

Pipeline Based Genetic Algorithm for Patient Scheduling in Hospital Outpatient Department and Laboratory

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Abstract— This research propose the pipeline based genetic algorithm for patient scheduling. The time spent in the hospital outpatient department, laboratory, and the idle time caused by the scheduling are considered. According to the subject condition, the optimal solution related to medical service time spent for the patients in different medical departments with single or multiple medical services can be found. Through the cloud computing platform, the developed algorithm can be rapidly used for different requirements from hospitals or patients.

Keywords— Genetic Algorithm, Scheduling, Medical Service, Pipeline, Cloud Computing

I. INTRODUCTION

Recent years, due to infectious diseases, such as COVID 19, the workload of the doctors, employees, nurses, etc., in the hospital has increased. Due to the time spent of the inspection corresponding to individual patient would be different. In addition, the human resource in the hospital would also be tight. To maintain the quality of the health and medical care, a suitable work schedule for doctors, nurses, outpatient clinic or operating room, etc., is required.

There were various scheduling algorithms or methods proposed for the nurse scheduling [1-3]. According to the restrictions of the law and the working hours, the total number of nurses required for the hospitalized patients can be decided. However, the scheduling work corresponding to the nursing only focuses on the ward of the hospital and nurses. There are still doctors, inspectors, medical device operators, pharmacists, etc., in the hospital. In addition to the human resources, the physical spaces such as clinic or outpatient department, surgery room, X-ray laboratory, MRI laboratory, etc., are also limited resources. Considering the restrictions of the human resources, physical spaces, time, the various states of the illness corresponding to different patients, etc., how to provide the optimal medical service for patients could be an important issue.

To find the optimal solution, various algorithms were proposed [4-6]. Ant Colony Optimization (ACO) was proposed that emulates the behaviour of the ants finding optimal routes for food. Hence, when given the objective problem, the ACO algorithm could find the optimal solution [4]. Genetic Algorithm (GA) is another popular method to find the optimal solution. Based on the concept of “survival of

the fittest”, the optimal solution can be found after evolution of many generations [5]. Simulated Annealing (SA) is a kind of randomized algorithm and proposed to find the near optimal solution within a huge searching space [7]. Since the normal nurse scheduling problem (NSP) was proved as the NP-hard problem, to find the optimal solution instead of the manual operation is the acceptable method.

However, most algorithms for the NP-hard problems would require huge computing resources. Therefore, to achieve the good performance of algorithm computing with enough resources, cloud computing could be the possible solution. Some researches were proposed to find the optimal solution based on the genetic algorithm including Nurse Scheduling Problem (NSP) [1-3,6-7] and Job Shop Scheduling problem (JSP) [4-5,8]. Based on the parallel processing and distributed system, the speed of convergence can be faster than the traditional genetic algorithm executed on the single computer.

Since there exists multiple objective functions corresponding to the human resource, physical medical service places, and patients, the conflicting goals may happen between various optimal solution searching. Therefore, how to deal with the conflict of multiple objects optimal solution searching is an important issue.

In this research, section 2 will introduce the proposed genetic algorithm for the NSP and JSP optimal solution searching. The cloud for rapidly deploying the algorithms is also described. Then, section 3 provides the proposed system for module procedures of genetic algorithm. In addition, the adaptive process for multiple objects optimal solution searching corresponding to the medical service and scheduling in hospital is given. section 4 shows the simulation results. The conclusion is given in section 5.

II. RELATED WORKS

The Nurse Scheduling Problem (NSP) and Job Shop Scheduling problem (JSP) were already proposed. Mostly, the optimal solution is searched according to the time spent on the job done by all machines or procedures [5] or the minimized human resources of the nurse for schedule [6]. Suppose that the human resources can satisfy the requirements of the schedule, the research would focus on the quality of the schedule for more fair assignments [7].

Instead of the single objective function being considered for the optimal solution searching, some researchers developed

the algorithms for the multiple objectives optimal solution finding [5]. To find the optimal solution within the huge solution space, some researchers proposed the modularized algorithms and procedures for the multiple objectives optimal solution searching [5-6,8]. Then, by rapidly implementing the on demand defined modules, the algorithm can try to find the optimal solution according to various configurations or methods. In other words, based on the cloud computing which owns huge computing resource, the various combinations of the algorithms or methods for the optimal solution searching can be achieved.

In addition, the computing job can be divided into multiple sub-partitions. When an optimal solution searching is required and triggered, the computing data can be separated into the multiple missions of the original job. These missions could be delivered to the computing nodes of the cloud computing environment. In other words, if the data or the mission will be managed and computed by various algorithms or methods, cloud computing environment can execute data or mission corresponding to the algorithm or method individually. Several researches assume that the procedure or process dealing with the data or computing missions can be on demand deployed in the virtual machines of the cloud. Recently, the cloud services based on the container were popular and generally used. Through the same Docker engine, the container with the service program can be deployed directly. Hence, when the services are rapidly and repeatedly required, the on demand configured Docker containers can be built immediately.

