the number of patients lost and optimize the operating costs of the departments.

Keywords—optimization of beds allocation, queuing theory, particle swarm optimization algorithm, patient loss rate, bed utilization rate.

I. INTRODUCTION

In recent years with the intensification of China's aging population and the opening of two-child policy the number of patients has been increasing dramatically, which makes the bed resources even more scarcer than before in China. Hence it is very important to make effective use of existing bed resources. Based on queuing theory and particle swarm optimization algorithm (PSO) the model of the allocation of bed resources among the hospital departments are built and designed, aiming at providing a solution for hospital managers to arrange the beds scientifically and systematically.

The related research are reviewed as follow. Gorunescu et al.[1] used the M/PH/c/c loss queuing system to give the optimal bed capacity under the condition that the delay probability was lower than the predetermined value. Following [1], Gorunescu et al.[2] considered M/PH/c/N queuing system with a waiting space to analyze the effect of introducing spare beds in the special period. Li et al.[3] set up a decision-making model based on queuing theory. They also build a goal planning to optimize inter-departmental bed resources with the aim of minimizing operating cost to address the problems of potential patient loss and bed waste. Belciug and Gorunescu [4] introduced a genetic algorithm to determine the optimal bed capacity in geriatrics department by minimizing the cost. However, it is based on the unconstrained optimization model which merely considering the detrimental effect of the cost on public welfare of hospitals in china, while the hospital is in urgent need of improving the loss of patients, thus scarce bed resources are expected to be used reasonably. So this paper considers the reasonable range of the patient loss and the bed utilization, and aims at minimizing the total operating cost of the hospital, therefore the nonlinear and constrained allocation optimization model of bed resources is established by using the queuing theory, and the optimal solution of the model is proposed.

Wang et al.[5] studied the problem of hospital resource scheduling under constraints. Particle Swarm Optimization (PSO) shows a good superiority of solving nonlinear constrained optimization problems. It was proposed by Kennedy and Eberhart in 1995, which originated from the study of bird predation. Because of its simple principle, few

This work was supported by Science and technology research and development of Hebei province (Code No. 15456129), and the humanities and social sciences research project of Hebei University of higher education (Code No. SD 181050).

Yumei Hou is with the School of Economics and Management, Yanshan University, Qinhuangdao, Hebei Province 066004, China.

Hui Zeng is with the School of Economics and Management, Yanshan University, Qinhuangdao, Hebei Province 066004, China.

Yimin Wang is with the First Hospital of Qinhuangdao, Qinhuangdao, Hebei Province 066004, China.

Xueqin Wang is with the School of Economics and Management, Yanshan University, Qinhuangdao, Hebei Province 066004, China.

Qiuye Gao is with the First Hospital of Qinhuangdao, Qinhuangdao, Hebei Province 066004, China (Corresponding author; e-mail: drenzengyao@yeah.net).

parameters, implementation simplicity and so on, it is developed rapidly in a short time, and it is favored by many scholars in solving complex optimization problems. Gong et al. [6] developed a particle swarm optimization model for solving nonlinear goal planning and presented an allocation scheme of bed resources among different departments. At present, there are few researches on solving the problem of bed resource allocation by particle swarm optimization algorithm, and the cost index is not considered, thus it cannot solve the problem of the hospital bed resource allocation optimization in China.

Compared with the related study abroad, research into domestic bed resource are still under development, which is mainly about qualitative analysis, and relatively lacks quantitative research. At present, the linear programming model or queuing model, which mainly takes ophthalmology as an example, is established to optimize the current bed system[7-8]. Xu Lei et al.[9] establish bed assignment scheduling model taking the patients' waiting and transfer costs into consideration of by using mixed integer programming. Zhu Huabo et al.[10] constructed a non-waiting series queuing model with the minimum system blocking rate as the goal to optimize bed resources by employing neighborhood search and simulated annealing algorithm.

In summary, most existing researches addressed the bed resource optimization problem of a single department. There are few researches on the allocation optimization of hospital bed resources with the constraints for the purpose of factors in the total operating cost of all the departments in the hospital.

The patient's loss is the condition that the patient arrives at the department and finds that all the beds are occupied. This may aggravate the patient's condition, threaten the health of patients, and have a negative impact on the hospital. Taking account of sth / take sth into account the public welfare of our hospital, the allocation of hospital resources among the departments should consider not only the operating cost, but also the bed utilization rate and the patient loss rate. Therefore, the optimal allocation model of bed resources among the departments is established, by taking the operating cost as the objective function with two constraints-the patient loss rate and the bed utilization rate. The particle swarm optimization algorithm is employed to solve the problem.

