VARIABLE NEIGHBORHOOD IMPROVED FIREFLY ALGORITHM FOR FLEXIBLE OPERATION SCHEDULING PROBLEM

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Based on the mixed flow shop scheduling problem, a mathematical model of flexible operation scheduling problem was constructed. For the characteristic of flexible operation scheduling problem is NP hard, the two-layer coding method was used to discretize the firefly population, and the mode of individual generation and distance movement were redefined. In order to improve the optimization ability of the algorithm, the location update strategy was improved based on the cross-variation of genetic algorithm. The domain search capability of the standard firefly algorithm was enhanced by using the variable neighborhood search technology. Finally, the simulation experiment was performed, which shows that the improved algorithm can solve the flexible scheduling problem effectively.

Keywords: mixed flow scheduling; flexible operation scheduling; variable
             neighborhood search; improved firefly algorithm

1. Introduction

The rapid development of the medical and health services increased the market competition. In order to obtain more space for development, the hospital must be rational management of hospital resources, reduce hospital costs and improve patient satisfaction. The reasonable scheduling of resources related to the operating room becomes very important for it's in the center of the hospital [1].

Surgical scheduling is a multi-resource allocation process, which involving operating room, medical staff, medical equipment and supplies. A series of research results of the theory and methods of scheduling surgery were obtained. Dexter F et al. divided the surgical scheduling into block scheduling and non-block scheduling and suggested that the number of block and the time of operation were the key to maximizing the utilization of the operating room [2].

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Then, the optimal surgical scheduling strategy was obtained by computer model and simulation. Cardoen B et al. summarized the literatures of surgical scheduling and pointed out the future research direction of surgical scheduling [3]. Vashchenko V et al. considered preoperative (AU), intraoperative (OR), and postoperative (PACU) as a whole, studied the management process of the entire operation center, and proposed a new surgical scheduling procedure [4]. Li Hui and Jiang Dakui designed a hybrid optimization algorithm combining single parent genetic algorithm with tabu search algorithm and built the mathematical model of surgical scheduling problem to minimize the maximum time and mean time for all patients to complete the procedure [5]. Li Chong and Xiang Wei studied the multi-stage scheduling problem of surgical scheduling, considered the constraints of multiple additional resources and the resource flexibility of the surgeon, and proposed a multi-resource time constraint flexible shop scheduling expansion model [6]. Zhu Yue et al constructed a scheduling model containing the preparation time of the medical team to minimize all the surgical completion time and simulated the surgical schedule through the example to prove that the scheduling model greatly shorten the operation time [7].

As for solving algorithm design of the mathematical model, Glowworm Swarm Optimization (GSO) is a new bionic swarm intelligence optimization algorithm proposed by Indian scholars K.N. Krishnanand and D.Ghose [8]. After the GSO algorithm was proposed, it attracted many scholars at home and abroad due to its low-parameter and easy-to-implement characteristics [9], and was used in automatic control [10], situation prediction [11], combinatorial optimization [12], path planning [13] and other fields. The variable neighborhood search algorithm (VNS) proposed by Mladenovic and Hansen was widely used in the field of combinatorial optimization for its easy using and effective solution [14-15]. Considering the adaptability of the algorithm, Li Kun and Xu Zheng proposed an adaptive neighborhood search algorithm for HFSP with limited intermediate storage capacity [16]. Mastrolilli M and Gambardella L M studied the effective neighborhood functions for the flexible job shop problem [17].

Based on the analysis of the existing research results, it can be found that the model and the algorithm used in the operation scheduling problem are still greatly improved. For example, the model and algorithm of surgical scheduling were concentrated in the traditional hospital scenario, the study of the mass casualties of the disaster events is relatively small; and most of the surgical scheduling model was only a simple sort of medical resources, which easily lead to the differences between the scheduling system and the actual reality. Therefore, this paper proposed a mathematical model of flexible surgical scheduling problem based on the mixed flow shop scheduling problem. Considering the NP problem of flexible surgical scheduling problem, the double-layer coding method is used to discretize the firefly population, and the individual generation mode and the

distance movement mode are redefined. Combining the cross-mutation idea of genetic algorithm, the position updating strategy is improved, and the neighborhood search capability of standard firefly algorithms is enhanced by using the variable neighborhood search technology.