Considering the genetic algorithm for the optimal solution searching, there exist several steps of data computing. Excluding the initialization of the chromosomes which are used to represent the possible solutions or sequences, there are steps about selection, crossover, mutation, and survival, which various possible methods were proposed. To select the chromosomes for crossover, there are methods about random selection, roulette wheel selection, elitism, tournament, etc., with different advantages. The crossover method for the gene exchanging and offspring chromosome creating are generally used according to single-point crossover, double-point crossover, multi-point crossover, and uniform crossover. To possibly escape from the local search, the mutation method can be used based on simple mutation or uniform mutation. Finally, when the chromosomes compete each other for survive, the fitness value sort or other conditions for survive can be used. Therefore, various combinations related to different methods of these steps would contribute different performance corresponding to different objective functions for optimal solution searching.

Since the genetic algorithm has multiple steps with various methods, to deploy these methods individually would be the possible solution for various combinations. It means that these methods should be modularized for the computing data exchanging between each other in different steps. To enhance the feasibility of the "ready to use" methods, the container based on Docker engine is the solution. In this research, the genetic algorithm is modularized and divided into multiple

containers. The user could select the required methods corresponding to the steps of genetic algorithm for different combinations.

III. PROPOSED SYSTEM

Traditionally, the scheduling in the hospital would only focus on the nurse scheduling problem with the fixed time limitation and optimal solution with the balance about human resource and fair schedule. However, due to the time spending of various medical outpatient departments or the medical inspections may be different, the objective function to find the optimal solution of scheduling can be defined as two purposes: 1. shortest time for completing the patients' medical care, or 2. reduce the idle time of all medical outpatient departments and inspections.

In hospital, the specific medical inspection would be needed for multiple medical outpatient departments. For example, thoracic surgery department and orthopaedics department would both require the inspection report from the X-ray laboratory. However, various patients from different departments would cost various time spent in X-ray laboratory. In other words, patients from different medical outpatient departments would affect each other and cause the possible time delay or idle time in waiting the inspection of X-ray. Therefore, more factors such as the priority, quantity of patients, capacity of the laboratory, etc., should be taken into consideration.

Suppose that there are total K medical outpatient departments, where the set of these departments can be defined as $\{d_1, d_2, \dots, d_k\}$. The total patient corresponding to the k^{th} medical outpatient department can be defined as

$$P(d_k) = \sum_{i=1}^m p_i(d_k) \quad (1)$$

where

$$p_i(d_k) = \begin{cases} 1 & i^{\text{th}} \text{ patient is a patient of } k^{\text{th}} \text{ department} \\ 0 & i^{\text{th}} \text{ patient is not a patient of } k^{\text{th}} \text{ department} \end{cases}$$

and m is the total patients of the hospital.

Considering the real situation of the medical outpatient department, all the patients should seek treatment or doctor in order. Therefore, the patient list in order corresponding to the specific k^{th} outpatient department can be defined as:

$$P_{Lk}(d_k) = \bigcup_{i=1}^m p_i(d_k) \quad (2)$$

Suppose that the i^{th} patient in the k^{th} outpatient department would spend time $t_{i,k}$ with the probability $l_{i,k}$ of the further inspection at a laboratory. Assume that the normal time spent in the j^{th} laboratory corresponding to a patient from the k^{th} outpatient department is $t_j(k)$. If there exists the time delay or idle time for waiting the j^{th} laboratory or the medical outpatient department corresponding to the i^{th} patient, called D_{ij} , then each patient for the complete medical care about the outpatient department and laboratory can be defined as:

$$T_i = \sum_{j=1}^K [(t_j(k) + D_{ij}) \times l_{i,k} + t_{i,k} \times p_i(d_k)] \quad (3)$$

Therefore, according to eq.3, we can have the first objective function about the total time for an individual patient can be as:

$$\min T_i = \sum_{j=1}^K [(t_j(k) + D_{ij}) \times l_{i,k} + t_{i,k} \times p_i(d_k)] \quad (4)$$

Since the normal time spent in the j^{th} laboratory is already defined in advance, finding the minimized time according to eq.4 also means that the delay time or idle time should be minimized. In other words, to find the optimal solution for the patient's schedule in the hospital is very important.