II. BED SERVICE QUEUING SYSTEM AND ITS STEADY STATE INDEX

The queuing system of hospital beds is a complex and dynamic random queuing system. The customers who come to the hospital to receive the inpatient service are called patients, and the beds of the departments in the hospital are servers. They are composed of a random service queuing system, and it also called the bed service queuing system.

A. Bed Service Queuing System Description

It is a quite complex problem of bed allocation among the hospital departments. And we hope to apply a simple model to solve the problem. The system is described as follows.

In the bed service queuing system, the patients arriving in the department are endless, thus it can be considered that the patient sources are infinite. The interval time in which the patients arrive at the department i is mutual independence, which is negative exponential distribution with the parameter λ_i. The department i have x_i beds. When a patient arrives at the department i, if there is a free bed, the patient will be admitted to accept the service. If the patient arrives at the hospital found that x_i beds are occupied, they will leave the hospital. All of beds in the departments are homogeneous and serve the patients independently. The patient's condition is divided into different levels according to its severity, and the length of stay at each severity level is exponential distribution with the parameter α_j ($j=1,2\cdots,l$). The probability density function is given by $f_j(t)=\alpha_j e^{-\alpha_j t}$. So, the hospitalization time of each patient is an Erlang distribution with total of l levels. This is a special form of phase-type distribution. The probability density function of the distribution is

$$f(t)=\sum_{j=1}^{l}\alpha_j\rho_j e^{-\alpha_j t} \tag{1}$$

where ρ_j is the probability that the patient is at the j serious level, and $\sum_{j=1}^{l}\rho_j=1$. The average length of stay in the department i is $\tau_i=\sum_{j=1}^{l}\rho_j/\alpha_j$. So, the hospital bed service system of the department i can be established as the $M/PH/x_i/x_i$ loss queuing system, which patient arrivals follow a poisson process and the hospitalization time is phase-type. We ignore the process of solving the queue indexes. The relevant indexes are referenced as follows.

(a) Average number of patients arriving at the department i during the average length of stay is $a_i=\lambda_i\tau_i$. The probability that c $(c=1,\cdots,x_i)$ beds are occupied in the department i is

$$p_c=\frac{a^c/c!}{\sum_{n=0}^{c}a^n/n!} \tag{2}$$

when $c=x_i$, p_{x_i} is the probability that the x_i beds are occupied, i.e. the Erlang loss formula.

(b) According to the Erlang loss formula, the probability R_i of all beds (x_i) being occupied in the department i is

$$R_i = \frac{a_i^{x_i} / x_i!}{\sum_{n=0}^{x_i} \left(a_i^n / n! \right)} \tag{3}$$

Accordingly, R_i is defined as the patient loss rate in the unit time.

(c) In order to measure the degree of bed utilization, we define that the bed utilization rate in the department i is

$$\rho_i = \frac{a_i \left[1 - R_i \right]}{x_i} \tag{4}$$

In order to make the system in a stable state, the bed utilization should be met $\rho_i < 1$.

The operation status of the bed service queuing system can be described by applying the above-mentioned performance indexes, and it can achieve the optimal operation state through the control of the system.

B. Features of Grain Model of Beds Allocation

The purpose of optimizing the hospital bed allocation among the departments is to minimize the average cost of the departments under the premise that the patients have access to bed resources. In this paper, the basic inventory theory is used to determine the cost function of the bed service queuing system in the department i. If a patient arrived in the department i finds that all beds are occupied, he cannot be admitted to hospital to make the patient lost in the department i, this creates the penalty cost p_i that is the loss of income due to the loss of the patient. If there are idle beds in the department i, this creates the holding cost h that is the cost of per idle bed per unit time. According to the above definition, the patients lost in the department i in the unit time are $\lambda_i R_i$. The penalty cost of the department i is $p_i \lambda_i R_i$. The average hospitalized patients of the department i is $\lambda_i \tau_i (1 - R_i)$. The holding cost of the department i is $h\left[x_i - \lambda_i \tau_i \left(1 - R_i \right) \right]$, the average cost function of the department i is the sum of the above two parts as shown below. The focus of this study is to find out the optimal cost of hospital beds to balance the holding cost and the penalty cost.