2 Flexible surgical scheduling model

2.1 Problem description

Hybrid Flow Shop Scheduling Problem (HFSP) is also called flexible flow shop scheduling [18]. According to the industrial engineering production scheduling theory, the research framework of hospital operating room scheduling optimization was established based on the parallel machine scheduling and flow shop scheduling theory in production scheduling theory and combined with operating room resource scheduling characteristics [19]. In this paper, the scheduling problem was analogous to the production scheduling problem, which patients are needed to surgery can be seen as the work pieces, the surgery doctors, nurses, medical resources such as machine. So, the procedure of patient's operation is similar to the process of the work piece being processed by multiple machines. Based on the three-stage mixed flow shop scheduling model, this paper constructs the dispatching model of disaster casualty operation combined with the characteristics of "preoperative - intraoperative - postoperative" of the wounded operation. The process of the scheduling operation is shown in Fig. 1.
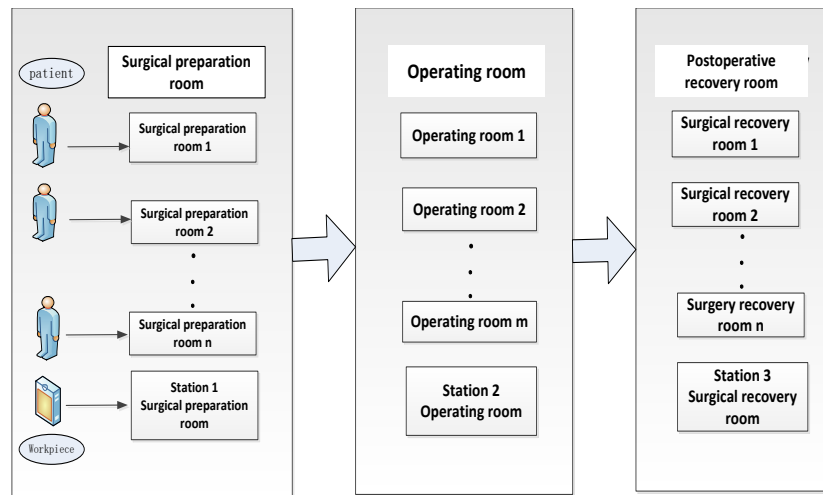

Fig. 1. The flow chart in flow shop mode

In the course of the operation of the wounded, in order to simplify the problem, the paper assumes that the following conditions are true.
(1) Each patient in each operation stage can only be in a surgical bed.
(2) Do not consider the doctor and the patient late, all the necessary medical

resources (equipment, materials, etc.) unified default are ready.

(3) The three stages of same patient's surgery in accordance with the fixed order, which cannot be reverse.

(4) Once a surgical stage being start, it cannot stop halfway during surgery.

(5) All patients undergoing surgery can start the operation at zero time and apply the same priority between different operations.

(6) The patients follow the first-served rule.

(7) The transfer time from the preoperative preparation room to the operating room and from the operating room to the recovery room are ignored.

(8) The operating table can be used continuously.

(9) The duration of each surgery phase is known and will not change because of the change in sorting.

(10) After the operation, the patient needs to be immediately sent to the surgical recovery room.

During modeling, the model parameters are described in Table 1.

Table 1

Summary of model-related notation

Symbol	Name/meaning/property
m	Number of surgical phases
n	Number of patients
T_{ijk}	The end time of the patient i carries out the k position at the j stage.
M_j	The number of operating beds in the j stage
P_{ijk}	The duration of the patient i carries out the k position at the j stage
Y_{ijk}	Whether the j stage of patient i be in the k operation position? If it is 1, otherwise 0.
S_{ijk}	The start time of the patient i carries out the k position at the j stage
X_{il}	Whether the patient i is arranged in the l position? If it is 1, otherwise 0.

2.2 Mathematical model

Based on the mixed flow shop scheduling problem, the operation scheduling model was established with the optimum goal of minimized operation time of all patients. The mathematical function expression of the model is as follows.

Objective function:

$$Min\ F = Min\left[\ max(T_{ijk}\ )\right] \quad (\ i = 1\cdots\cdots n\ ) \tag{1}$$

Restrictions:

$$\sum_{i=1}^{n} X_{il} = 1, \qquad l = 1, 2, \cdots, n \tag{2}$$

$$\sum_{l=1}^{n} X_{il} = 1, \qquad i = 1, 2, \cdots, n \tag{3}$$

$$\sum_{k=1}^{M_j} Y_{ijk} = 1, \quad i = 1, 2, \cdots, n; \;\; j = 1, 2, \cdots m; \;\; k \in M_j \tag{4}$$

$$T_{ijk} \leq S_{i(j+1)r} \quad i = 1, 2, \cdots, n; \;\; j = 1, 2, \cdots m; \;\; k \in M_j; \;\; r \in M_{j+1} \tag{5}$$

$$T_{ijk} = S_{ijk} + P_{ijk}, \quad i = 1, 2, \cdots, n; \;\; j = 1, 2, \cdots m; \;\; k \in M_j \tag{6}$$

$$Y_{ijk} \in \{0,1\} \quad \forall i, j, k \tag{7}$$

In the above mathematical model and restriction equations, (2) and (3) show that all patients have to be arranged to the operating room for surgery, (4) indicates that each patient can only undergo an operation on a surgical bed at each stage of surgery, (5) shows that the patient's next operation cannot start before the completion of the previous surgery phase, (6) shows that the operation time of the patient in the same operation phase is equal to the start time of surgery plus surgery time, (7) defines the range of variable values.