However, various patients from different outpatient department would need the inspection report from the same laboratory. To reduce the idle time or delay time in laboratory, considering the normal time spent in the j^{th} laboratory corresponding to a patient from the k^{th} outpatient department and the time delay or idle time for waiting at j^{th} laboratory is important. Hence, the second objective function for the j^{th} laboratory can be defined as:

$$\min T_j = \sum_i \sum_{k=1}^K [(t_j(k) + D_{ij}) \times l_{i,k} + t_{i,k} \times p_i(d_k)] \quad (5)$$

However, due to the immediate outpatient needs, some patients after the j^{th} laboratory should return to the outpatient department for the immediate inspection report with the probability $R_{j,k}$. Therefore, even the total time for the i^{th} patient at the k^{th} outpatient department can be defined in advance, the subject condition to the laboratory returned patient should be:

Medical Service for a returned patient should follow the order: 1. outpatient department, 2. Laboratory, and 3. outpatient department.

In other words, the objective function for individual patient defined in eq. 4 should be as:

$$\min T_i = \sum_j \sum_{k=1}^K [(t_j(k) + D_{ij}) \times l_{i,k} + t_{i,k} \times p_i(d_k) + (t_{i,k} + D_{ij}) \times p_i(d_k) \times R_{j,k}] \quad (6)$$

In this research, the patient is the first important thing for scheduling. Therefore, instead of the nurse scheduling, we would focus on the minimum time of the patient in the hospital for all the required medical services.

However, the physical spaces for the outpatient department are also limited as the subject condition. The law also limits the total work time of the doctor. Therefore, another subject condition should be given as:

Upper bound of the k^{th} outpatient department is T_k

Therefore, the probability of the further medical service such as $l_{i,k}$ and $R_{j,k}$ would change the possibility of optimal solution searching. If more patients require the second even third step of the medical service, due to the subject condition, the patient may not complete the medical service in time. Therefore, the objective function for the k^{th} outpatient department should be:

$$T_k \geq \sum_i \min T_i \\ = \sum_i \sum_j \sum_{k=1}^K [(t_j(k) + D_{ij}) \times l_{i,k} + t_{i,k} \times p_i(d_k) + (t_{i,k} + D_{ij}) \times p_i(d_k) \times R_{j,k}] \quad (7)$$

Since the patient of the outpatient department may need the further inspection at another laboratory, the next patient in the outpatient department could be served in the current department. Therefore, the medical service in this research is defined as the pipeline. Each outpatient department is one individual work section included in the pipeline. Hence, the pipeline sections of i^{th} patient who is a returned patient from

the j^{th} laboratory in k^{th} outpatient department can be shown as follows:

k	j	k
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If the patient needn't to have the inspection report or not a returned patient, then the pipeline sections can be shown as

k	k	null
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If the patient needn't the laboratory, the pipeline sections can be shown as

k	null	null
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Therefore, in the k^{th} outpatient department, the possible pipeline for multiple patients can be shown as Figure 1. Suppose that the time $t_j(k)$ is longer than the time $t_{i,k}$. Therefore, the section k which represents the time $t_{i,k}$ of the i^{th} patient in k^{th} outpatient department is shorter or smaller than the section j which indicates the $t_j(k)$ in j^{th} laboratory from k^{th} outpatient department. Hence, the first patient who is the returned patient should be idle when the third step of the medical service, k^{th} outpatient department, is also occupied by the third patient. When the second patient requires the service of the j^{th} laboratory, additional idle time is needed for waiting the served first patient. Suppose that the third patient needn't to have the third step of the medical service. Then, the total time spent for these three patients would be started from the first patient's first k^{th} outpatient department service to the ended j^{th} laboratory of the third patients. Since the time spent in various laboratories and departments would be different, the additional idle time corresponding to individual patient is also various.

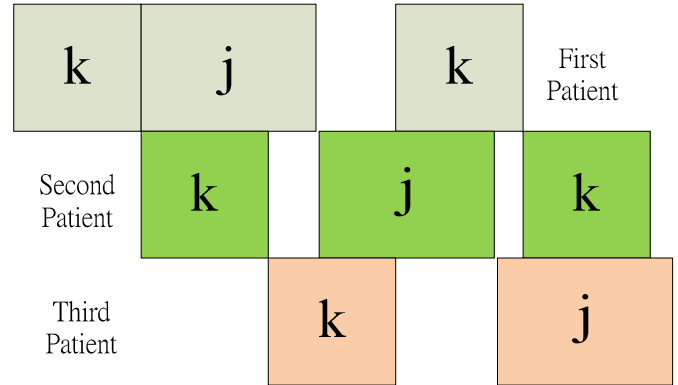


Figure 1. Example of the pipeline corresponding to k^{th} outpatient department and j^{th} laboratory

In this research, we have two coding methods to represent the pipeline into the genetic algorithm chromosome. First, the longest section is used as the time unit for all other sections. Then, all the time sections corresponding to the outpatient departments and laboratories can be the same. Second, crossover can only exchange the whole sections of individual patients. Therefore, only the sort or order of patients would be changed. The required medical service corresponding to each patient is still kept.