$$\pi(x_i) = p_i \lambda_i R_i + h\left[x_i - \lambda_i \tau_i \left(1 - R_i \right) \right] \tag{5}$$

where $i = 1, 2, \cdots, N$, $x_i \in \mathbb{Z}$ ($\mathbb{Z}$ is a set of integers). The total operating cost of the departments is

$$\pi(x_1, x_2, \cdots, x_N) = \sum_{i=1}^{N} \pi(x_i) \tag{6}$$

This paper is based on the threshold of patient loss rate and bed utilization rate mentioned by Belciug and Gorunescu (2015), and it makes appropriate adjustments according to the actual situation of our hospital. The patient loss rate is considered from the perspective of patient satisfaction, and bed utilization rate is taken from the perspective of hospital. According to the standard of Tertiary General Hospitals, the bed utilization rate is not the higher the better. In order to reduce the number of patients lost, the department i should control the patient loss rate within 20%, and bed utilization rate between 85% and 95%. Accordingly, the bed resource allocation optimization model should make the total operating cost of the departments the lowest by ensuring the patient loss rate and the bed utilization rate in a reasonable range. This is a nonlinear constrained optimization problem. Hence the bed resource allocation optimization model short as BRAOM is described as

$$\begin{aligned} \min \quad & \pi(x_1, x_2, \cdots, x_N) = \sum_{i=1}^{N} \pi(x_i) \\ s.t. \quad & R_i \le 20\%, \\ & 85\% \le \rho_i \le 95\%, \\ & \sum_{i=1}^{N} x_i \le B, i \\ & x_i > 0 \left(i = 1, 2, \cdots, N \right) \text{ and integer for } i \end{aligned} \tag{7}$$

where x_i is the bed capacity in the department i; B is the total bed capacity threshold of N departments. The first formula (7) is the objective function, which means that the total operating cost is the lowest. The two constraints closed to the objective function represent the reasonable ranges of the patient loss rate and the bed utilization rate.

The BRAOM involved in this problem is a nonlinear target optimization, and it is very difficult to be solved by the general mathematical programming methods. So it is necessary to adopt intelligent algorithm. The PSO in the intelligent algorithm has the ability to quickly converge on the optimal solution. Therefore, more and more scholars have been attracted to solve the complex and high dimensional nonlinear optimization problem using it.

III. OPTIMIZATION OF BRAOM BY PSO

A. The Design of PSO for BRAOM

The bed capacity of each department is initialized to a group of particles. There are N departments in the hospital, and each particle is a N dimensional vector, which each component of the vector represents bed capacity of a department. The population is composed of m random particles, $X_i = \left(x_{i1}, x_{i2}, \cdots, x_{iN} \right)$ ($i = 1, 2, \cdots, m$) is the position vector of the i th particle in the N dimensional space. According to the fitness function of the BRAOM, the fitness value of X_i is calculated to measure the advantage and disadvantage of the position. $V_i = \left(v_{i1}, v_{i2}, \cdots, v_{iN} \right)$ is the velocity of the i th particle, which is the movement direction of the particle. The optimal location currently searched by the particle $(pbest)$ is $P_i = (p_{i1}, p_{i2}, \cdots, p_{iN})$. The optimal location currently searched by the entire particle group $(gbest)$ is $P_g = (p_{g1}, p_{g2}, \cdots, p_{gN})$. After finding the two optimal solutions, the update formula of particle velocity and position for the $t+1$ th iteration is as follows.

$$v_{id}(t+1) = wv_{id}(t) + c_1 r_1 (p_{id} - x_{id}(t)) + c_2 r_2 (p_{gd} - x_{id}(t)) \quad (8)$$

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \quad (9)$$

where $i = 1, 2, \cdots, m$, $d = 1, 2, \cdots, N$. Acceleration factors c_1 and c_2 are nonnegative constants, which make the particles have the ability to self-summarize and learn from the excellent individuals in the group. r_1 and r_2 are two random numbers in the range of $[-1,1]$, which are used to maintain the diversity of the population. w is the inertia weight, which is used to weigh the local optimal ability and global optimal ability. The two abilities are different due to the different number of iterations, and this paper use the inertia weight by Shi decreasing linearly with the number of iterations increased[11]. The formula is

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{T_{\max}} t \quad (10)$$

where $w_{\max}$ is the maximum inertia weight; $w_{\min}$ is the minimum inertia weight; $T_{\max}$ represents the maximum number of iterations; t is the current number of iterations. In most practical problems, $w_{\max}$ =0.9, $w_{\min}$ =0.4.