3 Optimization algorithms

3.1 Improved firefly algorithm design

Hybrid flow shop scheduling problem belongs to the discrete combination optimization problems. However, firefly algorithm is mainly used in the field of real numbers and continuous combinatorial optimization problems, which cannot effectively update the discrete sequence of operation to solve the wounded operation scheduling problem. At the same time, the standard firefly algorithm can make a number of fireflies to find the optimal solution by setting the initial population of firefly. The global search ability of firefly algorithm is very strong, but the solving process of some problem always appears the condition of multi peak and multi pole which leads to firefly algorithm falling into the premature convergence and local optimum with the increasing of the number of iterations. Therefore, this paper improved the coding rule, distance calculation, location update and search mode of firefly algorithm to solve the mixed flow operation scheduling model according to the characteristics of the operation scheduling problem belongs to the discrete combinatorial optimization problems.

(1) Algorithm coding rules design

Aiming at the flexible flow operation scheduling problem of wound, this article uses a dual-layer coding based on the number of patients and the operation

rooms. In the dual-layer coding, the first layer is the patient encoding sequence number and the second layer encoding is the operation room number, which structure is shown in Fig. 2. Each surgical scheduling scheme is one-to-one correspondence with each double-layer code, which indicates the order in which each patient undergoes surgery in the operating room. Here, set a chromosome for Z.

$$Z = \left[\{x_{i1}, x_{i2}, ..., x_{in}\} \updownarrow \{y_{i1}, y_{i2}, ..., y_{in}\} \right]$$

Where X_{in} denotes the surgical sequence coding of patients, Y_{in} denotes the coding of operation room.
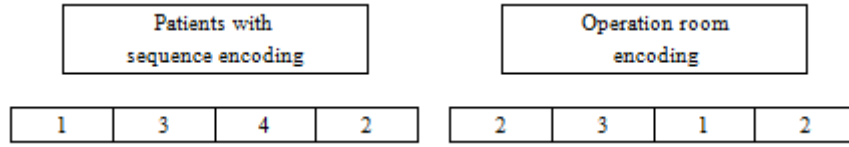

Fig. 2. the operation of flexible flow shop scheduling problems with double encoding structure

(2) The distance between the fireflies calculation mode

The paper uses the Hamming distance to calculate the distance between individuals, which is the number of different characters corresponding to the location of the two strings, here refers to the number of unequal elements in position vector of fireflies. Setting the position of *i* and *j* after the *N* iteration is: $X_{i(n)} = (X_{i1}, X_{i2}, ..., X_{in})$, $X_{j(n)} = (X_{j1}, X_{j2}, ..., X_{jn})$, so the Hamming distance after *N* iteration is denoted as hm_dij (T): hm_dij (T) = hamming_distance $(X_{i(n)}, X_{j(n)})$.

(3) The firefly location updates strategy

According to the cross mode in the workshop scheduling solution of Davis, randomly select a fixed match area in two parent strings, such as

C=1 2 3 |4 5 6 7| 8 9
D=2 5 6 |9 4 1 3| 7 8

Then, copy the following matching region in the offspring.

C'=X X X |4 5 6 7| X X
D'=X X X |9 4 1 3| X X

Place the matching sequence at the end and swap the non-matching sequence with the parent string as follows.

C"=7 8 2 5 6 9 4 1 3
D"=8 9 1 2 3 4 5 6 7

After removing the matching sequence from C" and D", the subsequence "82913" and "82567" can be obtained. Then, these subsequences are trapped and filled into the offspring C' and D', and the resulting subsequence is given as follows.

C*=9 1 3 4 5 6 7 8 2
D*=5 6 7 9 4 1 3 8 2

In the mutation operation, if the distance between the two adjacent codes in the entire string is the largest, it is considered unreasonable. Choose any non-adjacent code in the string to replace one of codes, if the fitness value is not optimized, repeat this operation. If a good fitness value cannot be obtained, another code would be replaced. If the optimal fitness value cannot obtain, think that is reasonable, and randomly selected two codes to switching operation. If the result is unreasonable, the original string is replaced with the variation string. The location update process is shown in equation 8.

$$x_i^{t+1} = \begin{cases} x_i^t \otimes x_j^t, & rand \le p_c \\ Mu\left(x_i^t\right), & rand > p_c \end{cases} \tag{8}$$

Where X_i^t denotes the position of the firefly i at the time of the iteration of t, X_j^t denotes the position of the firefly j at the time of the iteration of t, rand is random number from 0 to 1, P_c is the probability of cross mutation threshold.