IV. VERIFICATIONS

In this research, we design the scenario which includes 2 independent outpatient departments similar to the “thoracic surgery” and “orthopaedics”. These 2 outpatient departments may require the service of X-ray laboratory. Suppose that the probability of a patient about thoracic surgery and orthopaedics for the X-ray laboratory service could be α_{ts} and α_o . In addition, the probabilities of a patient who would be required to back to the related outpatient department after X-ray laboratory are defined as $R_{j,k}$. Then, according to the probability, the possible patients can be divided into 6 types of groups: thoracic surgery for only outpatient, thoracic surgery for both outpatient and X-ray laboratory, thoracic surgery for 2 times outpatient and single time X-ray laboratory, orthopaedics for only outpatient, orthopaedics for both outpatient and X-ray laboratory, and orthopaedics for 2 times outpatient and single time X-ray laboratory.

To process the algorithm, we implement the cloud computing environment based on the Intel CPU Xeon with 16GB memory. The Docker engine v23.0.5 for Docker Desktop application is used.

Suppose that the whole time period for the outpatient department is limited. Then, the probability of α_{ts} , α_o , and $R_{j,k}$ would affect the results. If probability value is high with huge total amount of patients, the optimal solution for all patients having medical service is unavailable due to too much time spending.

In this verification, we assume that the probability $l_{i,k}$ of the patients who require the laboratory checking is defined as: 0.4, 0.6, and 0.8, individually. The probability $R_{j,k}$ of the patients after laboratory is defined as: 0.4, 0.6, and 0.8, individually.

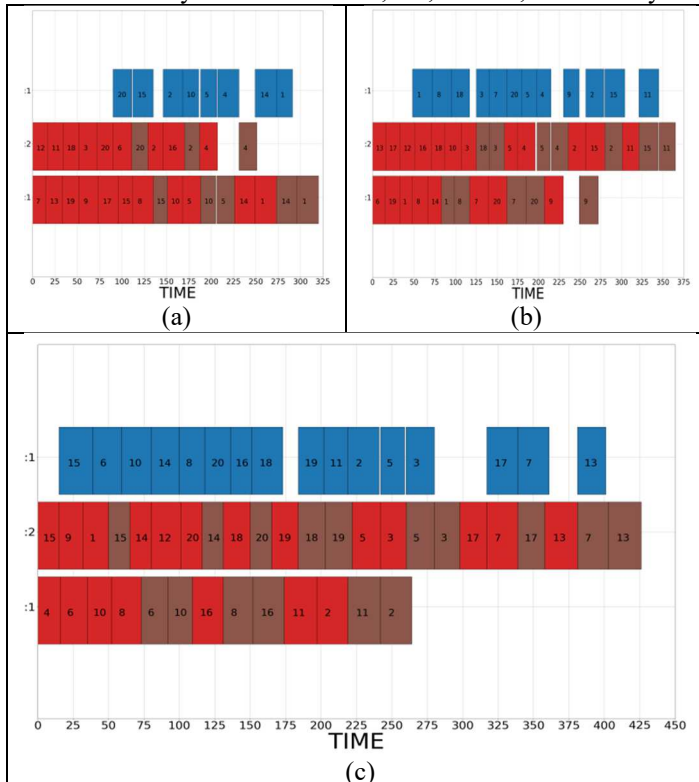


Figure 2. Example of the 20 patients with different probability values corresponding to 2 outpatient and 1 shared laboratory.

According to the figure 2, assume that room 1 is for laboratory, room 2 and 3 are the independent outpatient rooms for different medical clinic. There are total 20 patients. Each patient is assigned the unique ID number. According to the subject conditions, each patient should attend the outpatient first. Then, based on the probability, the patient would have further steps for laboratory or second outpatient. If the patient is first time in the outpatient room, the color in the figure 2 would be red. The laboratory time of the patient is shown in color blue. The time for outpatient and laboratory is randomly decided in the range from 15 to 25. In figure 2 (a), probability $l_{i,k}$ and $R_{j,k}$ are both set as 0.4. Figure 2 (b) shows the verification result with probability $l_{i,k}$ and $R_{j,k}$ which are both set as 0.6. Finally, in figure 2 (c), the probability $l_{i,k}$ and $R_{j,k}$ are both set as 0.8. The verification shows that the proposed system can successfully arrange the schedule of each patient. The progress time of patients, the independent outpatient and laboratory rooms, can be also optimized with the shortest total time spent.

V. CONCLUSIONS

The pipeline based genetic algorithm is proposed for dealing with the various medical services required by different patients. By considering the objective function, the minimized time spent for the medical outpatient department can be found. The optimal order or schedule for the patients corresponding to the medical outpatient can be provided.

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