The second term of the formula (8) is the "cognitive" section, which represents the learning ability of the particle itself. The third term of (8) is the "social" section, which represents the collaboration among the particles. The particle updates the velocity according to the velocity of the last number of iterations, the distance between the current position and their best experience, and the distance between the current position and the group best experience. Then the particles fly to the new position according to (9). In this paper, the basic continuous PSO is used to solve the problem of bed resource allocation optimization. The structure of the algorithm is given by (8) and (9). The advantage and disadvantage of the particles are judged by the fitness function. The fitness function is obtained from the BRAOM. In order to get the fitness function, the constraint handling method of the BRAOM is considered.

B. Constraint Handling with PSO for BRAOM

The treatment of constraint conditions is the key to solve the problem of bed resource allocation optimization by PSO. There are some infeasible search areas in the constraint optimization problem. It is important to evaluate the infeasible particles in these areas. At present, the method solving the problem of constrained optimization by PSO combines the constraint function with the original objective function by the penalty function method to obtain the new objective function. Then the constrained optimization problem is transformed into unconstrained optimization problem. In this paper, the dynamic penalty function method is used to transform the objective function of the BRAOM into the following form.

$$F(x,t) = \pi(x) + \eta(t)p(x) \quad (11)$$

where $\eta(t)$ is the dynamic penalty factor (t is the current number of iterations) and is expressed as

$$\eta(t) = t\sqrt{t} \quad (12)$$

$p(x)$ is the penalty function, which indicates the degree of the particle x violating the constraint conditions. And the specific form of the dynamic penalty function is as follows:

$$p(x) = \sum_{k=1}^{3N+1} \varphi(v_k(x)) v_k(x)^{\gamma} \quad (13)$$

where $\varphi(v_k(x))$ is the multi-stage allocation function; γ is the penalty intensity; $v_k(x)$ is the function of the particle x in the population that violates the degree of the k th constraint. The formula is as follows.

$$v_k(x) = \begin{cases} \max\{0, R_k(x) - 0.2\}, & k = 1, \cdots, N \\ \max\{0, \rho_k(x) - 0.95\}, & k = N+1, N+2, \cdots, 2N \\ \max\{0, 0.85 - \rho_k(x)\}, & k = 2N+1, 2N+2, \cdots, 3N \\ \max\left\{0, \sum_{i=1}^{N} x_i - B\right\}, & k = 3N+1 \end{cases} \quad (14)$$

The sum of the degrees that the particle x violates all constraints of the BRAOM is called the violation function, and is expressed as

$$\begin{aligned} Vio(x) = &\sum_{k=1}^{N} [\max\{0, R_k(x) - 0.2\}] + \sum_{k=N+1}^{2N} [\max\{0, \rho_k(x) - 0.95\}] \\ &+ \sum_{k=2N+1}^{3N} \left[\max\{0, 0.85 - \rho_k(x)\}\right] + \max\left\{0, \sum_{i=1}^{N} x_i - B\right\} \end{aligned} \quad (15)$$

The fitness function of the BRAOM is expressed as follows.

$$Fit(x) = \pi(x) + t\sqrt{t}\, p(x) \quad (16)$$

Through several numerical experiments, the multi-stage allocation function $\varphi(v_k(x))$ and the penalty intensity γ are set as follows.

$$\varphi(v_k(x)) = \begin{cases} 0, & v_k(x) = 0 \\ 1, & 0 < v_k(x) < 0.001 \\ 2, & 0.001 \le v_k(x) \le 0.1 \\ 8, & 0.1 < v_k(x) < 1 \\ 24, & v_k(x) \ge 1 \end{cases} \tag{17}$$

$$\gamma = 1 \tag{18}$$

C. *PSO Algorithmic Design for BRAOM*

The framework of PSO with constraints is as follows.

(a) Initialization. All particles the scale *m* is set randomly to form the initial population, and its velocity and position are produced.

(b) The multi-stage allocation function $\varphi(v_k(x))$ and the penalty intensity γ are determined from formulas (17) and (18).

(c) According to the formulas (15) and (16), the constraint violation degree and the fitness value of each particle are calculated to determine the *pbest* position and the *gbest* position of each particle.

(d) The velocity and position of each particle are updated according to formulas (8) and (9) and are limited to a given range.