The specific process of firefly location update is as follows. In the t + 1 iterative process, the firefly i select the firefly j as a target to move through the roulette method and generates a random number. If rand ≤ P_c, the firefly i crosses the firefly j and obtains the excellent gene sequence location of the firefly j; if rand>P_c, the firefly i mutation in the current position and generates a new individual position. Then, if the fitness function of new position of firefly i is better than that of the original position, the firefly i moved to the new position, or keep the original position.

(4) Variable neighborhood search technology

The paper takes the individual who carried out the position updated as the initial solution, and randomly selected neighborhood search from four neighborhood operations. If the current solution was optimized and remained unchanged in the later period, thought that it is the local optimal solution, ended the search process and compared the elite. If the current solution is not optimized within the set number of iterations, the search process is ended. Then, randomly generate a set of individual codes to replicate repetitive coding in order to maintaining the diversity of firefly populations.

The four variable neighborhood search operations are as follows.

(a) Exchange. Randomly generate two exchange positions and exchange the code of two positions. For example, the code of chromosome is "13458276", randomly generate two exchange positions 3 and 6, and the chromosome that can be obtained by exchanging the two positions is "13258476".

(b) Insertion. Randomly generate two encoding positions and insert the code at the large digit position into the front of the gene at the small digit position, the codes of the small digit position and its subsequent are postponed. For example, the code of chromosome is "13458276", randomly generate two code

positions 2 and 8, and the chromosome that can be obtained by insert is "16345827".

(c) Inversion. Randomly generate two encoding positions and reverse the two-point code to obtain a new code of chromosome. For example, the code of chromosome is "13458276", randomly generate two code positions 4 and 5, and the chromosome that can be obtained by reversing is "13485276".

(d) Disrupting interchange. Randomly generate some coding positions and disrupting their order to obtain a new code of chromosome. For example, the code of chromosome is "13458276", randomly generate three code positions 2, 3 and 6, which gene sequence is 342, and the chromosome that can be obtained by disrupting interchange is "12358476".

3.2 Steps to solve the modified variable neighborhood firefly algorithm

(1) Initializing the basic parameters of firefly algorithm. There, set X denotes the times of firefly iterations, m denotes the number of firefly population, l_0 denotes the initial concentration of fluorescein, ρ denotes the attenuation factor of fluorescein, γ denotes the enhancement factor of fluorescein, n_t denotes the neighborhood threshold, r_s denotes the initial perceived radius, β denotes the change rate of neighborhood radius, P_c denotes the probability of cross mutation threshold.

(2) Randomly encoding in the improvement of firefly algorithm, and randomly generated initial solutions.

(3) Calculating the firefly individual fitness function and update the fluorescein concentration of firefly.

$$l_i(t) = (1-\rho)*l_i(t-1)+\gamma*f(x_i(t)) \tag{9}$$

(4) Calculating the Hamming distance between the fireflies and the neighborhood set of firefly individual. If there is no neighborhood set in the current individual, the variation operation would be performed. If there is a neighborhood set, the roulette is used to select the outstanding individual.

$$Ni(t) = \{\, j : d_{ij}(t) < r_d^i(t); l_i(t) < l_j(t) \,\} \tag{10}$$

(5) Updating the position of the firefly individual based on the way of crossover mutation in the genetic algorithm and updating the perceived radius and neighborhood radius of the individual according to formula 11.

$$r_d^i(t+1) = \min\{\, r_s, \max\{0, r_d^i(t)+\beta(n_t-|N_i(t)|)\}\,\} \tag{11}$$

(6) Carrying out the neighborhood search in the current optimal individuals to obtain a new contemporary optimal individual. Then, comparing the fitness values of two optimal individuals and taking the large individual as the current optimal individual.