(e) The fitness value of each particle is recalculated. And the *pbest* position and the *gbest* position of each particle are updated.

(f) The number of iterations is incremented by 1. If the end condition is not reached, go to (b), otherwise the optimization is ended.

IV. THE OPTIMIATION OF HOSIPITAL BEDS ALLOCATION AND ANALYSIS

It is well known that hospitals are always lacking one bed. So hospital bed distribution is a very important problem. With the BRAOM and PSO algorithmic in hands combining the data of one hospital we will make the optimal distribution for the bed in any hospital for example M hospital. This section we will make optimal distribution for M hospital with our BRAOM and PSO algorithmic designed and the data collected from hospital.

Firstly we collected the statistical data of a synthesized hospital in 2017 and clear the data for our use. Totally there are 1560 beds and 42 departments in the hospital. According to the investment on the hospital manager, it is no needs to optimization the whole departments. By the knock-out system ten key departments in the hospital are selected. The reallocated rules are as follows: the department which the average bed utilization rate is less than 100%, or the average number of admissions is less than 70 is eliminated. The objective of this reallocation is to reduce the cost of hospital operation and the number of patients lost by redistributing the bed resources of the selected departments to meet the needs of the hospital. The cleared data are listed as Table 1.

Combining the data in Table 1 and the formula (5) the operating costs of the selected departments are obtained byand a part of the, as shown in Fig. 1. It shows that the operating cost of each department is a convex function of the bed capacity. Due to the independent operations of the various departments, only the lowest operating costs are achieved in the departments to minimize the total operating cost of the bed resources.

Table 1 The current bed capacity of the selected departments and the relevant indexes of queuing system

Department	x_i	λ_i	τ_i
CCU	14	3.76	6.76
Neurology	64	6.67	12.21
Hematology	27	2.39	13.41
Rheumatology	22	2.45	12.40
Gastroenterology	75	8.16	12.09
Respiratory	64	5.38	12.69
Hand and foot surgery	36	3.50	13.25
General surgery	88	8.60	12.86
Pediatrics	48	8.15	7.17
Oncology radiology	33	4.19	14.63

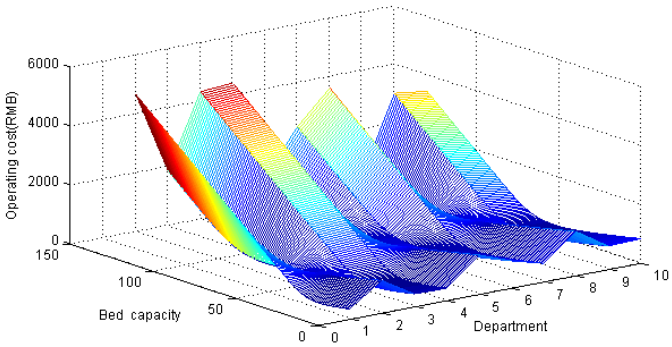

Fig. 1. The relationship between the bed capacity and the operating cost of each departmen

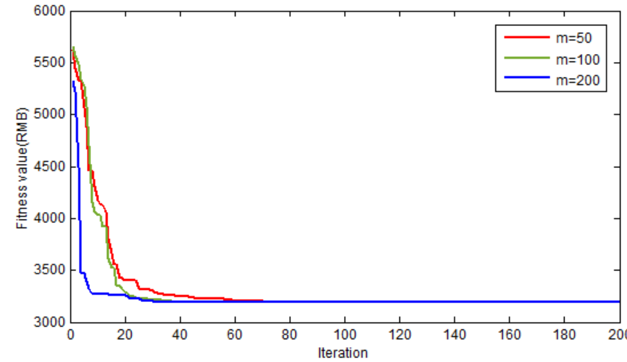

Fig. 2. Convergence curve of function fitness

On the basis of the above data and algorithm preparation, the numerical experiment of the BRAOM operated in Matlab R2014a environment. Acceleration factors $c_1 = c_2 = 1.49445$. The maximum number of iterations $T_{\max}$ is 200. The population size m is 50, 100 and 200 respectively. Under the same condition, the PSO program solving the constrained BRAOM is operated independently for 10 times to obtain the optimization results - best result (Best), average result (Mean) and worst result (Worst), as shown in Table 2. The convergence curve is shown in Fig. 2. In the best results, the bed capacities of the various departments corresponding to the different population sizes are shown in Table 3.

Table 2 Experimental results of the total operating cost optimization value

m	$T_{\max}$	Best(RMB)	Worst(RMB)	Mean(RMB)
50	200	3205.23	3209.53	3207.38
100	200	3203.97	3208.02	3206.00
200	200	3203.57	3207.38	3205.47

It can be seen in Table 2 that the ability of PSO searching the optimal value will be improved with the increase of population size.

It can be seen in Fig. 2 that the larger the population size is, the faster the convergence rate of the algorithm is. And the global optimal value is obtained preferentially in the iterative process. In other words, the search ability of the algorithm is stronger.

Table 3 Experimental results of bed allocation in the departments

m	$T_{\max}$	bed capacity										Bed (RMB)
		1	2	3	4	5	6	7	8	9	10	
50	200	24	72	29	28	89	60	41	102	50	53	3205.23
100	200	24	74	29	27	90	61	41	102	50	54	3203.97
200	200	24	72	29	28	88	59	41	101	50	53	3205.23

Note: 1 CCU; 2 Neurology; 3 Hematology; 4 Rheumatology; 5 Gastroenterology; 6 Respiratory; 7 Hand and foot surgery; 8 General surgery; 9 Pediatrics; 10 Oncology radiology

The results in Table 3 show that the algorithm will obtain a more satisfactory solution as the population size increases. The single bed capacity calculated by the full enumeration method is compared with the bed allocation scheme obtained by the PSO, and the results are consistent. Thus the particle swarm optimization algorithm can be used to find the best bed capacities of the various departments. In the best situation and the current situation, the comparison of the operating cost in each department is shown in Table 4, the comparison of the bed allocation relevant indexes in each department is shown in Table 5.

Table 4 Comparison of the operating cost between the best situation and the current situation in each department

Department	p_i (RMB)	Current situation		Best situation	
		x_i	π_i (RMB)	x_i^*	π_i^* (RMB)
CCU	90.91	14	212.83	24	214.51
Neurology	164.17	64	403.87	72	381.35
Hematology	180.19	27	225.58	29	233.70
Rheumatology	166.62	22	219.48	28	230.43
Gastroenterology	162.50	75	476.65	88	423.77
Respiratory	170.58	64	356.98	59	345.61
Hand and foot surgery	178.07	36	281.73	41	280.72
General surgery	172.89	88	491.70	101	451.64
Pediatrics	96.31	48	318.55	50	316.55
Oncology radiology	196.57	33	445.11	53	325.29
Total	1578.81	472	3432.49	545	3203.57

Table 4 gives the performance comparison of the operating cost in each department between the two situations. The penalty cost is related to the average length of stay in each department, and increases with the increase of the average length of stay. The hospital should be based on reducing the number of patients lost, therefore, the operating costs of some departments in the best situation increase slightly, which affected by the two constraints — the patient loss rate and bed utilization rate, such as: CCU and Hematology, etc. And the total bed capacity of the selected departments increase. But the total operating cost is far less than the current situation. In the two situations, the change of the operating cost in each department is shown in Fig. 3.

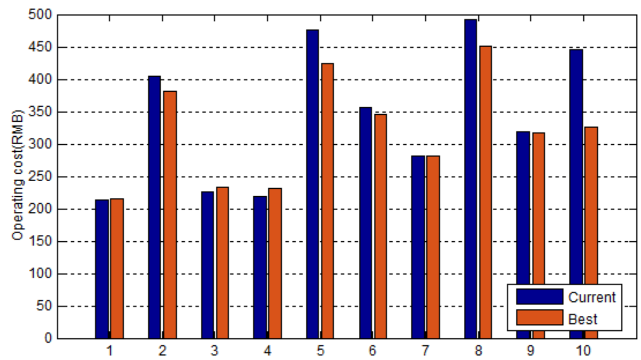

Fig. 3. Comparison of the operating cost between the two situations in each department

As shown in Fig. 3, the operating costs of general surgery, Gastroenterology, oncology radiology and Neurology are higher in the current situation., The operating costs of a few departments have a slight increase in the best situation, which affected by the two constraints - the patient loss rate and the bed utilization rate, but the operating costs decrease greatly in most of the departments. It shows that the optimal allocation scheme reduces the operating cost of the hospital under the condition of improving the patient loss rate and the bed utilization rate.