(7) Determining whether the maximum number of iterations is reached, if

it is, the loop is over, and the optimal scheduling program and fitness value are output, if not, step 4 is performed. The solving process of the improvement of firefly algorithm is shown in Fig 3.
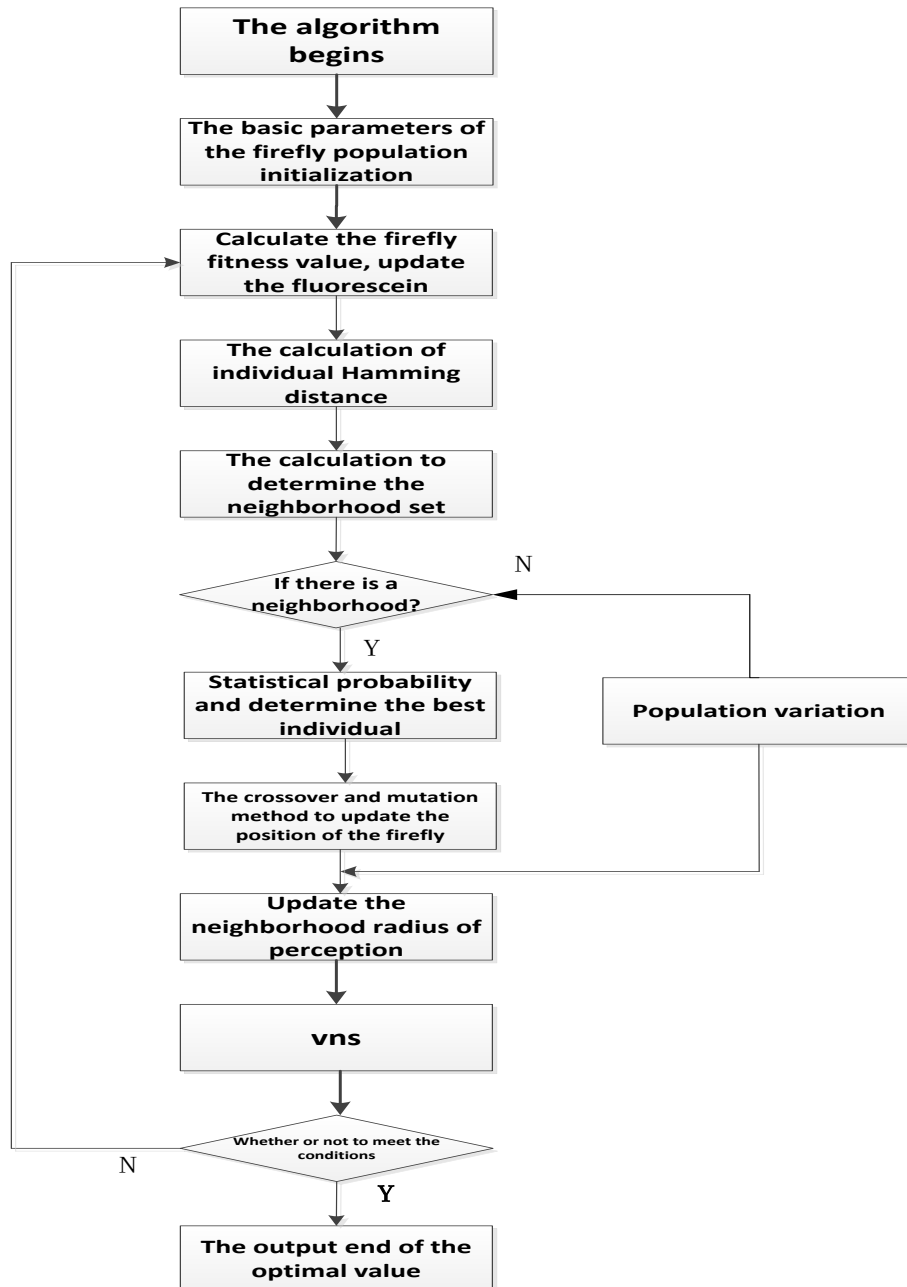
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Fig. 3. Flow chart of improved firefly algorithm

4 Simulation experiment

4.1 Background information

The paper takes a hospital as an example to carry out simulates experiment. This hospital has five operating rooms, and its medical resources, preoperative preparation and postoperative recovery rooms are enough. The time required for the three phases of surgery can be estimated by normal distribution based on historical experience and data. The operation scheduling problem consists of five operating rooms and 20 wounded, and the specific time information for the three stages of operation is shown in Table 2.