Table 5 Comparison of the bed allocation relevant indexes between the best situation and the current situation in each department

Department	Current situation			Best situation		
	x_i	R_i (%)	ρ_i (%)	x_i^*	R_i^* (%)	ρ_i^* (%)
CCU	14	48.59	93.29	24	17.67	87.15
Neurology	64	24.74	95.85	72	16.56	94.45
Hematology	27	23.41	90.75	29	18.88	89.48
Rheumatology	22	33.12	92.34	28	18.12	88.82

Gastroenterology	75	26.54	96.68	88	15.32	94.99
Respiratory	64	13.16	92.62	59	18.67	94.09
Hand and foot surgery	36	27.21	93.77	41	18.67	91.98
General surgery	88	23.15	96.65	101	13.32	94.98
Pediatrics	48	22.62	94.12	50	19.86	93.57
Oncology radiology	33	47.82	96.89	53	19.00	93.63

Table 5 shows the performance comparison of the patient loss rate and bed utilization rate in each department between the two situations. The best bed allocation scheme is the one that minimizes the total cost of the hospital under the condition of satisfying the two constraints - the patient loss rate and the bed utilization rate of the selected departments. In Table 5, the bed capacities add more than 10 in the majority of the departments due to the constraints, but the patient loss rate and the bed utilization rate become more balanced in this scheme. In the two situations, the changes of the patient loss rate and the bed utilization rate in each department are shown in Fig. 4 and Fig. 5.

As can be seen in Fig. 4, the patient loss rates of CCU and Oncology radiology are higher in the current situation. The patient loss rate of each department is relatively balanced in the best situation, which is maintained between 10% and 20%. As can be seen in Fig. 5, the bed utilization rates of Gastroenterology, General Surgery and Oncology radiology are higher than 96%. The hospital should aim to reduce the number of patients lost, therefore, the bed utilization rates of some departments are relatively low in the best situation, which limited by the patient loss rate, such as: CCU, Hematology, Rheumatology and Hand and foot surgery. In addition to the above departments, the bed utilization rates of other departments are maintained between 93% and 95%. It can be figured out that the bed optimal allocation scheme not only reduces the operating cost of the hospital but also improves the number of patients lost.

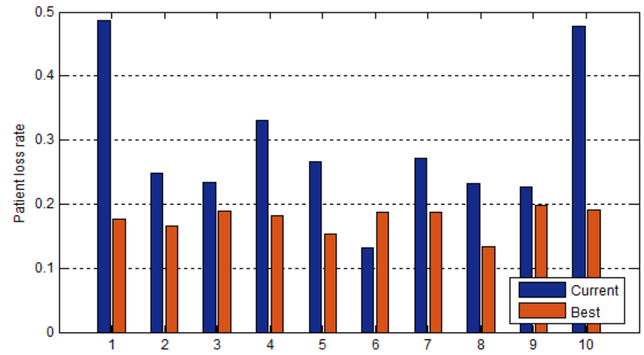

Fig. 4. Comparison of the patient loss rate between the two situations in each department

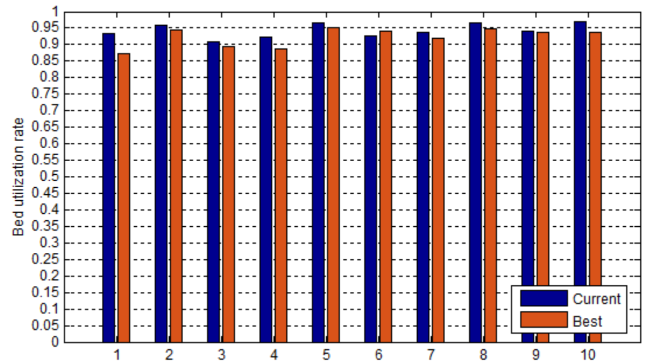

Fig. 5. Comparison of the bed utilization rate between the two situations in each department

V. Conclusion

The hospital bed resource shortage problem is becoming increasingly serious in recent years, and it is urgent to carry out the research of bed resource allocation optimization combined with the actual situation of China's hospitals. In this study, the model of bed resource allocation optimization with constraints is established by analyzing the statistical data of hospital bed resources in M hospital. And the bed resource allocation optimization scheme is discussed. The results indicate that the bed resource allocation optimization scheme not only improves the patient loss rate and the bed utilization rate of each department, and reduces the operating cost of the hospital, but also balances the bed resources among the departments. It shows that the model demonstrates the effectiveness in the bed resource allocation optimization, and provides an effective tool of bed allocation for hospital administrators.

All in all, the queuing models and PSO are use to improve the bed allocation. The future research directions will be carried forward as follows:

(a) The use of an extended queuing system of M/PH/c/N type, allowing a fixed N>c maximum capacity, which avoids the straight patient rejection when all beds are occupied. Such a system allows the existence of a(N–c) waiting room.

(b) Improved PSO models can obtain even more better algorithm. With the Improved PSO algorithm the astringing time of the calculation will be shorter and the veracity of the optimization will be better.

(c) Consider the impact of seasonal factors on the allocation of beds the dynamic optimal bed resource allocation is another direction of our future research on beds alocation.

REFERENCES

[1] F. Gorunescu, S. I. McClean, P. H. Millard, "A queueing model for bed-occupancy management and planning of hospitals", Journal of the Operational Research Society, vol. 53, no. 1, pp. 19-24, 2002.

[2] F. Gorunescu, S. I. McClea, P. H. Millard, "Using a queueing model to help plan bed allocation in a department of geriatric medicine", Health Care Management Science, vol. 5, no. 4, pp. 307-312, 2002.

[3] X. Li, P. Beullens, D. Jones, et al., "An integrated queuing and multi-objective bed allocation model with application to a hospital in China", Journal of the Operational Research Society, vol. 60, no. 3, pp. 330-338, 2009.

[4] S. Belciug, F. Gorunescu, "Improving hospital bed occupancy and resource utilization through queuing modeling and evolutionary computation", Journal of Biomedical Informatics, vol. 53, pp. 261-269, 2015.

[5] S. Wang, H. Q. Su, G. H. Wan, "Resource- constrained Machine Scheduling with Machine Eligibility Restriction and its Applications to Surgical Operations Scheduling", Journal of Combinatorial Optimization, vol. 30, no. 4, pp. 982–995, 2015.

[6] J. Kenndy, R. C. Eberhart, "Particle swarm optimization", Proceedings of IEEE International Conference on Neural Networks", vol. 4, pp. 1942-1948, 1995.

[7] Y. J. Gong, J. Zhang, H. S. H. Chung, et al., "An efficient resource allocation scheme using particle swarm optimization", Evolutionary Computation, IEEE Transactions on, vol. 16, no. 6, pp. 801-816, 2012.

[8] Z. P. L, W. F. Zhou, B. W. Liu, "Linear programming method for hospital sickbed arrangement problem", Operations Research and Management Science, vol. 19, no. 6, pp. 1-5, 2010.

[9] J. C. Wang, T. Liang, Y. Chen, et al., "A distribution strategy of queuing system based on online optimization", Mathematics in Practice and Theory, vol. 43, no. 7, pp. 271-274, 2013.

[10] L. Xu, N. Li, Z. C. Zhang, "Mixed integer programming for gynecological ward bed planning", Industrial Engineering and Management, vol. 18, no. 6, pp. 147-151, 2013.

[11] H. B. Zhu, J. F. Tang, J. Gong, "Bed allocation in no-buffer tandem queuing system with blocking for healthcare unit", Journal of Northeastern University, vol. 35, no. 8, pp. 1088-1092, 2014.

Yumei Hou was born on January 22, 1965. She received the Ph.D. in the Academy of Mathematics and Systems Science, Chinese Academy of Sciences major in operations and control from. Currently, she is a professor and doctoral tutor at the School of Economics and Management of Yanshan University,in Qinhuangdao, Hebei Province. Her major research interests include supply chain and logistics management, medical service operation management and big data analysis. She has published more than sixty papers in related journals.

Hui Zeng was born on January 6, 1982. She received the master's degree in operations research and cybernetics from Yanshan University . At present, she is a doctoral student at the School of Economics and Management of Yanshan University. Her main research interests include queuing theory and medical operation management. She has published more than ten papers in related journals.

Yimin Wang was born on February 1, 1969. He received the Ph.D. in Oncology from Hebei Medical University. At present, he is the vice president of the Qinhuangdao First Hospital in Hebei Province. His main research direction is hospital operation management. He has published more than ten papers in related journals.

Xueqin Wang was born on June 5, 1991. She received the master's degree in Industrial Engineering from Yanshan University . Her main research interests include queuing theory and service operation management.

Qiuye Gao was born on August 15, 1989. She received the Bachelor's degree in software engineering from Beihang University. Currently, she is a researcher working in the Information Department of the First Hospital of Qinhuangdao, Hebei Province. Her main research is data mining and algorithm design.