Table 2

Time required for each stage of the surgical patients

Patient number	Preoperative time(min)	Operation time(min)	Postoperative time(min)
1	38	85	25
2	53	128	30
3	60	200	50
4	55	120	25
5	25	45	15
6	45	90	20
7	56	150	40
8	50	135	45
9	36	80	35
10	75	170	40
11	45	85	20
12	60	200	55
13	55	140	25
14	58	145	30
15	27	65	25
16	57	110	26
17	48	95	23
18	60	200	30
19	50	115	22
20	65	210	40

4.2 Solutions of example and results

(1) Parameter setting

The basic parameters of the algorithm are set as follows: the maximum number of iterations $X = 300$, firefly population size $N = 20$, the initial concentration of fluorescein $i_0 = 5$, the attenuation factor of fluorescein $\rho = 0.4$, update rate of fluorescein $\gamma = 0.6$, initial perceived radius $r_s = 10$, the neighborhood change rate $\beta = 0.08$, the neighborhood threshold $n_t = 5$, and the

probability of cross mutation threshold $P_c = 0.75$. Then, compare the results of the improved firefly algorithm with the genetic algorithm and the discrete firefly algorithm to prove the effectiveness of the improved firefly algorithm.

(2) Solutions of example

The paper uses the improved firefly algorithm to solve the established surgical scheduling model based on above parameters. The iterative process of the improved firefly algorithm and the results are shown in Fig 4 and Fig 5, and the total process time is 454min.
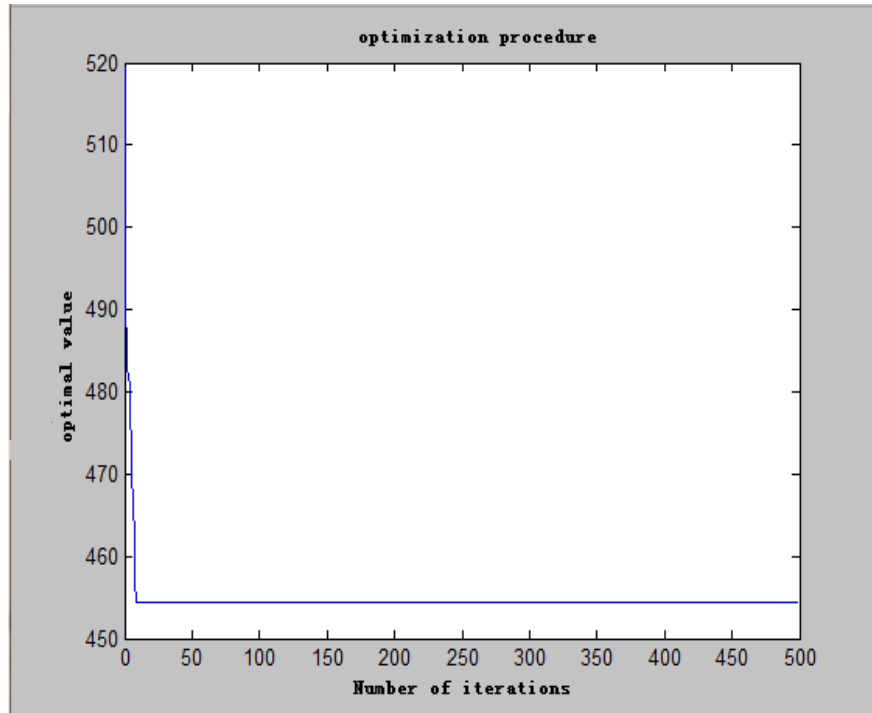
Fig.4 The iterative process of the improved firefly algorithm

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minChrom =

 Columns 1 through 23

    1    5   11   15    7   20   17    9    3   10    6    4    2   18   13    8   16   12   19   14    2    3    1

 Columns 24 through 40

    3    3    3    2    5    1    1    4    4    5    2    2    4    3    5    5    4
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Fig.5. The solving results of the improved firefly algorithm

It can be seen from Fig. 5 that the optimal solutions of the example

solution are as follows. The first layer of codes is the patient's surgical sequence coding, which are "1,5,11,15,7,20,17,9,3,10,6,4,2,18,13,8,16,12,19,14". The second layer of codes are the number operating room assigned to the patients, which are "2,3,1,3,3,3,2,5,1,1,4,4,5,2,2,4,3,5,5,4". Accordingly, the patient's operating room distribution program can be synthesized. The patients numbered 11, 3 and 10 followed the operation in the first operating room. The patients numbered 1, 17, 18, and 13 followed the operation in the second operating room. The patients numbered 5, 15, 7, 20 and 16 followed the operation in the third operating room. The patients numbered 6, 4, 8 and 14 followed the operation in the fourth operating room. The patients numbered 9, 2, 12 and 9 followed the operation in the fifth operating room.

(3) Comparison of solving process and result of different algorithms

In order to prove the effectiveness of the improved neighborhood firefly algorithm to solve the problem of surgical dispatching problem, the iterative process and solving results of genetic algorithm, discrete firefly algorithm, the Glowworm Swarm Optimization algorithm and improved firefly algorithm are compared and analyzed. [16-17] Here, the basic parameters of the genetic algorithm are set to that population size N = 20, crossover probability p_c = 0.5, mutation probability p_d = 0.05, the number of iterations X = 500. The parameters of the discrete firefly algorithm are consistent with the improved firefly algorithm. After 10 running independently, the results of the four algorithms are shown in Table 3 and Fig. 6.

Table 3

The running results of the three algorithms

number	Genetic algorithm (min)	Discrete firefly algorithm(min)	Glowworm Swarm Optimization(min)	Variable neighborhood firefly algorithm(min)
1	483	469	466	455
2	478	465	465	462
3	481	474	467	461
4	478	475	470	458
5	483	467	465	461
6	482	464	463	459
7	485	469	466	455
8	479	476	470	454
9	481	459	458	456
10	480	464	463	457
optimal value	478	459	458	454
worst value	485	476	470	462

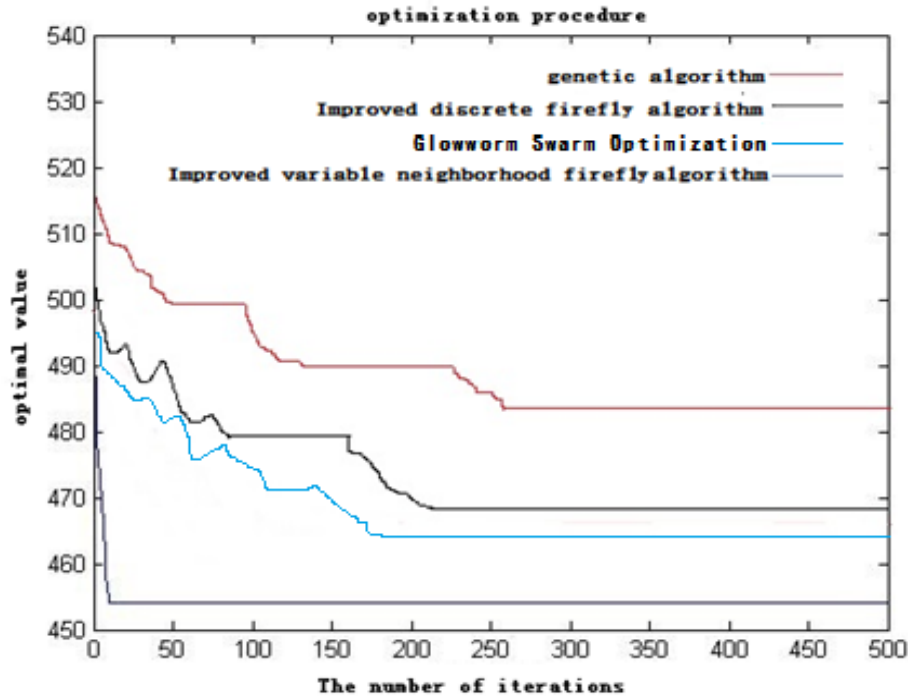| average value	481	468.2	465.3	457.8

Fig.6. The iterative process of the three algorithms

By comparing the results of the four algorithms and their optimization process, it can be seen that the convergence speed of the improved neighborhood firefly algorithm is better than that of the other three algorithms. The result of the improved firefly algorithm was 7.5 min lower than that of the GSO algorithm, and the operative efficiency was improved by 1.6%. The result of the improved firefly algorithm was reduced by 10.4 min compared with the discrete firefly algorithm, and the operation efficiency was improved by 2.2%. The result of the improved firefly algorithm was 23.2 min lower than that of the genetic algorithm, and the operative efficiency was improved by 4.8%. It is proved that the effectiveness and superiority of the improved firefly algorithm.

5. Conclusions

In this paper, the wounded surgical dispatching model was established based on the mixed flow shop scheduling problem, and the standard firefly algorithm was improved to solve this problem. In the aspect of model establishment, the characteristics of preoperative, intraoperative and postoperative time of wound operation were analyzed, and a flexible flow dispatching model of

the wounded surgical dispatching was established. In the aspect of algorithm improvement, the double-layer coding scheme was used to realize the discretization of the firefly algorithm, the distance between the firefly individuals was calculated by using the Hamming distance, the idea of the cross variation of the genetic algorithm and the target-oriented variation of the greedy heuristic algorithm were used to update the firefly location, and the variable neighborhood search ability of the neighborhood algorithm was introduced to avoid the local optimal. Then, the improved firefly algorithm was compared with the genetic algorithm, the discrete fireflies and the GSO algorithm. The results show that the modified variable neighborhood firefly algorithm is superior. The surgical scheduling model and the improved neighborhood-changing firefly algorithm have some guidance for hospital operation scheduling.

However, it only studies the initial surgical dispatching problem of batch casualty, and do not consider the interference of sudden factors in the process of wound operation. Therefore, how to combine the number of casualties and the change of the ambulance time in uncertain environment to build the time window scheduling and interference management scheduling model of the wound operation is the next step in research.

Acknowledgment

REFERENCES

[1] *Wang Fuyu, Ye Chunming*. Review and prospect of optimization on earthquake wounded distribution and operation scheduling. Application Research of Computers, **vol.** 33, no. 3, 2017, pp. 653-657.

[2] *Dexter F, Macario A, Traub R D, et al*. An operating room scheduling strategy to maximize the use of operating room block time: computer simulation of patient scheduling and survey of patients' preferences for surgical waiting time. Anesthesia & Analgesia, **vol**. 89, no. 11999, pp. 7-20.

[3] *Cardoen B, Demeulemeester E, Beliën J*. Operating room planning and scheduling: A literature

review. European Journal of Operational Research, **vol**. 201, no. 3, 2010, pp. 921-932.

[4] *Vashchenko V, Krivoshey A, Knyazeva I, et al.* Surgical case scheduling as a generalized job shop scheduling problem. European Journal of Operational Research, **vol**. 185, no. 3, 2008, pp. 1011-1025.

[5] *Li Hui, Jiang Dakui.* Research on operating room scheduling problem based on partheno-genetic tabu search algorithm. Application Research of Computers, **vol**. 30, no. 3, 2013, pp. 699-702.

[6] *Li Chong, Xiang Wei, Chen Saifeng.* Integrated surgeries scheduling and nurse roistering medium-term decision-making optimization research. Computer Engineering and Applications, **vol**. 52, no. 13, 2016, pp. 232-237.

[7] *Zhu Yue, Zhang Yulin, Song Minshan.* Surgical scheduling considering setup time between surgeries and setup time between surgical teams. Journal of Southeast University (Natural Science Edition), **vol**. 45, no. 6, 2015, 1218-1222.

[8] *Kaipa K N, Ghose D.* Glowworm Swarm Optimization. Springer International Publishing, 2017.

[9] *Marinaki M, Marinakis Y.* A Glowworm Swarm Optimization algorithm for the Vehicle Routing Problem with Stochastic Demands. Expert Systems with Applications, **vol.** 46, 2016, pp. 145-163.

[10] *Gu Zhongwei, Xu Fuyuan.* A novel Glowworm Swarm Optimization algorithm for solving the PID parameters self-tuning. Journal of Systems & Management, no. 1, 2017, pp. 101-106.

[11] *Li Jizhen, Meng Xiangru, Wen xiangxi, et, al.* Network security situation prediction based on gaussian process optimized by glowworm swarm optimization. Systems Engineering and Electronics, **vol**. 37, no. 8, 2015, pp. 1887-1893.

[12] *R. Venkata Rao, Dhiraj P. Rai, J. Balic.* Multi-objective optimization of machining and micro-machining processes using non-dominated sorting teaching–learning-based optimization algorithm. Journal of Intelligent Manufacturing, 2016: 1-23.

[13] *Marinaki M, Marinakis Y.,* A Glowworm Swarm Optimization algorithm for the Vehicle Routing Problem with Stochastic Demands. Expert Systems with Applications, **vol**. 46, 2016, pp. 145-163.

[14] *Pan Q K, Wang W H, Zhu J Y, et al.* Hybrid heuristics based on particle swarm optimization and variable neighborhood search for job shop scheduling. Computer Integrated Manufacturing Systems, **vol**. 13, no. 2, 2007, pp. 323-328.

[15] *Guo P, Chen W, Wang Y.* A general variable neighborhood search for single-machine total tardiness scheduling problem with step-deteriorating jobs. Journal of Industrial & Management Optimization, **vol**. 10, no. 4, 2017, pp. 1071-1090.

[16] *Li Kun, Xu Zheng, Tian Huixin.* An adaptive variable neighborhood search algorithm for the hybrid flow shop scheduling problem. Systems Engineering, no. 11, 2015, pp. 121-129.

[17] *Mastrolilli M, Gambardella L M.* Effective neighborhood functions for the flexible job shop problem. Journal of Scheduling, **vol**. 3, no. 1, 2015, pp. 3-20.

[18] *Marichelvam M K, Ömür Tosun, Geetha M.* Hybrid monkey search algorithm for flow shop scheduling problem under makespan and total flow time. Applied Soft Computing, **vol**. 55, 2017, pp. 82-92.

[19] *Applegate D, Cook W.* A computational study of the job-shop scheduling problem. Orsa Journal on Computing, **vol**. 3, no. 2, 2017, pp. 149-156.